University of Southampton

Faculty of Medicine

Human Development and Health

Assessment of low-intake dehydration in hospitalised older people and the role of Bioelectrical Impedance Spectroscopy

by

Saleh Alsanie

Thesis for the degree of Doctor of Philosophy

January 2024

University of Southampton

Abstract

Faculty of Medicine

Human Development and Health

Doctor of Philosophy

Assessment of low-intake dehydration in hospitalised older people and the role of Bioelectrical Impedance Spectroscopy

by

Saleh Alsanie

Background: Older people are susceptible to low-intake dehydration, which is often not recognised and can result in significant morbidity through falls, constipation, delirium, respiratory and urinary tract disorders, and even death. Identifying low-intake dehydration at hospital admissions is challenging, leading to treatment delays and poor outcomes.

Aims: To examine the factors underlying the identification of low-intake dehydration in older people admitted to Medicine for Older People (MOP) wards at University Hospital Southampton NHS Trust and to explore the feasibility of performing a study whereby bioelectrical impedance analysis (BIA) might be used alongside existing hydration risk screening tools in identifying low-intake dehydration in older people admitted to hospital.

Methodology: A narrative review of the role of water in the body and the consequences of dehydration was carried out. This was followed by a sequential explanatory mixed-methods study involving quantitative service evaluation of recognition of dehydration in MOP wards and qualitative staff interviews to determine barriers and facilitators of hydration care and examine the factors influencing the routine assessment and diagnosis of dehydration in MOP wards. This led to a systematic review of the literature on the role of BIA in detecting low-intake dehydration. Finally, a study was conducted to examine the feasibility of conducting measurements of hydration status in hospitalised older patients using the existing hospital screening tool for dehydration and BIA measurements.

Results: Most older patients admitted were at moderate to severe risk of developing dehydration. The service evaluation of hydration care provision showed good compliance with completing the initial hydration assessment. However, follow-up of patients at severe risk via 24-hour fluid balance charts needed improvement. Nursing and medical staff were aware of the importance of assessing hydration status but faced challenges in the diagnosis and management of dehydration. The proposed design for a study exploring the concurrent validity of the current screening tools and bedside measurements of BIA, its implementation and conduct was shown to be both feasible and acceptable to patients and staff and generated high-quality impedance measurements at the bedside alongside routine clinical care. Clinical demographics and directly measured impedance values of resistance, reactance, phase angle and impedance ratio were obtained in 25 patients reflected both age and hydration state but did not significantly correlate with risk categorisation of dehydration based on the established screening tools.

Conclusion: Identifying older people admitted to hospitals who are at risk of or have low-intake dehydration requires continued vigilance, adherence to screening and assessment, and continued oversight within ordered systems and processes. Continued service improvement and staff training are needed, together with objective measures of hydration status, such as bioelectrical impedance, which may be used to improve clinical decision-making and care. Further studies are required to determine the reliability and validity of BIA in detecting low-intake dehydration compared with pre-existing objective measures such as serum osmolality, as well as its cost-effectiveness and evaluability in clinical practice.

Keywords: Bioelectrical impedance; dehydration; low-intake; older people; feasibility

Table of Contents

Table of Tables

Table of Figures

Research Thesis: Declaration of Authorship

Print name: Saleh Alsanie

Title of thesis: Assessment of low-intake dehydration in hospitalised older people and the role of Bioelectrical Impedance Spectroscopy

I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published. Please see outputs from this project (page xi)

Signature: Date: 31/01/2024

Outputs from this PhD Project

Publications

Chapters published as peer-reviewed articles:

Chapter 5: Alsanie S, Lim S, Wootton SA. Detecting low-intake dehydration using bioelectrical impedance analysis in older adults in acute care settings: a systematic review. BMC Geriatr. 2022 Dec 12;22(1):954. doi: 10.1186/s12877-022-03589-0 (Appendix S).

Chapters unpublished yet as peer-reviewed articles:

Chapter 3: Alsanie S, Ibrahim K, Lim S, Wootton SA. Understanding the Scale of Low-Intake Dehydration on 'Medicine for Older People' Wards: A Mixed-Methods Study. 2024 (Manuscript in preparation).

Chapter 7: Alsanie S, Lim S, Ibrahim K, Wootton SA. An Evaluation of the Feasibility and Acceptability of Performing a Study to Identify Low-Intake Dehydration in Hospitalised Older People on Medicine for Older People (MOP) Wards through Concurrent Use of Bioimpedance Measurements and Existing Hospital Risk Assessment Tools. 2024 (Manuscript in preparation).

Published abstracts

Conference abstract 'Understanding the Scale of Low-Intake Dehydration on 'Medicine for Older People' Wards at University Hospital Southampton: A Mixed-Methods Study': Winter Conference 2023 - Diet and Lifestyle Strategies for Prevention and Management of Multimorbidity. The UK Nutrition Society. 2023;21. https://doi.org/10.26226/m.654909d29113b20019d9b523.

Presentations

Event/location	Date	Title of presentation	Type of presentation
UK Nutrition society, Winter Conference 2023, London	5-6 December 2023	Understanding the Scale of Low-Intake Dehydration on 'Medicine for Older People' Wards at University Hospital Southampton: A Mixed-Methods Study	Poster (Appendix T)

Acknowledgements

This thesis stands as an important steppingstone in my academic journey, reflecting not only my own endeavours but also the substantial support and guidance received from various people both within and outside the University of Southampton. With deep gratitude, I acknowledge those who have contributed significantly to the fruition of this research endeavour.

Foremost, I extend my sincerest gratitude to Allah, the most Beneficent and the most Merciful, whose boundless blessings have been the cornerstone of my journey as a PhD student. It is through Allah's benevolence that I have been endowed with the resilience, strength and wisdom requisite for the successful completion of this thesis.

To my supervisors at The University of Southampton, and particularly to my primary supervisor, Dr Stephen Wootton, my gratitude is beyond words. Your solid support and insightful feedback have been the bedrock upon which my research and academic activities were anchored. I have learned a lot from our discussions, which have not only deepened my understanding of clinical nutrition but have also transformed daunting challenges into fertile grounds for growth and learning. Dr Wootton, your supervision has been a compass in moments of uncertainty, a light guiding me towards clarity from my very 1st day at the University, making the realisation of this thesis not just a dream but a reality. For the wisdom you have imparted and the confidence you have instilled, I am eternally grateful to you.

I extend sincere thanks to Dr Stephen Lim for his significant contributions as my PhD supervisor and as my clinical fieldwork supervisor, which were fundamental to the collection of my data. Your continuous support, insightful guidance, and encouraging words did not just enhance my research rigour but also helped strengthen my confidence, driving me forward. The journey into the MOP wards at the University Hospital under your guidance was not only a journey of precise data collection but also filled with learning and growth.

Similarly, I express my sincere gratitude to my supervisor, Dr Kinda Ibrahim, whose motivational guidance, empathetic support and nurturing approach significantly alleviated the challenges I faced during my research journey. I found the conversations we had in MS Teams not only enjoyable, but profoundly enriching, encouraging an environment of collaboration and support. As well as enriching my PhD experience, your profound expertise, insightful wisdom, and supportive supervision significantly shaped the qualitative portion of my thesis, adding depth and clarity to my analysis.

I would also like to thank all the MOP clinical staff and study participants, whose contributions were key to the completion of my PhD research project. Special thanks are due to the medical staff in the

MOP wards who participated in the qualitative component, generously sharing their experiences and allowing their voices to be heard.

I am also sincerely grateful to Qassim University for providing me with a fully funded scholarship throughout my PhD studies in the UK and for providing me with consistent support and guidance throughout my PhD studies. Word of thanks to the Faculty of Applied Health Sciences at Qassim University, which I belong to as a lecturer, for their continued support and faith in my ability to complete this PhD programme.

My family's unconditional love and support have been a constant source of inspiration and strength for me throughout this journey. My deepest gratitude is extended to my mother, whose patience has bridged the distance of over 14 years. The thought of returning to her embrace, to feel her love and tenderness, has been encouraging throughout this endeavour. To my father, absent in body but ever-present within my heart, thoughts and prayers, your memory has been a guiding light throughout this journey, providing strength and inspiration at every step. Your firm belief in me resonates deeply within me, pushing me forward. To my sisters, whose continued support has been of utmost importance, I owe an immeasurable debt. Their belief in me has significantly shaped this journey, bringing this chapter of my life to its fruition.

Words fall short to express the depth of my gratitude to Dr Mashael Algethami, my wife, whose affirmation, "Yes, you can do it," fuelled my determination to succeed. Her boundless support, patience and kind words have been an integral part of my PhD journey. I am grateful to you. To my children, Abdulrahman and Ghaliah, you are the joy that refined my focus; your innocent questions and companionship have greatly enhanced my life. To all of my family members, your presence in every step whispers success; for that, I am eternally grateful.

Abbreviations

BIA	Bioelectrical Impedance Analysis
BIS	Bioelectrical Impedance Spectroscopy
CQC	Care Quality Commission
ECF	Extracellular Fluid
ERGO	University's Ethics and Research Governance Online
ESPEN	European Society for Clinical Nutrition and Metabolism
FFM	Fat-Free Mass
FM	Fat Mass
HCRW	Health and Care Research Wales
HRA	Health Research Authority
ICF	Intracellular Fluid
IRAS	Integrated Research Application System
MOFD	Medically Optimised for Discharge
MOP	Medicine for Older People
NHS	National Health Service
NIHR	National Institute for Health and Care Research
PhA	Phase Angle
R	Resistance
SACN	Scientific Advisory Committee on Nutrition
TBW	Total Body Water
UHS	University Hospital Southampton
Xc	Reactance
Z	Whole-Body impedance

Chapter 1 Introduction to the Programme of Work

1.1 Significance of Research

Water is one of the most vital nutrients that sustains life in all forms. In humans, life cannot exist without adequate water intake, as almost all cellular processes and functions require water, especially since endogenous mechanisms cannot function properly without sufficient water in the body that can support these processes[1]. In healthy conditions, children and adults tend not to observe water intake issues and dehydration due to intact thirst mechanisms that promote intake in response to variances in hydration status[2]. Only in instances of pathology do the young population encounter issues of hydration that may threaten life[3]. However, in older adults, maintaining hydration is much more challenging as the desire to drink water diminishes because of reduced thirst and comorbid health issues that may impede the ability or capacity to replenish losses. Thus, older people are susceptible to dehydration due to excess water loss relative to intake, resulting in excess morbidity and mortality[2]. Dehydration in older adults is a markedly under-recognised problem for various reasons, ranging from the poor reliability of clinical examination findings in determining hydration status to marked practice variation regarding investigative tests to diagnose dehydration[4].

Differences in the approach to the prevention, detection and management of dehydration also exist, further protracting the burden of the problem in older people associated with the lack of universal standards of water intake requirements[5,6]. Current means to diagnose dehydration in clinical practice rely upon the patient history, clinical assessment findings and point-of-care and laboratory tests, such as measurement of serum urea, creatinine and electrolytes, and plasma osmolality. However, concurrent illnesses and chronic long-term conditions can impact the results of these tests, which may complicate the diagnostic process, and lead to misinformed treatment decision-making in some cases[6].

Failure to detect dehydration is a key clinical issue, given the impact of dehydration on the physical and mental health of older adults, which can result in unexpected and rapid deterioration, including death[7]. The impact of dehydration on older adults has been reflected in the recent controversy, as detailed in the UK Francis Report where excess morbidity and deaths were reported due to failures to recognise and/or respond to dehydration was deemed avoidable in a considerable proportion of cases[8]. Although the Francis report identified numerous instances of failure in nursing care, it particularly stressed the insidious effects of dehydration, resulting from poor nursing care in terms of supporting patients to eat or drink. Older patients were either not offered water or did not have assistance or the means to drink it; furthermore, fluid intake was inaccurately recorded, resulting in under-recognition of dehydration and adverse consequences[8].

Epidemiological data has shown that dehydration is a markedly prevalent problem among the older population with rates varying between 30-50% depending upon the clinical context and health setting with the highest rates being observed in residents of nursing homes and patients receiving acute inpatient care[9,10].

The contribution of dehydration to mortality in older adults has been revealed in a large study of more than 10 million hospital records in the United States, as reported by Warren, et al. [11] where 30-day and one-year mortality were 17% and 38%, respectively. Research has also shown that dehydration and the clinical sequelae of dehydration among older inpatients account for prolonged lengths of hospital stay and consume excess resources and costs[12]. Evidence from the United States suggests that dehydration may cost more than $1.2 billion for clusters of hospitals within defined regions, whilst in the UK, the costs have been estimated to exceed £1 billion per year across National Health Service (NHS) hospitals, with half of the burden being related to dehydration-induced acute renal impairment[12,13]. However, due to challenges in diagnosing dehydration in older people and other population groups, the prevalence, cost and impact estimates are likely to underestimate the scale and costs of the problem.

The ongoing problem of dehydration among the older population remains a pertinent clinical issue despite UK policies targeting all health and care systems levels, from commissioners to frontline care providers[13-15]. The Scientific Advisory Committee on Nutrition (SACN) found that one-third of older adults admitted to the emergency departments in the UK were dehydrated on admission[9,15]. Furthermore, the Care Quality Commission (CQC) identified that staff in many hospitals did not encourage or assist older patients in drinking and that only two-thirds of hospitals in the UK (34 out of 50) met the expected standards for case record documentation of fluid input/output monitoring, suggesting that healthcare providers may not always view hydration as a priority for older inpatients, despite numerous guidelines to the contrary[16].

Dehydration is a complex problem to understand, both from an academic and clinical perspective where variances in fluid and electrolyte shifts are dynamic and subject to individual variation. In clinical practice, dehydration means a deficiency in total body water (TBW). There is no universally accepted definition of the presence or severity of dehydration[17]. Based on the plasma osmolality, dehydration can be hypotonic (with decreased osmolality <280 mOsm/kg); isotonic (with normal osmolality between 280-300 mOsm/kg); or hypertonic (with increased osmolality >300 mOsm/kg)[17] (Table 1). Dehydration is not synonymous with hypovolaemia, as hypertonic dehydration is associated with preserved intravascular volume. In terms of aetiology, dehydration can be categorised into two main categories: 1) low-intake dehydration (a deficiency of water due to insufficient drinking) which usually co-exists with hypernatraemia and to a lesser extent hyponatraemia; and 2) salt-loss dehydration, where water and sodium are lost proportionately,

leading to hyponatraemia[18]. Low-intake dehydration is defined as a deficiency of water due to insufficient drinking and it is more common in older adults, affecting one in four older people[19], due to the previously discussed issues of diminished thirst and reduced capacity to intake water because of comorbid health issues[20]. Moreover, age-related declines in physiology and homeostasis (senescence) increase the susceptibility of older adults to organ dysfunction in the presence of poor dehydration status[7].

Table 1 Comparison of different types of dehydration based on osmolality [21]

Hypotonic Dehydration	**Isotonic Dehydration**	**Hypertonic dehydration**
Plasma osmolality ≤280 mOsm/kg	Plasma osmolality 280-300 mOsm/kg	Plasma osmolality >300 mOsm/kg
Also described as hypo-osmolar dehydration	Also described as iso-osmotic, extracellular and salt-loss dehydration	Also known as hyperosmotic, intracellular, water-loss and low intake dehydration
Caused by loop and thiazide diuretics	Major causes: vomiting, secretory diarrhoea, sweating, burns, intrinsic kidney disease, hyperglycaemia, and hypoaldosteronism	Occurs secondary to fever (via increased sweating), increased respiration, and diabetes insipidus
Characterised by low serum sodium and osmolality	Characterised by normal serum sodium and osmolality	Characterised by elevated serum sodium and osmolality

There is a clear need to improve the recognition and accuracy of identifying low-intake dehydration among older people, particularly as improvement in treatment decision-making could reduce the risk of adverse outcomes. Diagnosing dehydration is not straightforward, as traditional reliance on symptoms (such as increased thirst) or signs (such as decreased skin turgor, low blood pressure) can be misleading due to co-existent medical conditions. As discussed in more detail in chapter 2, there are several caveats with using urinary and haematological indices to diagnose dehydration. Currently, direct measures of serum or plasma osmolality is considered the gold standard for objectively diagnosing low-intake or hypertonic dehydration. Plasma osmolality is determined as number of milliosmoles of solutes per kilogram of plasma (in contrast to osmolarity, which is the number of milliosmoles per litre of plasma). Osmolality can be directly measured using vapour pressure depression or freezing point depression osmometers. In the absence of direct measurement, plasma

osmolarity can be calculated using the formula below (i.e Khajuria and Krahn equation[22]) with an action threshold of >295 mOsm/L, although with lower diagnostic sensitivity and specificity compared to directly measured values[17,22]

Osmolarity (mOsm/L) = 1.86 x ([Na^+] + [K^+]) + 1.15 x [glucose] + [urea] + 14 (all measured in mmol/L)

Relying on plasma osmolality alone to determine dehydration can be associated with some caveats. As a laboratory test, directly measured plasma osmolality can take time to be processed, especially within the busy workload within the NHS. Calculated osmolarity has sensitivity of 85% and specificity of 59% for diagnosing low-intake dehydration with threshold of 295 mOsm/L, compared to the directly measured serum osmolality threshold of 300mOsm/kg. Furthermore, isotonic dehydration cannot be reliably determined by plasma osmolality[17].

One neglected but potentially important approach to improving the diagnosis of low-intake dehydration is using bioelectrical impedance analysis technology. However, its utility and role in clinical settings have been limited so far[23]. Evaluating the diagnostic utility of this technology in diagnosing dehydration and differentiating low-intake dehydration from other forms of dehydration could help support ongoing practice and improve patient outcomes. The importance of addressing this problem is reflected in evidence showing that low-intake dehydration is often an avoidable and treatable problem through encouraging or tailoring fluid intake based on individual patient needs[24,25].

In older adults, a loss of as little as 3-5% of total body water can lead to both physiological compromise and cognitive impairment and thus, objective tests for detecting dehydration must be sufficiently sensitive and specific to elicit variances in body water by the noted amount[26]. In addition, it has been recognised that older patients who become dehydrated within clinical settings observe protracted or uncorrected dehydration for as long as 48 hours following hospital admission. Therefore, an objective measure is needed to assess dehydration status and confirm its resolution following treatment[9]. This may help prevent or reduce the adverse effects associated with dehydration.

Bioelectrical Impedance Analysis (BIA) is a portable, easy-to-use, inexpensive, and non-invasive method that is accessible at the point of care and can be repeated frequently with minimal consumable costs[23,27]. It measures whole-body impedance (Z), the opposition of the body to alternating current consisting of two components: resistance (R) and reactance (Xc). Resistance is the decrease in voltage reflecting conductivity through ionic solutions. Reactance is the delay in the flow of current measured as a phase shift, reflecting dielectric properties, i.e., capacitance, of cell membranes and tissue interfaces. Both measures will alter with changes in hydration status:

dehydration is usually associated with higher resistance and lower reactance[28,29]. Phase angle represents the relationship between resistance and reactance as the arctangent of their ratio and is usually determined at the frequency where reactance is highest, which in most practical instances is 50 kHz. In dehydrated states, phase angle can be lowered.

BIA is not a direct method for the assessment of body composition and its utility relies on the relationship between impedance measures and the fluid and electrolyte status of the body. In the euvolaemic state, impedance measures can be used to derive estimates of total body water (as well as intracellular and extracellular fluid water), and, in turn, the proportions of fat and lean by applying suitable (i.e. age-, sex- and population- and device-specific) equations for the calculation of body compartments. However, these conditions are frequently violated in ill and hospitalised patients as disturbed hydration or altered distribution of extra- and intra-cellular water are often present. In contrast, the measured values of resistance and reactance and the derived parameter of Phase Angle are not affected by the factors that affect the assumptions used in the estimation of body composition, have both excellent accuracy and precision, and may offer an objective measure that can be used to mark differences in hydration status in older people at risk of low-intake dehydration in the clinical setting[23,30,31].

1.2 Thesis Aims and Objectives

The thesis aims to address two key research questions:

1. **What is the scale of low-intake dehydration among hospitalised older adults and what are the barriers and facilitators in providing good hydration care?**

A mixed methods approach was utilised with a sequential explanatory study design to address this question (Figure 1.1). Quantitative data were first collected through observational studies within a service evaluation framework to determine the current practice of hydration assessment in Medicine for Older People (MOP) wards in a tertiary hospital. Analysis of this quantitative data informed qualitative interviews which were carried out with NHS staff working in the MOP department to explore the barriers and facilitators to hydration care assessment and management in clinical practice. The interviews were analysed using a thematic approach, and consolidated data from both phases of the mixed methods study was used to highlight barriers to hydration care and the means to address these barriers in clinical practice.

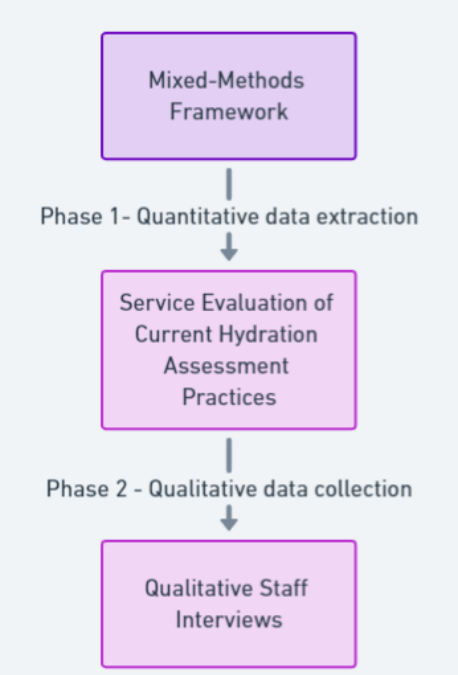


Figure 1.1 Mixed method's framework: a two-pronged approach was used for a sequential explanatory study design.

2. **Can bioelectrical impedance spectroscopy (BIS) be used to augment existing approaches and improve the detection and management of low-intake dehydration?**

The research approach to address this question is multifaceted. Firstly, I conducted a narrative review of water homeostasis, states of hydration and in particular dehydration, and consequences of low fluid intake, which is presented in Chapter 2. A mixed-methods study was used to understand the scale and problems arising from low-intake dehydration from MOP wards, the framework of which is outlined in Figure 1.1—this constitutes Chapter 3. This was followed by a narrative review of the role of BIA in hydration status assessment (chapter 4), which informed a systematic review of the role of Bioelectrical Impedance Analysis (BIA) in detecting low-intake dehydration in older adults in acute care settings (chapter 5). Finally, a study on the feasibility and acceptability of performing a study examining the concurrent use of bioimpedance measurements and existing hospital hydration risk assessment tool to identify low-intake dehydration in older adults in MOP wards was conducted (chapter 6). This research flow is presented in Figure 1.2:

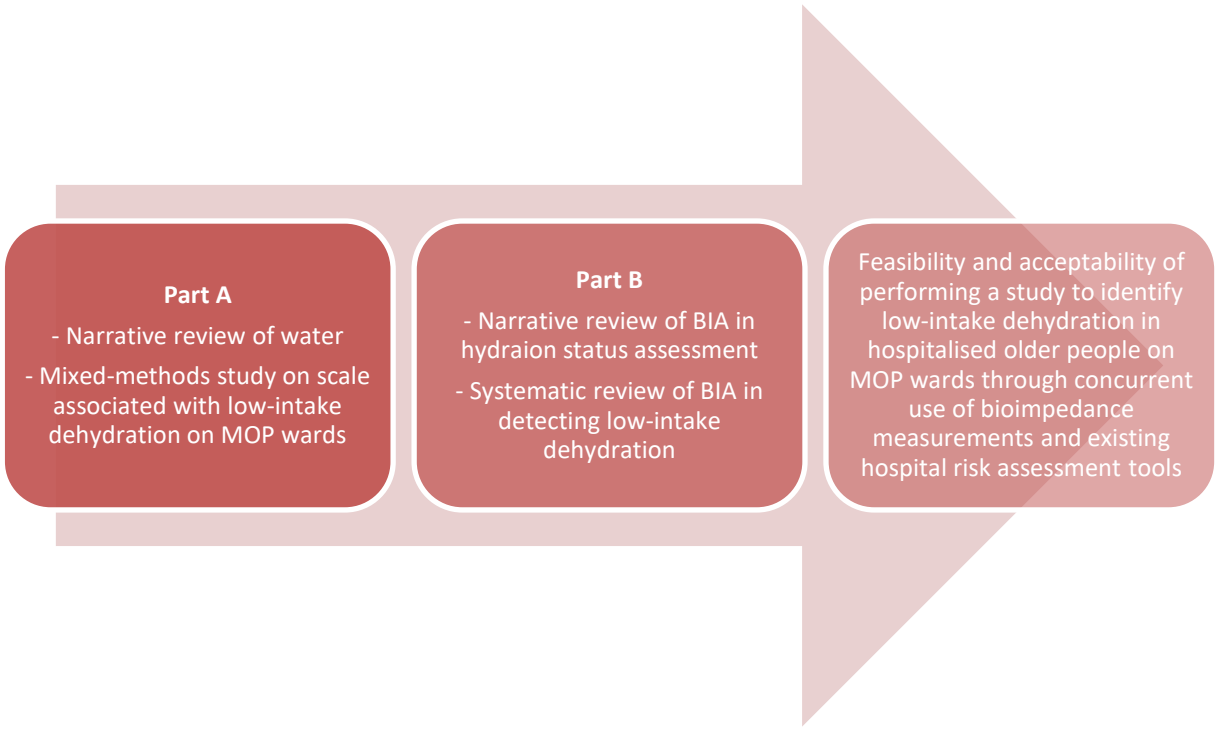


Figure 1.2 Research methodology to explore the feasibility of performing a study that would examine BIA as an adjunct to current hydration risk assessment methods of identifying low-intake dehydration

1.3 Reflection - The impact of the COVID-19 pandemic

In March 2020, approximately 10 months after I began my PhD in the UK, the country entered a national lockdown in response to the COVID-19 pandemic. As an international PhD student with type 1 diabetes, this period was especially daunting, steeped in global uncertainty and a plethora of unanswered questions. The pandemic began as an unfamiliar challenge and gradually became an everyday normal that required adaptation and strategic navigation. The escalated pressure on healthcare services led to significant delays in my research since it was deemed non-essential. It was only on 28th February 2022 that I could submit my ethics application for my Service Evaluation study, and I began collecting clinical data for my PhD project in May 2022. This interval offered a vital opportunity for reflection and recalibration of my project, including the systematic review and the development of protocols for my three key studies: a Service Evaluation, a Qualitative Study and a Feasibility Study.

Securing a Research Passport for conducting research at University Hospital Southampton (UHS) presented substantial hurdles. My status as an international student without clinical ties to UHS added to these challenges. The process entailed complex prerequisites, such as providing an immunisation record from Saudi Arabia and completing a Hepatitis B vaccination series (two initial doses and a booster), culminating in a 4-5 month wait for my occupational health certificate.

Moreover, the targeted population of my research, being older inpatients, necessitated obtaining a Disclosure and Barring Service (DBS) certificate to ensure safe recruitment practices, a process that took an additional two months.

Despite the frustrations encountered during this period, such as the cancellation of supplementary courses, there was a silver lining in the form of a shift towards virtual resources. This shift not only maintained but enhanced my academic progress. The pandemic's limitations forced a transition to remote learning and virtual collaboration, skills increasingly indispensable in modern research.

In retrospect, the COVID-19 pandemic, with its myriad disruptions and delays in my research programme, has been instrumental in shaping my growth as a researcher. It has fostered in me a resilience and adaptability critical to navigating an ever-changing academic landscape. This experience has not only strengthened my PhD project but has also granted me profound insights into the importance of agility and responsiveness in the face of unexpected challenges, insights that are particularly significant for an international student adapting to a UK academic environment.

Chapter 2 Background and Literature Review

2.1 Functions of Water in the Body

Water is considered the most vital nutrient as it is integral to life. It accounts for about 60–70% of the normal body mass, depending on age and biological sex[1]. Water, a molecule comprising two hydrogen atoms and one oxygen atom, is involved in various functions in the human body, including its primary function as a medium for nutrient transport into cells, the elimination of waste and metabolic by-products, and permitting the exchange of nutrients between cells, interstitial fluid and capillary beds[32,33]. Water exerts a key role as a building foundation to permit growth and development, as well as acting as a solvent, a medium to permit biomolecular reactions, a reactant itself and a product of reactions. These actions are exerted via the weakening of electrostatic forces and hydrogen bonds and high dielectric properties to permit the movement of ions[32].

Water plays a key role in maintaining intravascular volume and comprises the medium which permits blood flow and tissue perfusion, which is essential to organ function and, thus, life[33]. The organ systems that depend upon sufficient water (adequate hydration) to function normally include the cardiovascular, respiratory, gastrointestinal, renal, hepatic, reproductive, and peripheral and central nervous systems[32]. Furthermore, water helps to sustain thermoregulation by mitigating extreme changes in core body temperature in response to the external environment through facilitating perspiration and the vaporisation of heat to promote heat loss; it also acts as an insulator to protect from hypothermia[34]. Finally, water also acts as a lubricant of articular joints to permit functional range of motion, as well as providing lubrication through bodily fluids such as saliva, intestinal mucous and seminal fluid, and in maintaining cellular integrity and thus, function, as well as absorbing shock through cushioning impacts by being a constituent of synovial fluid[1].

The function of water in the body is reflected in its abundance; approximately 60-70% of total body weight is water, with the extent of water varying depending upon lean muscle and adipose tissue[2]. This complements observations that humans can only survive for a few days without water intake[1]. Moreover, wider research has shown that a sufficient intake of water to maintain hydration confers positive effects, psychological well-being and even longevity on sleep quality with life expectancy improving by three-fold. Maintaining adequate water balance is, therefore, essential for life, and disturbances in this balance can have significant consequences.

2.2 Water Homeostasis in Adults

In healthy adults of around 70kg weight, the estimated water content totals almost 42 litres. Two thirds of this is contained in the intracellular compartment, and one-third exists within the extracellular compartment, of which three litres is within the plasma, one litre is transcellular fluid, and 10 litres is contained within the interstitial space (Figure 2.1)[35]. In young children, the water content tends to be higher than adults at around 75% of total body weight; in contrast, it is much lower in older people at around 55% of total body weight, due to variances in body composition[28].

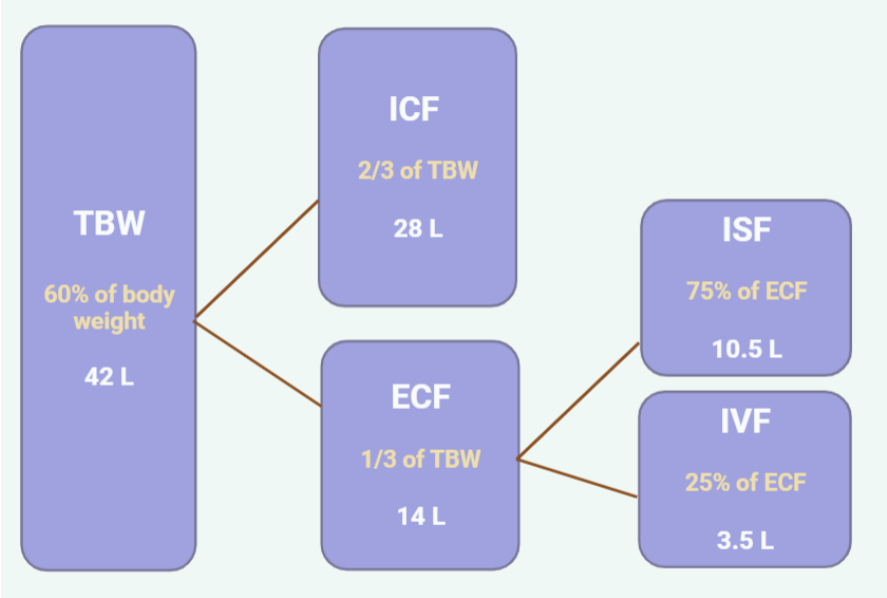


Figure 2.1 Representation of fluid compartments in the human body based on an average 70kg adult [17] TBW: total body water; ICF: Intracellular fluid; ECF: Extracellular fluid; ISF: Interstitial fluid; IVF: Intravascular fluid

The regulation of body water is under stringent control with losses of as little as 1% of total body water being compensated for within 24 hours via endogenous homeostatic processes[1]. As previously noted, water content tends to diminish with advancing age, which is thought to be a result of decreases in lean muscle mass and increases in adipose tissue; the latter being hydrophobic repels water[36]. Moreover, older adults experience a diminished thirst response, leading to lower average water intake compared to younger adults[2]. The homeostatic mechanisms responsible for maintaining the volume of water, as well as the composition, pH, osmotic pressure and temperature of fluid in the extracellular compartment, are co-ordinated by the neuroendocrine system, with adjustments in one or more of the noted variables being regulated by the circulatory, respiratory, renal and alimentary organ systems[3]. Regarding the constancy of water volume, it is primarily the renal system that has evolved and adapted to respond to variances in volume status and maintain stringent control of volume within the various compartments[37].

In a healthy adult, water homeostasis depends upon the intake of water matching the output of water; typically, water is ingested through solid foods and fluids (approximately 2,300ml) and produced through metabolic activity (approximately 300ml) to a total of 2,600ml per day[3]. In normal conditions, the water output would match the intake volume via typical losses in urine (1,500ml), stools (100ml), dermal insensible loss and sweat (700ml), and respiratory insensible loss (300ml) (Table 2)[37].

The ingestion of fluid is stimulated via thirst, as well as regular drinking habits that are independent of thirst, particularly in younger people who are often more self-conscious or aware of the importance of adequate fluid intake and hydration[5]. This has also been fuelled by widespread campaign messages for adults to consume at least eight cups of water per day (equating to around 1,800ml), despite unreliable scientific evidence that such consumptions benefit health[38]. Concerning the output of water, the renal and urinary systems are vitally important as the largest volume of water is filtered through the kidneys and lost through excretion. The associated volume can, therefore, be markedly increased or decreased depending upon volume status. Losses of water via other means are less suited to water volume homeostasis as large changes in water loss are only observed during vigorous exercise or in pathological conditions, such as chronic diarrhoea or sepsis[37].

Table 2 Average water intake and output of a 70kg adult [37]

Water input, ml		**Water output, ml**	
Solid foods	500	Stool	100
Fluids	1800	Sweat	200
Metabolism	300	Dermal insensible losses	500
		Respiratory insensible losses	300
		Urine	1500
Total	2600	**Total**	2600

Understanding the normal mechanisms of water homeostasis is important in discussing the disorders that affect water balance in older adults. The homeostasis of water, in the absence of water sensors, is guided by osmoreceptors as these permit the detection of changes in plasma tonicity. These osmoreceptors are sensitive enough to recognise 3mOsm/kg deviances from a set threshold, which is usually around 280mOsm/kg, with tonicity being the concentration of solutes that exert an osmotic effect; the most dominant solute is sodium[39].

The tonicity is usually calculated as:

$$Plasma\ osmolality = 2 * plasma[Na] + \left(\frac{glucose}{18}\right) + \left(\frac{blood\ urea\ nitrogen}{2.8}\right),$$

where plasma osmolality represents the concentration of solutes per litre of the solution[40]. However, variances to this equation exist with some authors advocating the formula $1.86 * [Na + K] + 1.15 * (glucose) + urea + 14$ [41]. These formulae provide reliable indirect means to determine the plasma osmolality and, thus, low-intake dehydration when the threshold level of 295 mOsm/kg is exceeded[41].

2.3 Disturbances in Water Homeostasis in Older Adults

Disturbances of water homeostasis in older adults can affect one or multiple previously discussed mechanisms[37]. Older adults are increasingly susceptible to dehydration (deficit of body water) due to the impacts of ageing upon systemic organ function; this general decline in physiological function and reserve is known on a cellular level as senescence[42]. One of the most common causes of dehydration is a diminished sensation of thirst that is independent of the responsiveness of osmoreceptors and circulating anti-diuretic hormone concentrations[43]. The precise mechanism of diminished thirst in older adults remains incompletely understood. Evidence suggests that such individuals observe dysfunction or downregulation of central volume receptors, due to findings that central volume expansion fails to inhibit thirst and drinking behaviours as compared to younger adults[44].

In addition to diminished thirst, older adults are also susceptible to water volume disturbances because of a reduced renal capacity to concentrate urine, increased resistance of the nephron to anti-diuretic hormone, and attenuated release and activity of renin and aldosterone[15,45]. This causes older adults to be less able to concentrate urine and to have higher minimum urine output[15]. The risk of dehydration is also heightened due to other complex psychosocial and situational issues, such as reduced mobility, difficulty in accessing drinks, impaired vision or cognitive decline to permit ready access to and consumption of drinking water, anxiety regarding urinary incontinence that may prevent water intake, and reduced hunger that limits water intake within food[37]. Older adults have smaller fluid reserves as total body water reduces with age and are also on several medications promoting water loss such as diuretics and laxatives[37,46]. Figure 2.2 highlights risk factors for dehydration in the older adult population:

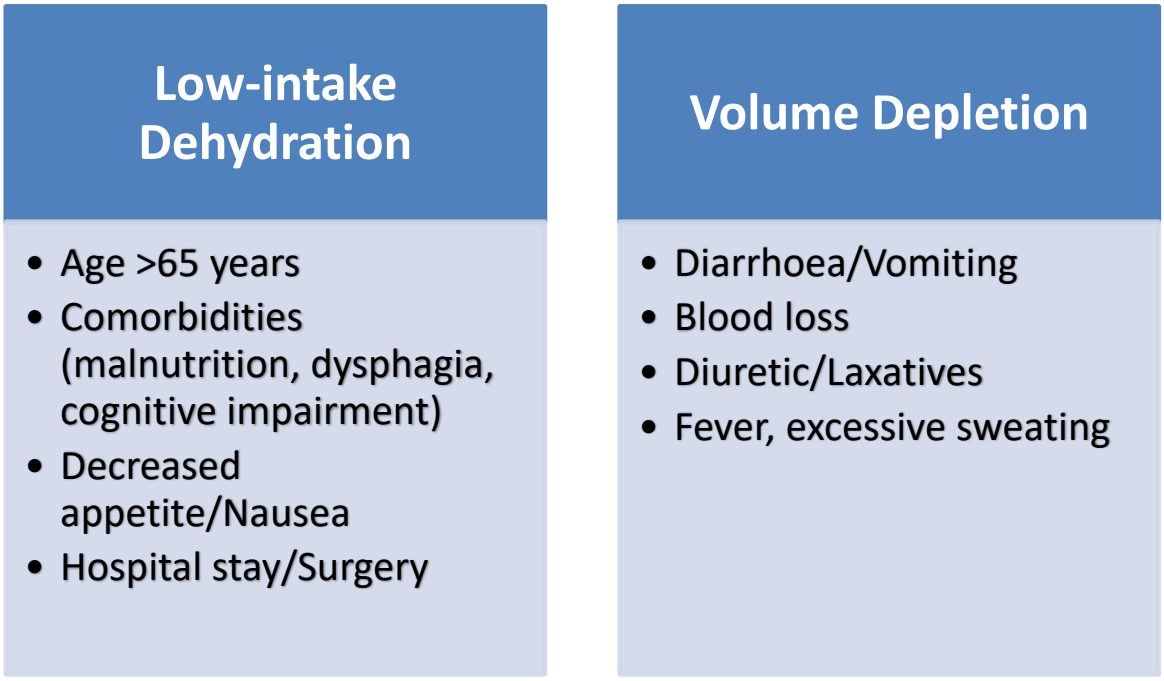


Figure 2.2 Factors predisposing to dehydration in older adults

2.4 Fluid Intake and Requirements in Older Adults

As previously noted, fluid intake tends to decline in older age, as compared to intake among young healthy adults, due to the diminished sensation of thirst[43]. This is supported by a body of research which has found the average water intake of cohorts of older adults to be much lower than their younger adult counterparts[47-49]. In the analyses of data from the United States National Health and Nutrition Examination Survey, 83% of older women and 95% of older men failed to meet the recommended requirements for water intake[49].

Water requirements in humans are not simply calculated based on exact (minimal) water intake, as this may lead to dehydration due to inter-individual variances in water loss related to metabolism, exercise, diet and climate[50]. Water requirements have been increased to account for the averages in the extent to which these factors promote water loss. According to the United States Food and Nutrition Board criteria for adequate water intake, males aged >19 years are expected to drink 3.7 litres per day, whilst females require 2.7 litres per day. These water requirements were based on data drawn from the Third National Health and Nutrition Examination Survey, which is one of the largest and most reliable data sources with sufficient representation of the general population[51]. The mean water intake correlates with adequate hydration criteria, which was defined as a total water intake of ≥45 ml/kg or plain water intake of ≥20 ml/kg. In patients aged 51-70 years and 71-80 years, 41.5-50.9% and 32.5-49.1% met this criterion respectively, highlighting that low-intake dehydration (a deficiency of water due to insufficient drinking) is a prevalent problem among older adults[51].

In contrast to the United States criteria, the European Food Safety Authority define differing daily water requirements for humans; 2.5 litres in males aged >14 years and 2.0 litres in females of the same age range[1]. Such international variances simply reflect the differences in water intake related to food and drink consumption patterns across the general population. Therefore, requirements for older persons in the UK should be based on local population data. The British Dietetic Association (BDA) adopted the recommendation from the European Society for Clinical Nutrition and Metabolism (ESPEN)[46] that the minimum daily water intake from fluids only should comprise 2.0 litres for older men and 1.6 litres for older women, whilst the Scientific Advisory Committee on Nutrition (SACN) refers to the eight glasses of water per day (1,600ml) but fails to stipulate key requirements by gender or age[15,52]. The SACN report recognises that the absence of a universal best test for determining dehydration can lead to missed dehydration in older adults[15].

Earlier research has identified that a range of formulae could be used to calculate water requirements for older adults, such as 30-35ml/kg/day (equating to 1,800-2,100ml in a 60kg person); or 100ml/kg for the first 10kg, 50ml/kg for next 10kg and 15ml/kg for remaining kg/day (equating to 2,100ml); or 1,500-1,600ml/m2/day (equating to 2,400-2,560ml in a 1.6m individual); or 3.4-4.0%/day of body weight (equating to 2,040-2,400ml in a 60kg person)[7,25,53,54]. However, these approaches are associated with some considerable variances in water requirements for a single individual and have been based on research that cannot be reliably applied to an older adult population or used for deriving accurate measures of water intake. Other methods to calculate water requirements have included using 1ml per expended kilocalorie as an estimate but deriving accurate measures of energy expenditure has been methodologically and practically difficult[53,54]. This approach also lacks feasibility for adjusting mean population requirements over time. However, it is generally accepted that a water intake of 35-45ml/kg is sufficient to optimise or maintain hydration in older adults, with variances depending on biological sex and external factors[25]. Due to individual differences in body composition among older adults, a small proportion of the population in this age group is likely to observe inadequate or excess intake when adhering to recommended water intake[25].

2.5 Consequences of Inadequate Fluid Intake

2.5.1 Dehydration

Dehydration is the most common consequence of inadequate fluid intake in older adults. Various definitions of dehydration exist, which have accounted for variances in estimates of the incidence and prevalence of dehydration[17]. The prevalence among older adults admitted to hospitals aged ≥65 years exceeds 30%, and this can be even higher up to 38% among persons in long-term facilities[9,10].

Simply dehydration is a deficit in total body water to an extent that elicits signs and symptoms and, thus, is beyond variances that occur and are rapidly controlled by endogenous homeostatic mechanisms; however, no universal consensus exists on this definition[55].

Other definitions have classified dehydration into various types such as hypotonic, isotonic and hypertonic dehydration; inadequate intake of fluid usually induces isotonic or hypertonic dehydration as the ratio of fluid to electrolytes initially remains stable but then changes as the ratio of electrolytes increases relative to body water[56]. However, these definitions have been unhelpful in eliciting the causes and informing the treatment of dehydration from a clinical perspective, and thus, the ESPEN advocate the use of alternative terms/definitions such as low-intake dehydration as opposed to water-loss dehydration, to emphasise the modifiable cause, of insufficient water intake[46]. Other definitions of dehydration have referred to body water compartments like intracellular versus extracellular fluid losses, although most experts agree that dehydration should reflect intracellular dehydration as this is osmotic dependent, whilst extracellular dehydration may be better defined as hypovolaemia[57]. Despite such complexity in diagnosing dehydration, mild to moderate dehydration tends to impart little impact upon physical and mental health when occurring transiently, however, severe dehydration can rapidly result in multi-organ dysfunction, failure and death when protracted[17]. Long-term dehydration in older adults is associated with chronic health problems such as poor health outcomes, increased length of hospital stay, falls and fractures; pressure ulcers and poor wound healing; constipation and urinary tract infections leading to confusion; kidney stones and renal failure; and stroke and myocardial infarction[15].

2.5.2 Falls

Falls are one of the significant and silent epidemics affecting older adults, with the issue often being associated with excess morbidity, disability and premature mortality[58]. In older adults who recover from falls, the problem frequently induces marked anxiety and psychological distress, leaving individuals in fear of recurrent falls and physical injury, which contributes to poor mental health, impaired psychosocial well-being and reduced quality of life[59]. The wider psychological effects of falls also include social isolation and loneliness, which is another major issue of the aged and one that can perpetuate a destructive cycle of worsening mental and physical health[59]. The prevalence of falls among adults aged ≥65 years has been estimated to be 30% but this increases progressively with advancing age with individuals aged ≥80 years observing a fall rate as high as 50%[60], as noticed while conducting the Service Evaluation study within this programme of work (Chapter 3). Among those with incident falls, the risk of recurrent falls is equally high at approximately 50% in the first year followed by 10% per year thereafter[60].

In a large proportion of cases, falls are caused by underlying dehydration and associated hypovolaemia, which can lead to orthostatic hypotension, causing dizziness upon changing position (usually standing from sitting) due to a sudden reduction in blood pressure as a result of delayed venous return[61]. In a large cohort of 30,600 older adults in the United States, research has shown that almost 38% of subjects who had a fall in the past year were dehydrated and 12% observed a recurrent fall within the follow-up period, suggesting that dehydration was linked to most cases of incident and recurrent falls[62].

2.5.3 Disorders of the Urinary Tract

Dehydration is also known to account for an increased risk of ureteric stones and urinary tract infections in older people[1]. Urolithiasis is one of the most common problems associated with acute and chronic dehydration, as the inhibition of ureteric stone formation depends upon urinary dilution to avoid the concentration and aggregation of stone-generating constituents[63]. An adequate intake of water of up to 2.4 litres per day was shown to be able to prevent the crystallisation of calcium salts, as well as reduce the ratio of calcium oxalate and brushite and inhibit the nucleation of calcium oxalate, which in turn, decreased the formation of urinary stones. The prevalence of urolithiasis within older adults with chronic dehydration is approximately 20%[64]. The impact of dehydration on the risk of urolithiasis has been reported as high as 29-38% in epidemiological studies conducted among populations with even greater water losses due to high ambient temperatures and excess physical activity[65,66]. Moreover, in patients with incident urinary stone disease, measures to increase fluid intake to recommended limits have been shown to reduce the formation of new stones and prevent the growth of pre-established stones, suggesting that adequate hydration is key to preventing and managing urolithiasis[67].

There has also been research showing that even mild dehydration can increase the risk of urinary tract infections due to reduced renal filtration and urinary flow and excretion, which promotes stagnation of residual urine retained in the urinary system and in turn, colonisation with uropathogens[68]. This may help to explain why the incidence of urinary tract infections is markedly higher in older adults, who also have a range of other risk factors for infective disease such as urinary incontinence and poor compliance with personal hygiene[69].

The importance of sufficient fluid intake in preventing urinary tract infections among older adults has been highlighted by various studies. In one example, Lean, et al. [70] showed that the introduction of frequent and structured drinking rounds for nursing home residents significantly reduced the incidence of urinary tract infections requiring antibiotic therapy by 36% ($p<0.05$) and the incidence of hospital admissions for these infections by 58% ($p<0.05$). Similarly, Booth and Agnew [71] explored the impact of a hydration intervention, where fluid intake was increased by 200-400ml per day, among a

cohort of 24 older residents of a care home, and showed that there was a reduction in the rate of treated urinary tract infections, although the effect was not found to reach statistical significance ($p>0.05$). More recently, Scott, et al. [72] conducted a systematic review and meta-analysis of seven trials found that an increase in fluid intake for older adults significantly reduced the recurrence of urinary tract infections (OR 0.13; 95% CI 0.07, 0.25, $p<0.01$).

It is also thought that chronic dehydration may promote the development of chronic renal disease. Dehydration is a well-known cause of acute renal impairment, but its role in chronic renal disease has been postulated to result from persistent water deficit that can induce glomerular ischaemia and in turn, glomerulosclerosis and tubulointerstitial disease[73]. The impact of dehydration on chronic renal disease has emerged due to observations of idiopathic chronic renal disease in Central America, which has been termed Mesoamerican nephropathy[74]. Renal biopsies have failed to elicit the cause of chronic renal disease among such populations, with one common factor being dehydration and hypovolaemia due to excess dermal water losses as a result of the extreme climate and working conditions[75]. However, it is also thought that renal impairment induced by dehydration may also enhance the susceptibility of the kidneys to injury caused by exposure to noxious substances, such as pesticides and heavy metals[74,75]. However, much of the evidence informing such postulates has been based limited experimental in-vitro and in-vivo studies, which may not apply to human physiological mechanisms of renal injury related to dehydration[73].

2.5.4 Constipation

Constipation is both a lay and clinical term that is used to describe difficulties in passing faeces, although constipation as a diagnosable problem is usually defined as the chronicity of the issue (symptoms for ≥3 months) characterised by a reduced frequency of stools with difficulty in passing stools and associated discomfort, stiffness or pain[76]. The aetiology of constipation in older adults can vary markedly ranging from underlying benign to malignant conditions, or dietary and lifestyle factors that disrupt colonic absorption and/or motility[77]. Inadequate water intake has been a widely reported risk factor for constipation in older people, although the evidence has been mixed; some studies revealed poor water intake as a significant predictor of constipation, whilst others failed to observe the same effect[78].

Low-intake dehydration is not a surprising cause of constipation, considering that the colon usually receives an estimated 1.5 litres of fluid from the small bowel each day, and a third of this is excreted within stool[79]. The colon usually functions to reabsorb water and nutrients within intestinal effluent, to ensure the elimination of unwanted waste products and the retention of useful constituents; water absorption is time-dependent and actively regulated by physiological processes and thus, varies depending on hydration status[80]. Sodium is actively absorbed from the lumina of the colon via

active transport channels and due to the flow of sodium, water passively follows via osmosis. Conversely, the colon can secrete fluid and electrolytes via the cystic fibrosis transmembrane conductance regulator chloride channels, but these tend to observe dormant activity in healthy states, and thus, net reabsorption of electrolytes and water occurs[79]. In low-intake dehydration, the extent of small intestinal fluid for secretion may be limited and the reabsorption of water within the colon is excessive, promoting the formation of dry stools that are prone to impaction[81].

2.5.5 Delirium

Traditionally, it was believed that as all life requires water, older adults required extensive measures to maintain hydration through oral intake, prevent the biological effects of ageing, and protect themselves from cognitive decline[82]. Although this has been widely disproven, the importance of hydration in sustaining cognitive function remains clear; inadequate water intake leading to dehydration is strongly associated with delirium and mild cognitive impairment in older age[83]. Evidence has shown that dehydration promotes an increase in the activity of cerebral adenine dinucleotide phosphate diaphorase, which is a form of nitric oxide synthase that reduces circulating nitric oxide levels; this has been linked to impairments in cognitive functions, such as learning and memory that are typical of cognitive impairment[83]. The mechanisms leading to acute confusion (delirium) in states of dehydration are yet to be elicited[84].

The importance of adequate hydration for the central nervous system, and particularly the brain, has been reflected in studies showing that in states of dehydration, astrocytes upregulate aquaporin-4 channels, to enhance the uptake of water[85]. The overexpression of aquaporin-4 channels is thought to protect the brain from permanent injury but as a result, in situations of persistent or marked dehydration, the intracellular uptake of water leads to extracellular dehydration, which is thought to be responsible for delirium or dehydration-related encephalopathy[86]. The propensity of older adults to observe delirium in response to low-intake dehydration is thought to be due to the age-related loss of astrocytic cells[87]. Moreover, the impact of ageing upon the risk of low-intake dehydration-induced delirium is marked with data showing that the problem can arise when the body water deficit is as little as 1-2%[88]. Furthermore, imaging studies have shown that older adults with dehydration observe reductions in the volume of both white and grey matter within the brain, although such findings should be interpreted given the limitations of diffusion tensor imaging as detection of water anisotropy varies markedly based on fluid dynamics in the brain[89,90].

Aside from causing delirium, hydration is also thought to influence the risk of cognitive disorders, such as Alzheimer's disease, multiple sclerosis and cerebral amyloid angiopathy, as water is known to play a crucial role in facilitating the conformational dynamics of various neuropeptides[91]. In essence, water can form hydrogen bonds with amino acids to permit their reduction into three-dimensional

conforms, which provides peptides with functional activity that in the brain, regulate a wide range of essential processes[92]. Thus, during dehydration, the conformational change of peptides is considerably slower and less efficient and as a result, various biomolecules may be unable to undergo the reactions required to derive the proper functional activity of these proteins[93]. The role of hydration in mitigating the development or progression of neurodegenerative disease has also been suggested, in view that most disorders involve the deposition and accumulation of neurotoxic substances, such as beta-amyloid, and that insufficient extracellular water reduces clearance capacity and therefore, prolongs and intensifies the exposure of the brain to noxious compounds[84].

2.5.6 Respiratory Tract Infections

Adequate hydration is required to support the usual function of cilia within the respiratory tract and the clearance of debris and invading pathogens through mucociliary clearance[94]. The release of anti-diuretic hormone in response to dehydration has been associated with various respiratory tract problems, including bronchitis, bronchiolitis, upper and lower respiratory tract infections and pneumonia[95]. However, it is not clear whether dehydration and anti-diuretic hormone secretion enhance the risk or lead to respiratory tract infections or whether hormone release occurs in response to parenchymal injury secondary to infection[96]. Indeed, research has found that the levels of anti-diuretic hormones increase in proportion to the extent of parenchymal involvement in patients with lower respiratory tract infections and pneumonia, which fails to identify the direction of causation or association regarding hydration status[95].

Other research has suggested that dehydration increases the risk of respiratory tract infections and infection progression due to impedance in immune system functioning, particularly when viruses are responsible for infection as cell-mediated immunity is necessary to eliminate virions[4]. Moreover, it is recognised that hydration plays a key role in maintaining the integrity of mucosal barriers and that dehydration impairs this barrier, which can enhance both the transmission and acquisition of respiratory pathogens[97]. This has been recently observed during the ongoing COVID-19 pandemic, where researchers believe that the excess inter-hospital transmission of the virus has been exacerbated by the lack of humidity in atmospheric air, as well as overt dehydration in older adults, through dried mucous membranes enhancing the likelihood of viral transmission and acquisition[98].

Persistent dehydration is also thought to prevent the adequate rehydration of mucous membranes and, thus, heightens the individual risk of acquiring respiratory pathogens even in the absence of poorly humid atmospheric air[98]. This has been supported by a study showing that increases in the humidity of an indoor environment to >40% can significantly lower the infectivity of the influenza virus[99]. Recent evidence has also found that low-intake dehydration is a risk factor for severe COVID-19 disease and related mortality among older adults; a problem attributed to biomolecular and

hormonal factors that promote the upregulation of angiotensin-converting enzyme-2 receptors within the lungs, which is the primary binding site for the severe acute respiratory syndrome coronavirus-2[100]. Furthermore, research into patients admitted to critical care with COVID-19 pneumonia has found a significant risk of hypernatraemia because of dehydration caused by marked insensible skin and respiratory losses. Whilst a number of these patients deteriorated as a result of acute respiratory distress syndrome and some died, it was not clear whether dehydration was responsible for these adverse outcomes, due to the difficulties in measuring and defining dehydration and as a result of confounding variables[101].

2.5.7 Death

Dehydration is a well-recognised factor contributing to excess mortality in older adults. Although death due to inadequate water intake is a markedly under-recognised problem, it is likely to have large indirect contributions[9]. Early literature has shown that the rate of 30-day mortality due to dehydration in older adults can be as high as 17%, and 1-year mortality can be even higher at 50%[11]. The impact of dehydration on premature mortality has also been supported by evidence of a heat wave in France that was associated with a significant 142% increase in deaths due to dehydration among older adults[102].

Wider epidemiological data has also found that mortality in older people is often associated with low-intake dehydration based on individuals who observed a habitual low intake of fluids[103]. In the UK, data from the Office for National Statistics has revealed that most deaths due to dehydration (defined as volume depletion) over the past decade have occurred in persons aged >50 years but mostly among those of the eldest groups, aged >75 years. The number of deaths has averaged 50 per year since 2013, although this is expected to be a gross underestimation of the dehydration-related mortality due to the problems of under-detection, under-diagnosis and under-reporting[104]. The primary mode of death due to dehydration is hypovolaemic shock; severe water and intravascular volume deficit leads to systemic organ hypoperfusion and multiorgan failure, eventually causing death[105].

2.5.8 Acute and Chronic Systemic Consequences of Dehydration

The systemic consequences of dehydration are summarised in Table 3:

Table 3 Systemic effects of dehydration [106]

Organ System	**Effects of Dehydration**
Circulatory system	Dehydration has been associated with a range of cardiovascular complications. It is strongly linked with orthostatic hypotension, especially in cases of severe hypovolaemia. Dehydration has also been shown to worsen clinical outcomes in patients with stroke and can increase the risk of deep venous thrombosis (DVT) in stroke patients as well.
Respiratory System	Dehydration can increase the risk of respiratory tract infections and can lead to poor outcomes in older patients with respiratory infections. Dehydration can also cause changes in pulmonary function, which are reversible with systemic hydration. There is ongoing research to investigate the link between dehydration and various broncho-pulmonary disorders.
Gastrointestinal System	Dehydration is strongly linked with increased risk of functional constipation in older adults.
Musculoskeletal System	Orthostatic hypotension secondary to dehydration is associated with increased incidence of falls, which can be recurrent. Acute dehydration in athletes has also been shown to compromise neuromuscular function.
Neurological System	While mild dehydration can impair cognitive function and mental performance, severe dehydration in older adults can presented with marked confusion and delirium, known as dehydration encephalopathy[107].
Urinary System	Dehydration has been associated with various urological disorders, such as urolithiasis, urinary tract infections, and acute and chronic renal injury. Improving hydration has been shown to decrease recurrence of urolithiasis. In older adults, dehydration increases risk of UTIs in combination with other factors; it also increases risk of development of chronic kidney disease. Hyperosmolar dehydration is associated with high prevalence of acute kidney injury, with increased mortality rate.

2.6 Diagnosing Dehydration in Older Patients

There are several methods of diagnosing dehydration in older patients, which include both subjective assessments of clinical presentation as well as objective measures based on laboratory or impedance spectroscopy data. Subjective assessments include determining skin turgor, checking the colour and volume of urine, heart rate, feeling of thirst, or presence of dry mucous membranes—these assessments are not reliable in older adults as they can be influenced by other medical conditions or by medications[6]. Objective measures of determining low-intake dehydration include plasma osmolality, which can be considered as a gold standard parameter[108]; and non-invasive methods such as bioelectrical impedance[46].

2.6.1 Clinical Signs and Symptoms

The clinical signs and symptoms of dehydration vary depending upon the extent of water/fluid deficit[33]. In mild to moderate dehydration, usually defined clinically as losing 5-10% of total body water, the typical features include dry mucous membranes, thirst, reduced urine output and/or dark/concentrated urine, muscle weakness, headache, and dizziness. In severe dehydration, usually defined as >10% of total body water, the features may include irritability and confusion, absence of perspiration, little to no urine output, sunken eyes, markedly reduced skin turgor, low blood pressure, and tachycardia. In the most extreme cases, patients may manifest with hypovolaemia shock and may rapidly deteriorate to life-threatening cardiac arrhythmias or cardiac arrest[109]. The 10% clinical threshold is often used as a simple means for diagnosing dehydration in the absence of other tests; the 10% loss of body water is thought to correlate with activation of the renin-angiotensin-aldosterone system due to baroreceptor activation in response to intravascular volume depletion[18].

2.6.2 Changes in Body Weight

Changes in body mass have been previously used to assess hydration status within children, as well as young and older adults due to the simplicity of measuring weight and using changes in weight over time to provide an indirect indication of hydration[6,17]. Provided the weight of an individual is known during a period of sufficient hydration (euhydration), reductions in weight can reflect the degree of fluid lost and thus, dehydration, although this approach is unreliable in the absence of determining euhydration using the gold standard test[17,110]. However, single gram changes in body weight can be assumed to reflect 1ml change in total body water content, although measuring scales can be inaccurate and unreliable and alterations in body weight vary based on a range of factors[110]. Variances in body mass can occur due to diurnal variation, food/drink intake, the degree of

perspiration, other insensible losses, metabolism, and exercise; these hinder the reliability of body weight in diagnosing dehydration in clinical practice[18]. Thus, changes in body weight are less useful for diagnosing dehydration and in particular, low-intake dehydration in older people.

2.6.3 Fluid Charts

Fluid charts are a useful means of monitoring the hydration status of patients within inpatient and some outpatient settings as they ultimately reflect the total input and output of fluids[111]. Fluid charts are also used to monitor hydration status and support the target setting of fluid balance. For example, fluid charts are useful in situations of fluid overload where a progressive deficit in fluid output is required to achieve euvolemia. Fluid charts are also useful to attain assurance of the correction of dehydration, as the input of fluid should be greater than fluid output[111]. However, the accuracy of fluid charts remains an ongoing challenge. This could be due to a variety of reasons such as insufficient completion, inaccuracy of input/output data, and relative infrequency of measuring fluid input and output[112].

2.6.4 Urinary Indices

Urine colour and specific gravity are two simple measurable indices at the point of care that can be used to support clinical evidence of dehydration in older adults. However, due to individual and diurnal variation, these biomarkers are not sufficiently reliable to inform or ascertain a diagnosis of low-intake dehydration[113]. Urine osmolality is another biomarker that has been previously used to assist in diagnosing the type of dehydration in terms of tonicity, although this is also unreliable as urea contributes to as much as 40% of the urine osmolality and can thus cloud the interpretation of hydration status[114]. The indices of urine colour, specific gravity and urine osmolality have also been observed to have poor diagnostic accuracies for dehydration in older adults i.e., 51%, 58%, and 56%, respectively[20].

2.6.5 Haematological Indices

Various biomarkers can be quantitatively determined from the plasma or serum of patients and can be indicative of dehydration status. Measurement of osmolality (number of solutes per kg of solvent) is currently the accepted gold standard test to determine dehydration[17]. This is based on the physiological process of dehydration where in the context of low-intake dehydration, the volume of extracellular fluid decreases, whilst the electrolyte content remains stable. Therefore, the osmolality increases and over a short time, normal osmolality is attained through water moving from the intracellular to extracellular space, although the persistence of dehydration eventually leads to a rise in osmolality across all fluid compartments[115].

Plasma osmolality can be determined through laboratory measurement using freezing point depression or vapour pressure depression osmometers, although these can be subject to excess variance due to thermal disruption[116]. Evidence has shown that plasma osmolality is associated with a sensitivity of 90% and a specificity of 100% for diagnosing dehydration in healthy adults, which reflects a 2% change in total body mass[115]. However, the reference test/comparator to derive the diagnostic accuracy indices has not been reported and thus the reliability of the evidence may be limited. It is also important to note that plasma osmolality cannot be reliably used to detect isotonic dehydration as in most cases, the osmolality will remain within normal limits[17]. Acuity of fluid loss can also affect plasma osmolality values-for instance, in acute dehydration secondary to burns, both water and salt are lost, leading to isotonic dehydration, rather than the hypertonic dehydration seen with low-water intake over time[21].

Urea is another haematological biomarker that can be accurately measured within serum and raised concentrations above normal limits provide an indication of dehydration status as urea is freely filtered by the renal system and reabsorbed or secreted within the renal tubules[17]. In dehydration, urea levels rise disproportionately to that of creatinine, as the latter marker is also freely filtered but is subject to tubular secretion, although the reliability of the rise in urea for low-intake dehydration is poor as it cannot discriminate this problem from intravascular volume depletion[114]. Moreover, disproportionate increases in urea can also occur due to other conditions, such as sepsis, major surgery, corticosteroid use and upper gastrointestinal bleeding[17]. Finally, the concentration of haemoglobin and the haematocrit (proportion of red cells in the plasma) are other useful biomarkers that can be determined from the plasma of individuals to support the diagnosis of dehydration; increases observed due to dilution effect result from the loss of water relative to solutes[117]. However, these haematological indices have also been shown to carry poor diagnostic accuracy for dehydration due to diurnal variation, inter-individual variation and deviances in a range of disorders[118].

2.6.6 Combining Index Tests to determine Low-Intake Dehydration

There is limited evidence that combining various methods to determine dehydration can yield consistent and better results compared to using a single subjective or objective measure for this purpose. Hooper, et al. [6] performed a systematic review of several minimally invasive signs, clinical symptoms, and tests used to identify low-intake dehydration in older adults. Their findings showed limited and inconsistent diagnostic accuracy for only three standalone tests (expressing fatigue, missing drinks between meals, and BIA resistance at 50 kHz). Combining these standalone tests in terms of both expressing fatigue and missing drinks between meals improved the diagnostic accuracy for determining dehydration, albeit with decrease in specificity[6].

Reconciling clinical symptoms and signs with laboratory values can be useful, especially to differentiate and diagnose different types of dehydration. Interpreting laboratory values or BIA measures for diagnosing dehydration should be considered alongside observing signs or symptoms that suggest dehydration[17].

2.6.7 Challenges to Measuring and Monitoring Hydration Status in Hospital Settings

There are multiple challenges to the measurement and monitoring of the hydration status of older adults in the hospital[119]. There is currently a lack of consensus and standardisation of the means to identify and diagnose dehydration. In practice, clinicians utilise varied biomarkers or rely mainly on clinical examination findings indicative of hypovolaemia[6]. This makes the diagnosis of dehydration more challenging, as subjective measures vary between assessors, and different clinicians may attach variable significance to objective biomarkers. Reconciling both subjective and objective biomarkers is therefore important in reaching at a diagnosis of dehydration. Interpreting objective tests and performing objective measures such as BIA require training and maintenance of equipment and staff skills, and it can be difficult to ensure this is uniform throughout the healthcare service.

Some clinicians may lack awareness of the seriousness of the problem of dehydration in older people and thus, fail to measure and monitor hydration status in this vulnerable group of hospitalised older people[119]. Furthermore, evidence has shown that even in staff with positive attitudes towards supporting the hydration of older adults, issues of monitoring and measuring hydration status occur due to a range of external factors, such as time pressures, inadequate education and training, short staffing, high nurse-to-patient ratio and prioritising other clinical needs[119,120]. Comorbid health issues can compound patient compliance with the means of measuring and monitoring hydration status, such as psycho-behavioural disturbances in dementia and urinary tract disorders[6].

Wider factors at the organisational level may also hinder proactivity among clinicians and clinical staff in determining and monitoring the hydration status of older adults, such as organisational cultures that fail to recognise the importance of hydration[121]. Finally, the COVID-19 pandemic has imparted negative implications upon the hydration status of older inpatients as measuring and monitoring hydration status has been impeded (reduced in frequency) due to restrictions of patient contact to help prevent transmission of the virus[122].

2.7 Conclusion

Given the issues discussed in this chapter, it is important to prevent and manage dehydration in older adults. Dysregulation of the homeostatic mechanisms surrounding water balance can be difficult to recognise, and even more difficult to treat. Low-intake dehydration in older adults can present with a myriad of both diagnostic and therapeutic challenges, and current methods to diagnose low-intake dehydration are limited by inter-individual variances within patients and lack of accuracy.

Chapter 3 Understanding the Scale of Low-Intake Dehydration on 'Medicine for Older People' Wards: A Mixed-Methods Study

3.1 Chapter Introduction

Dehydration during hospital stay is an important issue affecting patient outcomes. It is a common reason for hospital admission, and it is associated with increased morbidity and mortality, and prolonged hospital stays when not adequately addressed during admission[9,123]. Older adults are particularly vulnerable to chronic and acute dehydration, as described in Chapters 1 and 2. This is attributable to the ageing process and its associated pathological changes, in addition to higher rates of conditions such as dementia, which adversely affect the ability of the individual to maintain adequate fluid intake[9,124].

A study conducted among older residents of care homes in the UK showed that low-intake dehydration's typical signs and symptoms do not consistently indicate its existence in older adults, resulting in missed diagnoses or incorrect assessments of dehydration[125]. A recent report published by the Scientific Advisory Committee on Nutrition (SACN)[15] cited that up to one-third of older people admitted to emergency departments are dehydrated. In the hospital setting, empirical evidence highlights that dehydration is not adequately treated[9,126]. El-Sharkawy, et al. [9] reported that 37% of older people admitted to the hospital were dehydrated, and 48 hours later, 62% of these patients remained dehydrated. The Francis Report[8] also highlighted nursing care failures at Mid Staffordshire NHS Foundation Trust, resulting in significant patient harm, including inadequate hydration care. Lacking hydration management standards remains a problem within the NHS[127]. The Care Quality Commission (CQC) found that patients needed to receive the encouragement and assistance required to drink and that staff needed to accurately document patients' fluid intake during admission. Only 34 of 50 NHS hospitals in England that the CQC inspected met the required standard for records[16]. Hence, this demonstrates that hydration care is not always prioritised amongst healthcare professionals, despite the numerous guidelines that emphasising the importance of doing so[13,46]. Consequently, this issue has triggered a plethora of research exploring how nursing care on dehydration can be improved, better prioritised and managed in hospital settings. This mixed-methods study investigated the current hydration care practice in 'Medicine for Older People' (MOP) wards at University Hospital Southampton and explored the perspectives of the ward medical and

nursing staff around hydration care using quantitative and qualitative methodology (further details given below).

3.2 Study Aims and Research Questions

This mixed-methods study formed the first part of this PhD programme of work. It aimed to evaluate the hydration assessment for older inpatients at University Hospital Southampton (UHS) by reviewing patients' documentation and exploring the viewpoints of the MOP ward's medical and nursing staff on hydration care. Findings from this mixed-methods study would help develop and consolidate current understandings of the hydration care experiences of older inpatients and staff at UHS. In the 1st phase of the study, I reviewed the patients' nursing notes to explore the completion of a local hydration assessment tool by the nursing team and the completion of hydration and fluid balance charts for patients at risk of dehydration. In the 2nd phase of the study, I conducted qualitative interviews to evaluate hospital staff's beliefs about hydration care and its effect on patient's health and recovery. The findings aimed to inform the type of support system that should be developed for staff to be better able to monitor and enable their patients to stay hydrated.

The following research questions were formulated to understand current practices in low-intake dehydration assessment.

Is low-intake dehydration routinely identified and managed accordingly in MOP settings?

What are the experiences of healthcare professionals towards dehydration assessment and the current practice?

3.3 Methods

A mixed-methods research design is a methodological strategy that entails the gathering, examination, and fusion of both quantitative and qualitative data within a single study. The approach aims to provide a more comprehensive understanding of a research problem[128].

3.3.1 Study Design

There are different design methods of mixed-method study, but three are frequently used in research: sequential explanatory, convergent parallel and sequential exploratory designs[129,130]. The selection of a particular research design depends on the purpose of the research study and is briefly described below.

3.3.1.1 Sequential Exploratory Design

The exploratory sequential design is a mixed-methods research approach that initiates with qualitative data collection and analysis, succeeded by quantitative data collection and analysis[131]. This design explores a research question or phenomenon through qualitative methods, such as interviews or focus groups, to gain insights and formulate hypotheses. After the qualitative phase, the researcher engages in a quantitative phase to further investigate and generalise the initial qualitative findings to a broader population. This design is particularly advantageous when limited knowledge exists about the research topic, and a more profound understanding is required before hypothesis development and quantitative testing.

3.3.1.2 Convergent Parallel Design

The convergent parallel design is a mixed-methods research approach in which quantitative and qualitative data are simultaneously collected and independently analysed[132]. The objective is to merge the outcomes of both data types, yielding a comprehensive understanding of the research question. Two distinct data collection and analysis procedures are executed—one for quantitative data and the other for qualitative data. The results are then juxtaposed and combined to highlight commonalities and disparities between the two data sources. This strategy enables researchers to offer a well-rounded interpretation of their findings by triangulating insights from varied perspectives[131,132].

3.3.1.3 Sequential Explanatory Design

The sequential explanatory design is a mixed-methods approach used when the study aims to explain and understand quantitative findings. In an explanatory design, quantitative data are first gathered, and then qualitative data (interviews or open-ended questionnaires) are derived from the quantitative results[130,133]. This approach is beneficial when quantitative findings unveil unexpected or contradictory results that necessitate further exploration and clarification[131].

Based on the nature of the first part of this PhD work, the sequential explanatory design was deemed the most appropriate method for this study due to its systematic nature, ability to complement data, capacity to explain unexpected findings, and potential to offer comprehensive insights into complex research questions. This design allowed me to delve into the scale of dehydration and its impact on patients' health, and gather valuable perspectives from staff, leading to a more holistic understanding of hydration care practices in MOP wards. Below, I describe this mixed-methods study’s two phases (quantitative & qualitative) in detail.

3.3.2 Phase 1: A Service Evaluation

Conducting the service evaluation as the initial step was crucial in understanding the current clinical practice related to dehydration risk assessment and patient care. The quantitative approach of this phase offered objective data on the extent of dehydration assessment among older inpatients at University Hospital Southampton's MOP wards. I extracted data regarding their hydration care from patients' nursing notes. This approach ensured an unbiased and systematic assessment of hydration care documentation, accurately representing the situation. It also quantified the scope of the problem, enabling me to recognise the clinical significance of dehydration in the MOP wards.

Quantitative data was extracted to determine the current practice of the existing hydration assessment tools in MOP wards. A prospective chart review study was conducted on MOP wards over one month in May 2022. The MOP wards in the hospital are G5, G6, G7, G8, and F7. The study included adults aged 65 years and above admitted to the medical wards and deemed 'Medically Optimised for Discharge' (MOFD). The reason for selecting patients considered Optimised for Discharge was because there was a complete data collection of patients' hydration assessment from admission to the point when they were ready to be discharged. Fifty patients had their medical and nursing records reviewed: this sample was determined based on consecutive convenience sampling of all eligible patients who were medically fit for discharge over the period of 1 month of data collection. Analysis of this quantitative data informed qualitative interviews, which were carried out with hospital staff working in the MOP department to explore the barriers and facilitators to hydration care assessment implementation in clinical practice.

3.3.2.1 Ethical Considerations

Dr Ibrahim Bodagh, the clinical effectiveness lead for MOP, was contacted, and approval for this service evaluation was granted by University Hospital Southampton (UHS) on 25/02/2022 (Reference number: SEV/0439) (Appendix A). Following the approval from UHS, I applied to the Faculty of Medicine Ethics Committee via the Ethics and Research Governance Online II (ERGO II) system, which approved this service evaluation on 18/05/2022 (ERGO 71492) (Appendix B). As a PhD student without clinical staff affiliation to the UHS, I obtained a Research Passport, granted in April 2022, to facilitate my research activities for the current study and two other upcoming studies in this PhD programme. As the study involved the review of medical and nursing records of older inpatients, there were no direct interactions with patients, so informed consent was exempted. To ensure patient confidentiality and anonymity, each patient recruited in the service evaluation was assigned a unique participant ID. This ID allowed me to code the data extraction sheets without using real names, maintaining patient confidentiality.

3.3.2.2 Data Extraction

Quantitative data extraction was performed under the supervision of Dr Stephen Lim (Consultant Geriatrician and Academic Supervisor) on an approved data extraction sheet (Appendix C). Data was extracted through a non-probability consecutive technique[134]. In non-probability sampling (also known as non-random sampling), not all population members have a chance to participate in the study. In other words, this method is based on non-random selection criteria. This is contrary to probability sampling, where each member of the population has a known, non-zero chance of being selected to participate in the study. Using a consecutive technique entail selecting a sample or group and moving to another sample after data extraction and analysis. I approached the nurse in charge of one or two different MOP wards weekly over a period of one month. I introduced myself to the nurse in charge and asked them for a list of patients who were 'Medically Optimised for Discharge' (MOFD). Next, I reviewed the patient's medical and nursing records, including the Trust's hydration care assessment. I applied this procedure to all MOP wards.

Once selected, each patient was assigned a unique participant ID, which allowed me to code the data extraction sheets by ID and anonymise patient information. Medical and nursing records of older in patients undergoing medical treatment and care in pre-specified wards were reviewed, and variables such as the reason for admission, patients' age, biological sex, admission date, and usual place of residence were recorded on the data extraction sheet.

At UHS, the Trust's hydration care assessment (Figure 3.1) is used to assess the hydration status of inpatients and does not constitute a formal diagnosis of dehydration. Depending on the presence of risk factors for dehydration, patients can be assigned to one of three categories: no action required (colour-coded green), start hydration chart (colour-coded yellow) or create a 24-hour fluid balance sheet (colour-coded red). The last category includes patients at risk for severe dehydration, requiring continuous fluid intake and urine output assessment. Meanwhile, category two patients (colour-coded yellow) are at risk for mild to moderate dehydration. These individuals require less strict monitoring through a hydration chart (Figure 3.2), which records their fluid intake and output over three reviews during early, late, and night shifts. Patients who fail to meet the minimum intake (200 ml or eight glasses per shift review) or minimum output requirements (4 times a day or 1 litre of recorded catheter urine output) will undergo reassessment of their hydration status and can be escalated to the red category.

Name:.....

Hospital Number:.....

Date of Birth:.....

NHS
University Hospital Southampton
NHS Foundation Trust

Hydration Assessment

Ward:.....Chart ..... of .....

- All inpatients at UHS should be assessed for hydration status within 6 hours of admission.
- All patients should be reviewed at least once a day before 10 am or when condition changes to assess if a hydration chart, a fluid balance chart or no monitoring is required.
- Please **tick** appropriate factors. If patient has factors in **both** red and yellow sections, commence a fluid balance chart.

	Factors Influencing Hydration Any of the following:	Date	Date	Date	Date	Date	Date	Date
No action	None of the yellow or red risk factors.							
	Medical Fit patients awaiting discharge							
	Daily weights deemed appropriate for monitoring hydration							
	Monitoring not required after discussion with medical and/or nursing in charge							
	Patient on an individualised end of life care plan							
Start Hydration chart	Dry mucous membranes, dry lips, skin turgor, sunken eyes							
	Difficulty handling cups/cutlery, unable to pour their own drinks?							
	Age over 75							
	Respiratory rate more than 25bpm							
	Oral diuretics							
	Febrile patients (Temp > 38 C)							
	Delirium and/or dementia							
	Constipation							
	Diabetes							
	Decreased appetite							
	Thickened fluids							
	Consuming clear or free fluids only							
	Long term catheter							
Start 24 hour fluid balance chart	Acute kidney injury and/or sudden decrease in urine output (<0.5mls/kg/hr)							
	Sepsis							
	IV fluids/NG/PEG feed or TPN							
	IV diuretics							
	Diarrhoea/High stoma output							
	Post Op < 48 hrs. (Excluding Day case)							
	Nil by Mouth > 6 hours							
	Fluid restriction (Exclude long term restrictions e.g. Dialysis)							
	IV Chemotherapy							
	High drainage wounds							
	Increased vomiting/High NG output							
	Short term catheter/Catheter removed < 24h							
	Request by Clinical team							
	NEWS2 ≥ 3							
	Initials:							
	Grade:							

Hydration assessment and chart v4. 12/9/2018

Figure 3.1 The hydration risk assessment tool utilised at the University Hospital Southampton

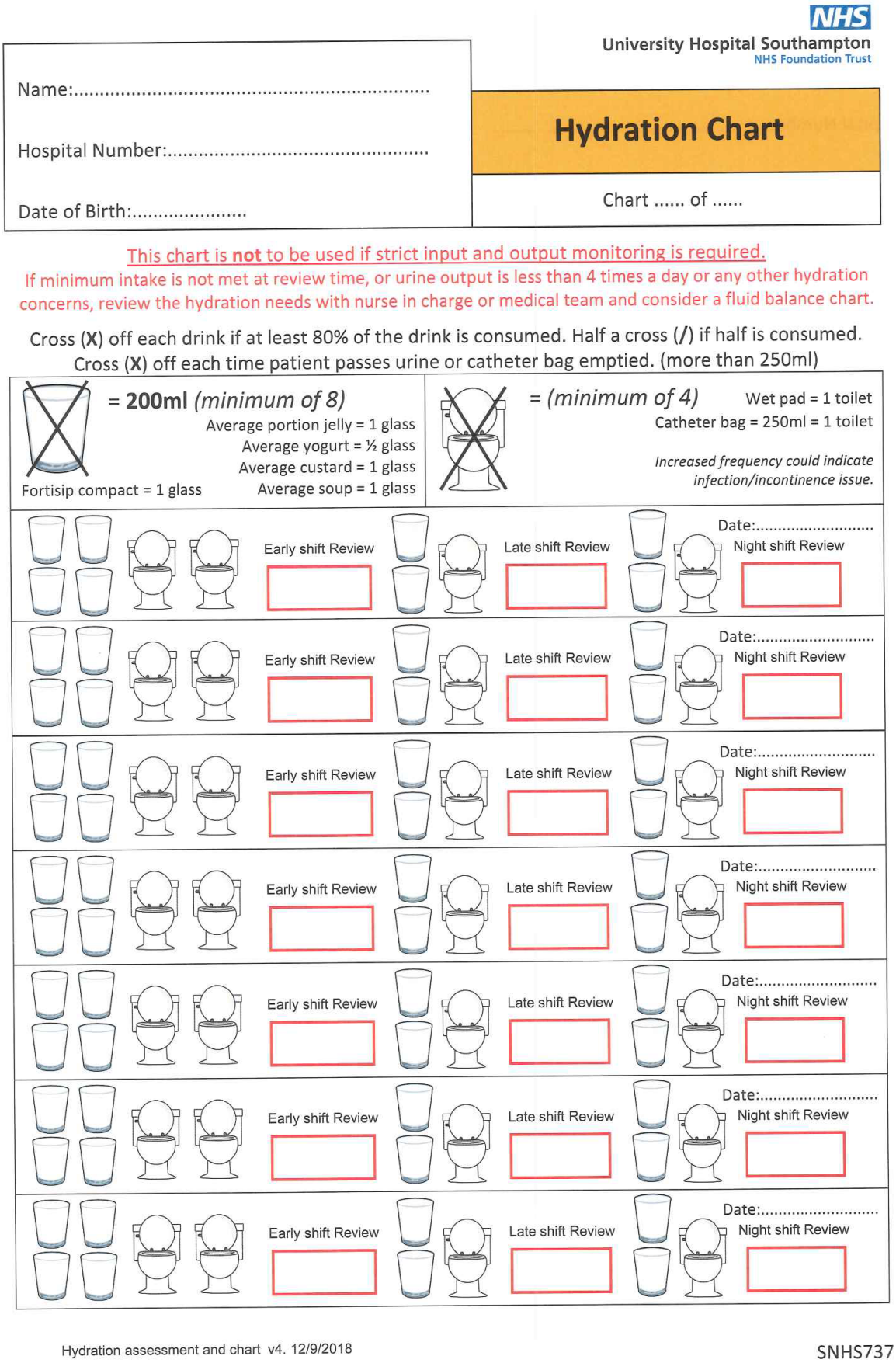


Figure 3.2 The hydration chart used to determine fluid intake and output

In this study, I recorded compliance in completing the hydration assessment tool within 24 hours of admission. For patients in yellow or red categories, I also recorded whether a hydration chart or fluid balance sheet was completed appropriately and how frequently patients' hydration assessment was conducted during their admission. I recorded data on these variables on the data extraction sheet.

3.3.2.3 Data Analysis

For the quantitative study, statistical analysis was conducted using Statistical Package for Social Sciences software (SPSS; IBM Version 26). Categorical variables such as biological sex, marital status, residential status, the reason for admission, and the proportion of patients in different hydration categories were recorded as frequency (percentages). Continuous variables such as age and missed shift reviews for hydration charts were recorded as mean ± standard deviation. Marital status and residential status were correlated against the severity of dehydration using the chi-square test, with a significant p-value set as ≤0.05.

3.3.3 Phase 2: Qualitative Interviews

Following the extraction of quantitative data, qualitative interviews in Phase 2 played a vital role in exploring the reasons and challenges staff faced with dehydration risk assessments and providing patient care.

The qualitative interviews delved into the perspectives, experiences and attitudes of staff members in MOP wards. Hearing directly from staff through semi-structured interviews provided rich insights into the clinical practices, enabling a deeper understanding of their challenges. Through open-ended questions and probing, phase 2 uncovered barriers and challenges that might hinder accurate hydration risk assessment, monitoring and optimal patient care. This information sheds light on potential obstacles and gaps in current practices. The qualitative data from this phase provided context and meaning to the numerical results obtained in phase 1. It allowed me to interpret the quantitative data in the context of staff experiences and perspectives, creating a more comprehensive picture of hydration care practices on MOP wards. A sample size of 10 participants was chosen in order to provide a sample large enough for adequate qualitative data to be obtained. Clarke and Braun [135] suggest that a sample size of 6-16 participants is adequate for a thematic analysis approach and data saturation.

3.3.3.1 Ethical Considerations

Ethical approval for the qualitative interviews was granted by the Faculty of Medicine Ethics Committee (ERGO 73109) (Appendix D) and the University Research Governance office on 24/06/2022 (Appendix E). Ethics application was then submitted to the Health Research Authority

(HRA) and Health and Care Research Wales (HCRW) Ethics Committees, which granted ethical approval for the study (REC reference 22/HRA/2759) (Appendix A).

Before conducting the interviews, participants (MOP staff) were provided with detailed information about the study's purpose, procedures, confidentiality measures, and their right to withdraw at any time (Appendix G). Informed consent was obtained from all participants, ensuring their voluntary participation in the study (Appendix H). In the following section, I outline how qualitative data was collected.

3.3.3.2 Data Collection

The qualitative data collection, participants (i.e. hospital staff) were identified and recruited from the 'Medicine for Older People' (MOP) department and wards at UHS. Staff were recruited through a gatekeeper; Dr Stephen Lim. Dr Lim passed the information sheet to colleagues. In the hospital setting, I made an additional invitation flyer available to all potential participants in the MOP department and around MOP wards. I directly contacted all the interested medical and nursing staff via email, and we mutually agreed on a date and platform (in-person or virtually via MS Teams) for the interview.

After selecting eligible participants, semi-structured in-depth interviews were held with each participant. Each participant was given a choice of where they would feel comfortable being interviewed, in line with lone-working safety advice. My academic supervisor, Dr Stephen Lim, was informed of any in-person interview at the hospital and the location of the interview before conducting the interview. Participants were provided with participant information sheets to give details of the purpose of the investigation, how the study was to be undertaken, how confidentiality, privacy and anonymity were maintained, how the research might be disseminated and a written statement that they may decline or withdraw at any time from the study. Semi-structured in-depth interviews are commonly used in qualitative research and are the most frequent qualitative data source in health services research. This method typically consists of a dialogue between a researcher and a participant, guided by a flexible interview protocol and supplemented by follow-up questions, probes and comments[136,137]. The method allows the researcher to collect open-ended data, explore participant thoughts, feelings and beliefs about a particular topic and delve deeply into personal and sometimes sensitive issues. I opted for individual interviews with the medical staff over focus groups in my research. This method allows for more in-depth, emotional responses, ensuring confidentiality and a comfortable environment, which is crucial in encouraging open and honest responses. The choice of conducting interviews online rather than in person was entirely driven by the participants' preferences, as described below, especially given their demanding schedules in the medical field.

This approach accommodated their availability and fostered a comfortable environment for candid discussions, which is essential for the integrity and depth of the qualitative data collected.

Each individual consented to participate in the study at a mutually agreed time using either an online method (i.e. MS Teams) or in person, depending on the participant's preference. I conducted all the interviews, which each lasted 30-45 minutes. The interview's opening included participants' demographic information, including clinical role and duration of tenure of current role. The main body of the conversation had open-ended questions that enabled participants to share their personal experiences and views on their attitudes and beliefs towards hydration care and the factors that affect the detection and management of low-intake dehydration in older inpatients admitted to MOP wards.

A topic guide was used to direct the semi-structured interviews (Appendix I). I developed this topic guide in close collaboration with Dr Kinda Ibrahim (Academic supervisor), and together, we refined it as we worked over time. All interviews were recorded on a digital recorder. It was clear to the participants that their confidentiality and anonymity would always be maintained. No names were attached to the digitally recorded tapes. Code numbers were used during transcription and analysis instead of real names to ensure participant anonymity. Moreover, keeping a reflective/research diary helped me recall and understand the perceptions of the complexity surrounding hydration care in older people.

Furthermore, my doctoral training courses on mixed-methods and qualitative methods research included ‘Approaches to Mixed Methods Research Design’, ‘A Comparison of Qualitative Methods', 'Qualitative Interviewing', 'Analysing Qualitative Data', and 'Using NVivo for Qualitative Research'. I also received training on collecting and analysing qualitative data through the 'Qualitative Methods for Public Health' module. In the wake of this training, I conducted two pilot interviews. Still, these interviews were not included in the analysis as they were not conducted on MOP staff but on general healthcare professionals. I only used these interviews to refine and improve the guided interview and interview process. I used them to determine the length of interviews and the suitability of the interview guide and to make any changes needed in phrasing the questions.

3.3.3.3 Data Analysis

Thematic analysis was used to examine the qualitative data. According to Clarke and Braun [135], thematic analysis is a method for spotting, analysing, and comprehending significant trends in qualitative data. I used NVivo 12 Plus software for data management[138,139]. CAQDAS (computer-assisted qualitative data analysis software), such as NVivo, has become very popular in qualitative research (and thematic analysis) over the last decade. One of the main advantages of using NVivo is that it can handle large and diverse datasets, which can be difficult to manage manually or with other

software. Data can be stored and analysed in one place and be coded by theme and sub-themes efficiently and consistently. Coding is assigning labels or categories to data segments that represent themes, concepts, or patterns. NVivo offers various ways to code your data, such as using a predefined or emergent coding framework, automated coding based on keywords or queries, or in vivo coding based on the words of the participants.

Thematic analysis can be performed on semantic and latent levels to interpret the data. At the semantic level, I kept close to the participants' words and did not evaluate the complex underpinning ideas. Beyond the semantic level, I looked at the latent level to find underlying trends and ideas.

Both inductive and deductive methods can be used to conduct theme analysis. In an inductive thematic analysis, themes are linked to the data and do not come into being from the theoretical viewpoint. The deductive thematic analysis uses codes from previously published works; the themes are established before the analysis[140]. An inductive approach was used for the current study, meaning the codes emerged during the analysis. The analysis followed the six-step process outlined by Clarke and Braun [135]. The initial phase entails getting acquainted with the data, which involves interview transcription and constant reading of transcripts. In the second stage, codes were created from the data and applied across the transcripts. In the third stage, themes were sought by grouping related codes into a single category. Rechecking the created codes and themes is step four. After topic identification and description in step four, theme formulation comes in step five. Writing out the report for the examined data is one of the last processes[135].

3.4 Results

3.4.1 Phase 1: A Service Evaluation

3.4.1.1 Participants Characteristics

As previously noted in Section 3.2.2, the medical and nursing records of 50 admitted patients were selected for review as part of the service evaluation. This service evaluation had a female predilection (n=35; 70%), with the average participant age being 85.6±4.9 years. Most participants (n=29; 58%) were widowed, living alone in private homes. At the point of data extraction, patients in the study had been primarily admitted for more than six days (n=39; 78%) in various MOP wards (see Table 4).

Table 4 Demographic characteristics of patients

Demographic	n (%)
Biological Sex	
Male	15 (30%)
Female	35 (70%)
Marital Status	
Single	9 (18%)
Married	10 (20%)
Divorced/Separated	2 (4%)
Widowed	29 (58%)
Usual Residence	
Private home living alone	29 (58%)
Private home living with friends/relatives	16 (32%)
Nursing/residential home	5 (10%)
Day since admission	
Day 2	3 (6%)
Day 3	4 (8%)
Day 4	1 (2%)
Day 5	3 (6%)
Day ≥ 6	39 (78%)
Ward Name	
F7	5 (10%)
G5	15 (30%)
G6	10 (20%)
G7	9 (18%)
G8	11 (22%)

3.4.1.2 Completion of Hydration Assessment

For 40 (80%) patients, the hydration assessment tool was completed by the medical team within 24 hours of admission. However, it was not recorded how soon after admission the hydration risk assessment form was filled out. Among the remaining ten, seven (14%) had their assessment completed on day 2, one (2%) patient was assessed on day 5, and the remaining two (4%) patients were assessed on or after day 6. All 50 patients were found to be at risk for dehydration. Figure 3.3

highlights the pathways taken for patients at risk for dehydration and Figure 3.4 indicates the causes for admission to MOP wards.

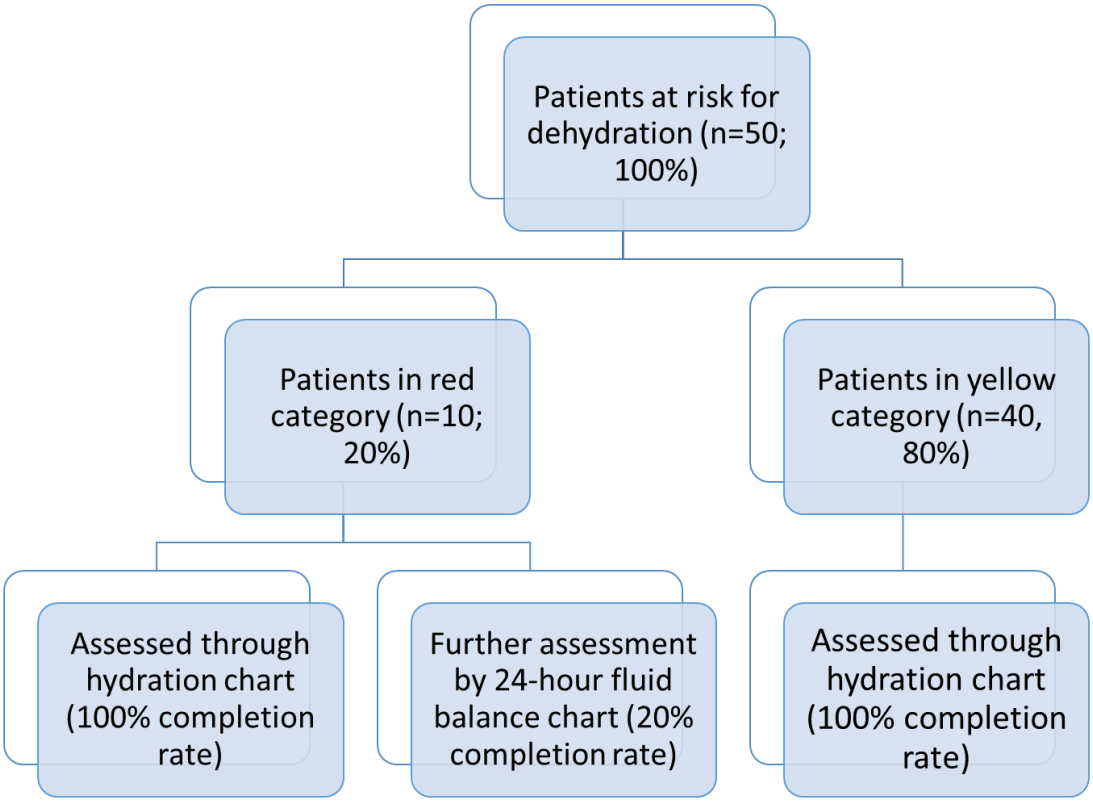


Figure 3.3 Hospital pathways for dehydration assessment and management

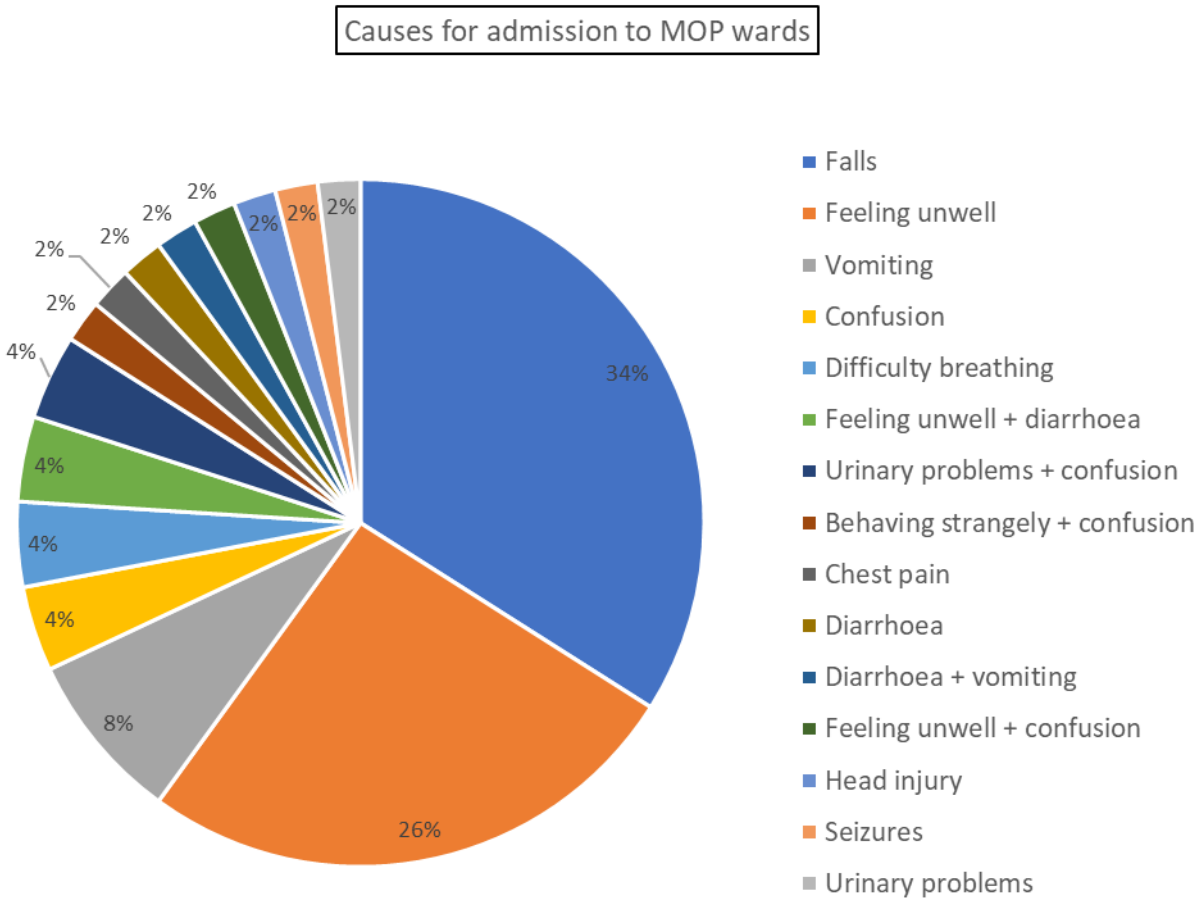


Figure 3.4 Causes for admission to MOP wards

All patients underwent assessment through the hydration risk assessment, with hydration chart reviews during early (7 am-2.30 pm), late (2.30 pm-10 pm), and night (10 pm-7 am) shifts. Although hydration charts were completed for all patients, some reviews needed to be included during various shifts. The average number of missing reviews was higher for late (6.0±4.1 times) and night (6.8±4.5 times) shifts compared to the early shift (3.1±2.6 times).

Most 24-hour fluid balance sheets (n=8; 80%) were not completed for patients in the red category. Most of these patients had been admitted for diarrhoea (n=3; 30%) or feeling unwell (n=4; 40%), with a minority (n=1; 10% each) admitted for seizures, urinary problems, and difficulty breathing. Mostly widowed (n=7; 70%) patients and patients living either alone (n=4; 40%) or with friends/relatives in private homes (n=5; 50%) were found to be at risk of severe dehydration in the red category, although none of these correlations was statistically significant ($p>0.05$). Using numerical data, this service evaluation provided insights into the extent of the problem, thereby guiding the development of phase 2.

3.4.2 Phase 2: Qualitative Interviews

3.4.2.1 Participant Information

A total of ten participants, four doctors and six nurses were interviewed using semi-structured interviews. Out of ten participants, two were male, and eight were female, with years of experience ranging from 4 to 12 years. Table 5 outlines key participant demographics.

Table 5 Demographics of Interviewees

Participants	Biological Sex	Designation	Years of Experience
P1.	Dr (female)	Consultant Geriatrician	6
P2.	Female	Ward Sister (nurse)	7
P3.	Dr (male)	Internal Medicine Training (IMT) Stage 2	4
P4.	Dr (female)	Consultant MOP/orthogeriatric medicine	7
P5.	Dr (female)	Advanced Clinical Practitioner (MOP Front Door)	5
P6.	Female	Ward Sister (nurse)	10
P7.	Female	Ward Sister (nurse)	7
P8.	Female	Ward Sister (nurse)	8
P9.	Female	Ward Sister (nurse)	12
P10.	Male	Staff Nurse	10

3.4.2.2 Qualitative Findings

The following themes ‘(1) Staff Experiential Knowledge of Hydration’, ‘(2) Difficulty in Dehydration Assessment and Diagnosis due to Resources’, ‘(3) Patient Attributes Contributing to Difficulty in Dehydration Assessment’ and ‘(4) Challenges Related to Staff Levels and Skills’ were identified in the data and described in detail below. Figure 3.5 represents the qualitative phase's findings, including the main themes and sub-themes. See Appendix J for the entire coding framework of central themes and sub-themes.

Figure 3.5 The findings (Themes|SubThemes|) of the qualitative phase. Major themes which emerged from the qualitative interviews included staff knowledge of hydration based on knowledge and experience, difficulties in dehydration assessment and diagnosis due to resources, challenges related to staff levels and skills, and patient attributes which added to the difficulties in dehydration assessment. Several sub-themes were explored from these major themes, as illustrated.

Theme 1. Staff Experiential Knowledge of Hydration

Participants explained their understanding of dehydration and their challenges in keeping patients hydrated. They discussed their awareness of the risks associated with dehydration in older inpatients and how it impacted their physical well-being. This was demonstrated in Phase 1, when all patients admitted to MOP wards were assessed for dehydration risk, despite 20% of them not being evaluated within the first 24 hours of admission. Participants also shared their experiences of difficulties in ensuring patients' hydration due to various factors, such as limited access to hydration stations, lack of preferred beverages, and inadequate hydration education.

A. Dehydration Risk and Its Significance

Doctors and nurses demonstrated a thorough understanding of the risks of dehydration in older adults and the crucial role of adequate hydration in their recovery and overall well-being. Participants recognised that older inpatients often experienced dehydration, and the extent of dehydration varied depending on their physical condition and hospitalisation status. Participants discussed how dehydration posed challenges to older adults' recovery and contributed to various health issues. They also expressed awareness that well-hydrated patients experienced fewer adverse health consequences and hospital readmissions. In light of this, it is likely understandable why all Phase 1 patients were at risk for dehydration.

i. Risk of Dehydration among Older Inpatients. Participants expressed those older adults, particularly inpatients, frequently experience dehydration. They noted different factors contributing to dehydration in the hospital, for example, fasting in preparation for a potential surgery that may or may not happen, leading to dehydration.

> *"There is also orthopaedic. They are older people who have come in with trauma. They have potentially fractured their hips, and sometimes they are waiting for surgery. So when they wait for surgery, they may start putting 'nil by mouth' the night before, in case they may have an operation the next day, and that operation may or may not happen. P4_D."*

Participants mentioned several physical factors contributing to dehydration, including age, cognitive decline, diuretic use, and medical conditions such as diabetes.

> *"If they are over 75 years old, or if they are on diuretics, or if the respiratory rate is high or if they are febrile or delirium or with dementia, or they are constipated or they have diabetes or the patient is on thickened fluids or long-term catheter. P10_N"*

ii. Perceived Effects of Dehydration on Organ and Recovery. According to the participants, dehydration had long-term negative consequences on the health of older adult patients, leading to

prolonged hospital stays and delayed recovery. Participants highlighted that patients who required assistance in drinking and could not do it independently faced challenges in the discharge process. Participants expressed that patients with dehydration are frequently given IV fluids to help them temporarily. Still, a thorough evaluation is required to rule out the causes of dehydration and develop a long-term treatment strategy.

> *"Increased length of hospital stay definitely because if a patient is not drinking and eating, that is a really difficult one because doctors might give IV fluids, but that is not a long-term solution, so sometimes they really have to look at what is the long-term plan for this patient. Yeah, like if they are not going to continue eating and drinking. P2_N."*

Participants describe the devastating consequences of dehydration in older individuals and the various associated adverse events, including "*Acute kidney injury*," "*Delirium*," and "*Weakness*". They expressed awareness that older adults were at a higher risk of experiencing renal damage due to dehydration, particularly when combined with other comorbidities. Participants discussed the knock-on effects of renal impairments on slowing medication metabolism, leading to delayed recovery.

> *So dehydration that's just what we see clinically, but then obviously it has effects on their organs. So it leads to renal impairment. It can affect the actual breakdown or the body's metabolism of certain medication, so it makes it affect them even more than in ways we don't want… Um, the consequences can reduce their recovery time - they are in hospital longer, their illnesses take longer to resolve. P1_D"*

Additionally, they acknowledged that dehydration could contribute to developing urinary tract infections (UTIs), which require antibiotic treatment. Furthermore, participants highlighted that dehydration could cause delirium in older adults, leading to prolonged hospital stays and disorientation about their surroundings and themselves.

> *"Umm so they are obviously at high risk of kidney injuries - They have obviously often got underlying comorbidities which affect their kidneys so they are obviously at high risk of kidney damage. I think there are increased risk of delirium if they are dehydrated. P3_D.*

iii. Perceived Benefits of Hydration Assessment. Participants emphasised the importance of monitoring hydration to mitigate the negative consequences of dehydration on older adults' health. Detecting dehydration early was believed to be vital in preventing acute renal damage, delirium, and urinary tract infections, leading to shorter hospital stays and faster recovery. The participants mentioned that treating moderate dehydration early on was more manageable than addressing it at a later stage.

"So I guess it is like we talked we mentioned before like I think if you pick up dehydration earlier, it's probably easier to treat, and you are probably going to get less side-effects or less adverse effects and reduce hospital admissions, reduce the chance of kidney injury. P3_D."

"So what happens in hospital is that part of their (patients') medical treatment usually involves keeping them hydrated, so the human body needs hydration for proper bodily function. So that is why it is important to assess hydration every day and it also helps the recovery of the patients and maintaining their health really.P1_D.

I think the advantages of course will be for preventing any further injury to the patients like UTI or kidney injury, and probably it will help shorten the length of their stay in the hospital. P10_N"

B. Strategies to Keep Patients Hydrated

Participants discussed the challenges they faced in hydrating older adult patients. They explained that these strategies included ensuring that water stations were easily accessible, providing patients with reminders to stay hydrated, involving their family members in the hydration process, learning about their preferred beverages, finding effective ways to motivate patients to drink more water and maintain proper hydration and educating patients about the benefits of staying hydrated for their health. There were 10 patients in Phase 1 who were not moved from the red category (those at risk of severe dehydration) to the yellow category (those at risk of mild to moderate dehydration) during their stay at the hospital. Therefore, these patients may have been severely ill and incapable of following the strategies described below by the participants.

i. Encourage Fluid Intake. The primary approach taken by participants as the first course of treatment was to encourage patients to increase their oral intake of fluids. They emphasised the importance of motivating patients to drink more water. However, in cases where patients could not increase their oral intake or maintain proper hydration levels, participants took the necessary steps to inform doctors about the patients who required intravenous (IV) fluids. They believed that timely communication with doctors was essential to ensure appropriate medical intervention and support for patients who could not meet their hydration needs through oral intake alone.

"Um, so I think generally first step we just try and encourage the patient to drink, and um if we are concerned that the patient is not drinking for whatever reason, we will inform the doctors and then they decide whether they should have IV or not. P2_N."

The main objective of participants was to motivate older patients to enhance their oral fluid intake. They actively reminded patients to stay mindful of their fluid intake and diligently monitored their urine output to assess their hydration levels accurately. By closely tracking the urine output,

participants could gain valuable insights into the patient's hydration status and make informed decisions to encourage them to drink more fluids as needed. The focus on regular monitoring and personalised reminders aimed to ensure that older patients received adequate hydration, which is crucial for their overall health and well-being during hospitalisation.

"So, if it is a matter of encouraging them to have more oral intake, then yes. So a patient would just need us to say, oh, you have to drink a bit, or you are not drinking enough, and that is if you start drinking better. P1_D."

Participants stressed the importance of promoting oral fluid intake as a preferable and more effective means of hydration for patients. While IV fluids could be necessary in certain situations, such as when patients could not consume fluids orally or needed immediate rehydration, the goal was to encourage patients to drink fluids independently whenever possible. By promoting oral intake, participants aimed to establish a sustainable and patient-centred approach to hydration care, helping patients maintain their hydration levels and support their overall health and recovery during their hospital stay.

"I do not think putting an NG or subcutaneous fluids should be an option to give someone fluids or oral replacement or IV replacement really because we don't really use subcutaneous fluids or NG fluids very often. Or if they are dehydrated and you want them to drink I will often try and get them to take a few sips Pag. While I am there – but that is a few sips of water in a whole day you know I do not really think that is a good solution.P3_D."

Several participants mentioned that they attempted to get patients to drink fluids orally if they could swallow them. Still, nurses can only help patients drink more by encouraging and directing them to do so. The decision to increase oral intake is left to the patient's free choice and health. Nurse 6 revealed, *"You know if they can swallow and if they can orally take fluids, then we would be in a positive link and encouraging them to drink as well."* Another nurse (7) added, *"And the encouragement and for the patients' participation, you cannot make someone drink. You can only guide the patient."*

Participants acknowledged the challenges encountered when dealing with patients who were too unwell or unable to comprehend their encouragement to drink more fluids orally. In such instances, participants noted that providing IV fluids became a necessary intervention to address severe dehydration and prevent further complications. Participants highlighted their careful monitoring of patient's blood pressure and other vital signs to assess their hydration status and response to treatment. The participants described their commitment to continuously monitoring patients and taking prompt actions to address dehydration-related issues and optimise patient outcomes.

“Basically, the first option will be to encourage patients with the fluid intake, and if they are really sleepy and drowsy and they are not able to take a drink or anything. We check the patient’s blood pressure and we encourage them drinking and give them some IV fluids for like 10 hours. P9_N.”

“We need to be increasing their oral intake because sometimes we have to flag it up say actually they are on the cusp of needing IV fluids – Can you encourage her and we will monitor we will check bloods again in the morning.P8_N.”

ii. Accessibility of Hydration Stations. Participants stated that they found it helpful to keep water jugs beside patients' tables, which may make it easier for patients to access water and stay hydrated. Additionally, providing older adult patients with water beakers was beneficial, encouraging them to drink more frequently. The participants believed that making water visible and easily accessible reminded patients to drink and helped them maintain proper hydration. These insights are based on the participants' perspectives and experiences.

> *"So I think a hydration station which is really visible and obvious to patients would be good if they could go help themselves, or at least it would make them think you know, I'd like a drink. Having something visible beside the bed that they could see would remind them to keep hydrated. P5_D."*

> *"I think trying to resolve those issues I guess like making sure that a patient always has a jug of water by their bed, making sure they can get to it and you often see that we give patients like beakers rather than cups if that makes it easier for them to drink. P3_D."*

Participants explained that families play a crucial role in assisting patients to stay hydrated by bringing flavoured drinks and ensuring they consume enough water. Family members often have the opportunity to sit with patients, encouraging them to eat and drink. Moreover, being familiar with patients' histories allows family members to recognise signs of dehydration before medical personnel can, which can help prevent patients from becoming dehydrated. These insights highlight the importance of family involvement in supporting patients' hydration, as reported by the interview participants.

> *"I think once a family member and a relative or a friend comes in they are usually very good at prompting patients to drink from what I have seen, and they often like they will recognise things sometimes more than we will, but I guess it is because they have that dedicated time to prompt that patient to drink. P3_D."*

> *"Think sometimes having less visitors like you know when the visitors came from 4 to 8 and sometimes you say you drink tea! Yeah you know, having even no visitors or only one hour a*

day, sometimes they are there to encourage even with eating and drink and with anything like that. P7_N."

iii. Availability of Patient's Preferred Drinks. Participants shared their approaches and strategies to promote increased water intake among patients, advising them to aim for eight glasses of water daily. One nurse stated, "*Ideally, we try to encourage them to drink at least 4 glasses of water in the morning, two glasses in the afternoon and two glasses at night, so that will be eight glasses in total. P10_N.*" They actively enquired about patients' drinking habits and reasons for needing to consume more fluids. When patients disliked plain water, staff offered alternative options such as flavoured water or other drinks that patients preferred to ensure they stayed hydrated. These insights highlight participants' proactive measures to address patients' preferences and encourage proper hydration practices.

"So offering them fluid sometimes, I asked them, have you had anything to drink? Do you want some water and there and then you know some of them get to see fluids or let me see your sips of water or why you're not drinking. P1_D."

"Some of our patients they will say I do not like water - water is boring for me. So as much as possible we try to, you know, individualise what they want to drink. I think usually it is getting to know the patient and what are what are their preferences? P10_N."

Participants explained that in cases where they could not obtain information about a patient's preferred beverages directly from the patient, they would proactively encourage family members to bring the patient's favourite drinks and motivate them to consume them. They believed family members could influence the patients' choices and actions, especially regarding their beverage preferences and overall hydration. Participants recognised the significance of family support in ensuring patients' hydration needs were met and appreciated its positive impact on their willingness to stay hydrated.

"Yeah, so like we have squash to add to water if the patient dislikes the taste of water or encourage patient's relatives to bring in drinks that they like. And try and find out what their preferences are for hot drinks. If they are not able to tell us, then find out from family members what their preferences are - quite a lot of older people, like quite sweet drinks – those kind of things. P4_D."

"Just ask what they normally drink. What do they like? What are their preferences? What do they have at home? Is your family able to bring you anything? If they only drink fizzy you know, can they bring you something in there? P6_N."

iv. Hydration Education for Patients. Participants shared their experiences and ways to take a patient to increase their oral intake confidently. One way of doing this is to educate patients about the significance of hydration on their health. Doctor 1 said, "*Well, apart from talking to them and letting them know how important it is, that is how to get the patient on board with drinking."* Another doctor (4) added, *"Giving them a reason to drink - So explain why drinking is important."*

Participants emphasised the importance of tailoring their approach to each patient's unique situation and cognitive ability. For cognitively healthy patients, the participants found that providing clear explanations and reasons for the necessity of proper hydration was helpful. They believed patients who understood the reasons for staying hydrated were more likely to actively participate in maintaining their fluid intake. *"You know if they are cognitively good and got all the faculties, then educating them to drink more and the importance of it might be helpful,"* a nurse 6 stated. Another nurse, number 7, added, *"About the importance, you know, just to remind them that they may leave the hospital early if they drink well,"* which leads to a better result.

Participants took an active role in "educating" patients about the consequences of dehydration, including *"Fatigue," "Headache,"* and how dehydration could "*Hamper*" their "*Recovery*". They would make them "*Stay more at the hospital*." Participants emphasised the impact of dehydration on kidney functions, cautioning patients against consuming diuretic beverages such as caffeinated drinks, which could increase the risk of dehydration. Through these educational efforts, participants aimed to raise awareness about the significance of maintaining proper hydration for overall health and well-being. They believed that by providing personalised education and addressing individual concerns, patients would be empowered to make informed decisions and take charge of their hydration needs, potentially leading to improved outcomes and shorter hospital stays.

> *"So it helps their kidneys to work, so for example, if they (patients) are coming with dehydration and have AKI (high creatinine) clearly tell them that you are quite dry and can see on your blood test and it is affecting your kidneys. If you drink more, it will make it better. P1_D."*

> *"Um I always told that coffee and tea will dehydrate people a little bit, so it is trying to encourage patients to actually have like water intake or lime juice or something like that rather than drinking like 10 cups of tea a day Or like water flavoured with lemon squash or something like that, but our patients just do not like that. P3_D."*

Theme 2. Difficulty in Dehydration Assessment and Diagnosis due to Resources

Participants expressed their challenges in identifying dehydration among older adult patients due to the lack of necessary diagnostic tools in MOP wards, as specified in Phase 1, that there is no formal

diagnosis of dehydration in MOP wards. They relied on clinicians' subjective inferences and verbatim patient reports to assess dehydration. This reliance on personal observations sometimes made it difficult to identify dehydration accurately. The use of the trust's fluid charts for hydration monitoring also presented issues, as they were often inaccurately filled out or left incomplete due to the hectic workload of the staff. To compensate for the lack of diagnostic tools and some incomplete fluid charts in MOP wards, staff members resorted to estimating patient hydration levels based on the number of water jugs given to them. This might explain why most 24-hour fluid balance sheets (80% of patients in the red category) were not completed in Phase 1. Participants also highlighted that identifying mild dehydration in older adults was particularly challenging due to pre-existing symptoms and medical issues, which could mask the signs of dehydration. These factors combined made accurately identifying dehydration a complex and multifaceted task for the healthcare professionals involved. Participants emphasised the need for better tools and strategies to improve dehydration assessment accuracy and ensure older adult patients' well-being.

A. Lack of Screening Tools and Difficulty in Diagnosis

According to one participant, a significant concern was the absence of standard evaluation/diagnosis tools. Despite being aware of the need for hydration, there was no rigorous hydration assessment; instead, fluid charts that were poorly maintained were frequently used as observed in Phase 1, night (6.8±4.5 times) and late (6.0±4.1 times) shifts had a higher average number of missed reviews than early (3.1±2.6 times) shifts. They utilised verbatim evaluation and estimated water jugs and patients' symptoms, making assessment subjective. This subjective approach made it difficult to have a standardised and objective evaluation of hydration status. Moreover, participants pointed out that the absence of readily available standard clinical tools made it particularly challenging to identify mild-moderate dehydration in older adult patients. The lack of standardised tools hindered their ability to accurately assess the degree of dehydration and determine appropriate interventions for these patients. Participants emphasised the need to develop and implement objective hydration evaluation tools to improve the quality of care for older adult patients and enhance their overall well-being, with a particular focus on patients who need more help to remain hydrated.

i. Lack of Availability of Screening Tools. Participants voiced their opinions on the lack of an objective dehydration diagnostic instrument. Most participants said the lack of screening tools meant hydration must be explicitly checked. One clinician stated, "*As far as I am aware, we do not have. I might be wrong, but I do not think we have a screening tool for dehydration in inpatients at the moment.P3_D."* Another shared,

> *"I think there is not a routine screening process. I do not think there is something that we would specifically document on every patient regarding their hydration status. I do not know if there is an actual method or questionnaire. I think maybe in the nursing notes they do. P5_D."*

Participants reported that the most common way to assess hydration risk was through hydration charts, but they questioned the accuracy of this method. The charts could have been better maintained in Phase 1, leading to doubts about their reliability. As one doctor said, *"The nursing staff have some charts that they fill out to monitor the amount of fluids and that is fairly damaged as standard. P4_D."* They also said that while hydration charts may be used to evaluate patients' fluid consumption, precise measurement is challenging due to a lack of objective screening tools. Also, due to the staff's busy schedule, hydration is not often evaluated.

> *"So basically in the morning that is why I mentioned earlier, in the morning shift the patient should have drunk at least four glasses of water, but of course sometimes we can't really accurately measure if the patient is actually drunk, you know how much they drink? We monitor them at least three times a day basically, but sometimes it's just the accuracy. P10_N."*

> *"I am not saying it is not adequately assessed. I think I will say I think it is assessed. Obviously, I do not think it is 100% accurate and not every day there is an opportunity to check their hydration status.P1_D."*

> *"Actually, I do not really. We have the hydration charts which monitors how much they are drinking and things, but as for an official assessment, I do not think there is anything really the nursing staff do to assess the hydration. We are like trying to make sure everyone drinks, but we are not really assessing whether the person's hydrated or not. Yeah, not officially. P2_N."*

ii. Difficulty in Recognising Mild Dehydration Symptoms. Participants believed it was difficult to recognise mild dehydration in older adult patients clinically. The symptoms of mild hydration overlap with older adult patients' general appearance, such as dry skin because of ageing.

> *"So actually the mild hydration is quite difficult to assess. Usually, it's a bit difficult for us to assess the mild ones because of course, we're talking about older adult patients. Usually, they are already presenting that their skin looks dry already. Some of them as well you know is normal for them. So we cannot actually tell. P10_N."*

Participants also mentioned that because of the explicit clinical portrayal, such as "*Dry mucous membranes*," "*Dry lips*," and "*Probably tachycardia*," identifying moderate to severe dehydration was easy. They said that it was difficult to recognise mild hydration in older adults because of their health conditions, such as dementia or lack of expression of thirst. Moreover, participants expressed that

medical professionals frequently overlook mild dehydration in low-risk patients while actively searching for it in high-risk patients.

> *"And then, biochemically, you can look and see if that if the sodium is going up then you can get an idea or if the haemoglobin gone up, you can get an idea that the dehydrated (I: yeah), but again, I think if a patient is not obviously at risk of that, I think it often goes missed because just because we are not looking for it and it is not. P3_D."*

> *"I suppose I think I am probably quite confident in recognising people that are very dehydrated (I: yeah the severe stage of dehydration). And then I think, probably from a clinical bedtime point of view, it probably is slightly under recognised really. P4_D."*

Some of the participants added that they "*would not know the early-early stages of dehydration. P9_N*" until dehydration gets severe and "*becomes more of a problem and it affects, you know, the kidneys and then, you know, that is when the blood results would show that there is a problem going on here. P10_N*" One reason for not identifying mild dehydration was not putting "*enough emphasis on the early stages of dehydration. P6_N."* Another nurse (P7) agreed and added, "*I think it is not that easy for mild and moderate dehydration for us to easily recognise." It is only noticeable "when the symptoms arise from moderate to severe dehydration. P8_N.*" Another reason dehydration is often unrecognised is the staff's busy schedule. They miss symptoms and face difficulty in providing treatment at the right time.

> *"So sometimes we might miss out some of the patients, but we try to like assess them individually because of the busyness. We might miss some of the patient, though we might not recognise that at the right time to get the right treatment. P9_N."*

Theme 3. Patient Attributes Contributing to Difficulty in Dehydration Assessment

Participants shared two perspectives on the characteristics of patients that made it challenging to maintain hydration levels. According to one view, patients' behaviours—such as drinking less water to avoid using the toilet, preferring flavoured or bottled water, being unmotivated or unwilling to consume fluids—keep them from rehydrating. The other perspective centred around the patient's physical condition, making it challenging to keep them hydrated and get their cooperation for hydration measurement. Many participants recognised that difficulties in maintaining adequate hydration resulted from behavioural and physical factors, based on their observations and experiences. This shed light on why none of the Phase 1 patients had their status changed from the yellow and red to the green (no action required) categories during their stay.

i. Patient Factors Contributing to Dehydration. Participants thought that several things led to the patient's dehydration. Because going to the toilet entails much physical work for older patients and occasionally requires assistance, they would refrain from drinking fluids to avoid using the restroom.

> *"So a lot of them just have reduced oral fluid intake and some of them because of the effort they need to use to get up, go to the loo and come back, they actually automatically reduce their intake and they have done that even before coming to hospital, but in hospital obviously it's more because it is not their usual environment and they have to wait to be offered the drink. P1_D."*

According to participants, older individuals frequently prefer alternative liquids and detest the taste of water. Other than that, they do not want staff help; sometimes, they need help getting to the table, and water is only occasionally available.

> *"I think we should know the patients and what their preferences are. Quite often, our patients don't like to say water is boring and they have a specific drink, especially for patients who have dementia. Yeah. P10_N."*

> *"Having access to water sometimes because sometimes you will see like empty jugs and I do not know how many times a day they come around and refill the jugs, but sometimes that is an issue… I would say AMU has that issue more - The wards seem to be very good at refilling patient's waters and just being able to like reach their water like physically being able to get it because often you will see the bedside table is just out of reach and an older patient cannot reach it. P3_D."*

ii. Patient's Health Conditions. Participants highlighted that besides the patient's preferences for different drinks, their health conditions were one reason for dehydration and difficulty assessing their hydration status. Participants reported "*cognitive impairment*," "*being delirious*", and "*acute illness*" as causes for being dehydrated. Participants also mentioned that due to poor health, older adults may be unable to frequently express their needs as they could be sleepy and tired. Participants said that various illnesses and cognitive impairment further contribute to dehydration and reduce the motivation to drink water.

> *"Patients that I look after are often delirious so often sleepy. And also obviously lots of inpatients have dementia and cognitive impairment - that's definitely a risk for them becoming dehydrated and they may have an acute illness that's causing them to be dehydrated, like sepsis. So been feeling unwell, if they are having significant cognitive impairment and dementia – they don't seem to want to drink or to have that motivation or thirst. P4_D."*

"I think a lot of our older patients come into hospital already dehydrated, but for several reasons we've got a lot of older adults patients who have got cognitive impairment or need quite significant amounts of care to support them with their hydration and encourage them to drink at home. P5_D."

Theme 4. Challenges Related to Staff Levels and Skills

Participants highlighted various challenges because of their personal traits, skills and experiences. One of the main issues was the need for adequate training and expertise in escalating dehydration cases and handing over patients to the following staff. Due to staff shortages, it was also difficult for participants to monitor patients, especially consistently on busy days, as reflected in the findings derived from Phase 1, when seven (14%) patients had their first hydration risk assessment completed on day two after admission, one (2%) patient was assessed on day 5, and the remaining two (4%) patients were assessed on or after day 6. Participants emphasised the importance of vigilance in hydration assessment since nurses were under pressure and had limited time for each patient due to their heavy workload.

Participants expressed their concerns about the challenges faced by staff in monitoring patients' hydration. Despite their understanding of the importance of hydration, they could not monitor patients continuously due to a lack of expertise, inadequate hydration training, poor doctor-nurse communication, and scarcity due to frequent turnover. Due to their excessive patient load and workload, the nurses often overlooked cases of dehydration.

i. Staff Skills and Training in Hydration Assessment. Participants thought that staff training and experience influenced their ability to assess hydration accurately. Staff with less expertise frequently need more confidence to identify dehydration and refer the patient to the doctor. However, some trusted their abilities and appropriately alerted doctors to dehydration. One doctor (P3), shared, *"I think so, in the sense that it becomes like down to an individual staff level. Some nurses are very good at saying this patient is not drinking very much - do you think they need some fluids."*

Moreover, nurses mentioned that online training does not include hydration-related information and that new staff only receive hydration once at the beginning, which is why dehydration is difficult to detect due to a lack of knowledge and awareness.

"I think we probably need to put a bit more emphasis on it in terms of educating the staff because you know they may not pick up on somebody in mild dehydration. Yeah, and quite often I think that probably is the case that it's just not picked up in the early stages. P6_N."

"We do have some online training but I'm not 100% sure with hydration care content. We should be aware of as a healthcare professional, we should be aware of this documentation

and as we filling the documentation, we should we remind ourselves before has this patient had a drink? How many drinks they had? And we have a little paperwork if they have one copy. P9_N."

ii. Staff Shortage Impact on Hydration Assessment. All participants viewed short staffing as a challenge. Because of the shortage of nursing staff, it was difficult for them to monitor patients, and they could not sit with patients for extended period to encourage them to take fluid intake, which impacted dehydration assessment.

"It is usually the only hindrance that often we encounter during the hydration assessment is staffing because sometimes unfortunately or most of the times actually we are short-staffed. The only lack of the resource is the staff itself the nurses. So the challenges are usually the cognition, and of course the lack of staff to sit with the patient and encourage them to drink. P10_N."

"You know, I think nurses are obviously struggling with staffing levels as much as medics are. Um and so I think that it is often that the nursing staff can often miss that a patient is becoming dehydrated or at risk of becoming dehydrated. P3_D."

"The usual story really, you know if we had enough people on the ward to care for the patients then I think you know these things would be less – not overlooked because I do not think they are overlooked, but I think that the staff are just so incredibly busy that maybe they do not see as much importance surrounding hydration. P6_N."

iii. Workload and Time Constraints. Participants highlighted that nurses and doctors were overburdened with the number of patients due to staff shortages and had limited time to spend with each patient. Participants expressed that they consistently need help with time pressure, especially on busy days, often leading to missed or inaccurate hydration assessments. A nurse (P10) shared, *"Usually one nurse looks after nine patients, so of course it's quite tricky to actually assess it accurately."*

Participants expressed that due to time constraints and prioritising severe health conditions, medical professionals often had to focus on urgent medical needs ahead of hydration. As a consequence, accurate hydration risk documentation suffered. Participants also highlighted that staff members' hectic schedules make it challenging to serve everyone relatively at once, and they frequently overlook dehydration, which lengthens a patient's stay in the hospital.

"I think that the staff are just so incredibly busy that maybe they don't see as much importance surrounding hydration. It's just frustrating because as you've alluded to is, you know, unfortunately, if people become dehydrated while they are in hospital, which does happen

quite often through infection or whatever it might be, then it increases their hospital stay. P6_N."

"Yeah, so I think the time that the healthcare assistants and the nursing staff have to fill out the documentation is limited. Umm and again the clinical pressures on doctors as well means that I think more urgent matters are seen to and that this is certainly something that could be easily missed or neglected, but yeah, staffing certainly and time for nursing staff and doctors I think and time pressures again on nursing staff and doctors. P4_D."

3.4.2.3 Summary of Qualitative Findings

The qualitative study's conclusions focus on four major elements that serve to clarify the findings derived from Phase 1 of the current mixed-methods study. The staff's practical knowledge of hydration is highlighted in the first theme, along with their awareness of the risks of dehydration and the value of proper hydration for patient recovery. However, difficulties such as scarcity of preferred drinks and restricted access to hydration stations were mentioned. The second theme examines how the absence of critical resources, such as diagnostic instruments and standardised screening techniques, makes it difficult to assess and identify mild-moderate dehydration effectively. The third theme focuses on patient characteristics that make it difficult to identify dehydration, such as behavioural tendencies and physical limitations that limit fluid intake and information gathering. The last theme discusses difficulties with staffing levels and expertise, such as shortages, insufficient training, and time restraints, which affect the regular monitoring of patients' hydration. These findings indicate the need for increased hydration education, objective hydration risk assessment techniques, patient attribute consideration, and staff-related problems to improve hydration care practices in MOP wards. These could be used with the current trust's hydration risk assessment.

This sequential explanatory mixed-methods design was vital to this research and would serve as a framework for the next phase of this PhD programme. To ensure the integrity and robustness of the research findings, it was essential to adopt approaches that enhance the study's credibility, validity and reliability. Consequently, the first research question in this PhD programme was addressed using the data triangulation research strategy[133,141,142].

3.4.3 Triangulation of data

Triangulation in research refers to using multiple data sources, methods, investigators, or theoretical perspectives to study the same research question or phenomenon[142]. Triangulation aims to enhance the credibility, validity, and reliability of research findings by corroborating evidence from different angles. Researchers can minimise bias and increase confidence in the results by utilising diverse data sources or approaches. In addition, this approach allows researchers to examine the phenomenon

from multiple perspectives, reducing the risk of relying solely on the limitations of one method or data source[143]. When evidence converges from different sources, it enhances the validity of the findings and strengthens the overall research design[144].

In this study, triangulation was achieved by combining quantitative and qualitative data from two separate studies: Phase 1 - service evaluation and Phase 2 - Qualitative Interviews. The qualitative insights from Phase 2 complemented and added depth to the quantitative results obtained from Phase 1. Integrating the data from both studies gave me a more comprehensive and nuanced understanding of dehydration risk assessment and related patient care practices on MOP wards. I also developed a broader view of the hydration care practices in MOP wards, reducing the likelihood of drawing inaccurate conclusions based on a single data source.

In summary, this study's sequential explanatory mixed-methods design achieved triangulation by integrating data from multiple sources, including quantitative data from Phase 1 and qualitative data from Phase 2 (semi-structured interviews). This approach enhanced the credibility and validity of the present study findings, providing a more robust understanding of the complex phenomenon of dehydration risk assessment and patient care on MOP wards.

3.5 Reflexivity

Through my lens as a dietitian, my expertise in nutrition and hydration influenced my focus on hydration-related factors such as fluid types and the amount that could be consumed, potentially shaping the emphasis during data extraction, collection and analysis. As a result of my professional training, I may also be biased towards nutrition and hydration practices in clinical settings. This could impact the interpretation of the data. However, being aware of my professional bias and sensitivities, I always intended to approach the research objectively, engage in critical self-reflection, and seek diverse perspectives to obtain a balanced interpretation of the data.

3.6 Integration and Data Triangulation

In complex healthcare issues, such as identifying dehydration among older inpatients, relying on just one angle may not provide the whole picture. In the future, I will delve into the intricacies of hydration risk problems by combining data from different sources: A service evaluation (Phase 1) and qualitative interviews with MOP staff (Phase 2).

3.6.1 Identification of Converging or Diverging Patterns

The importance of implementing an objective dehydration measurement on MOP wards in conjunction with the current trust's hydration risk assessment was apparent from the convergence of the quantitative and qualitative findings. It was noted from the service evaluation that there was no formal diagnosis of dehydration in MOP wards. The quantitative and qualitative findings showed the significance and advantages of hydration risk assessment in older patients, although the current trust tool needed to be appropriately documented. The quantitative findings showed that most patients (80%) had their hydration level assessed within 24 hours of admission, emphasising the importance of low-intake dehydration assessment. The qualitative data, which highlights the perceived effects of low-intake dehydration on organ function and recovery, further supports this conclusion. In the qualitative data, participants acknowledged the benefits of hydration assessment and understood that early monitoring could reduce adverse effects such as kidney damage, delirium, and urinary tract infections. However, I found various staff awareness levels about hydration, with some staff members needing more information. The availability of hydration workshops and staff members' different levels of expertise were identified by participants in qualitative interviews as potential barriers to their awareness of dehydration and its consequences.

The qualitative findings highlighted the significance of early low-intake dehydration detection since it allowed for prompt treatments that could shorten hospital stays and encourage a quicker recovery. The combination of quantitative and qualitative data highlighted the importance of hydration assessment and its potential effects on patient outcomes and well-being.

Both bodies of data point to a recurring trend regarding the difficulties and shortcomings in hydration assessment and lack of dehydration objective diagnostic tools on MOP wards. The quantitative data revealed a gap in the established practice, indicating that 20% of older patients were assessed 24 hours after admission. The qualitative findings emphasise that understaffing significantly affects hydration risk assessment and monitoring. Participants frequently discussed their challenges in properly monitoring patients due to a nursing staff shortage. The qualitative data also highlighted the impact of time constraints, as current MOP staff need help to allocate enough time for each patient and prioritise urgent issues over hydration risk assessment or even diagnosis. I also noted that nursing staff on MOP wards needed help balancing various duties and attending to the patients' diverse requirements.

Furthermore, for the nursing staff to regularly monitor and promote fluid consumption on MOP wards with larger nurse-to-patient ratios was beyond their capacity much of the time. These results confirm that time constraints and a lack of resources, particularly nursing staff, cause numerous

patients to be missed or ignored. The consistency of these quantitative and qualitative findings emphasises the structural problems preventing accurate hydration assessment on MOP wards.

The quantitative and qualitative findings highlighted the difficulties and constraints in filling out fluid charts and correctly determining hydration status. According to the quantitative data, eighty per cent (80%) of the liquid balance sheets for the ten patients in the red group needed to be completed, which suggests inefficiency in keeping records. The qualitative findings further supported this, which showed that fluid intake and chart documentation were usually inaccurate or not updated regularly. I examined the documentation procedures for hydration assessment while reviewing the patient's medical and nursing records. It was observed that the nursing staff in the MOP wards needed to adequately assess, document, or tick off the patients' hydration assessment forms for many patients who presented obvious physical indicators of dehydration. This disparity between the observed physical indications and the recorded hydration assessment showed a potential knowledge or awareness gap on the part of the nursing staff regarding the symptoms and indicators of dehydration and their documentation procedures. This mismatch may fail to properly assess or manage dehydration brought on by inadequate fluid consumption. Staff pressures and time restraints, which impacted how thoroughly hydration status was recorded and monitored, were to blame for this disparity, and this was observed during the data extraction and collection of phases 1 and 2. Together, these results offer a thorough grasp of the challenges in precisely determining and recording hydration status.

3.6.2 Triangulation of Results to Strengthen Overall Findings

Dehydration risk assessment and related healthcare difficulties were better understood when combining quantitative and qualitative data. The quantitative data demonstrate that most patients had their hydration assessed within 24 hours of their arrival, confirming the importance of this practice as shown by the qualitative evidence. The participants acknowledged the advantages of hydration assessment in reducing adverse effects, and the qualitative findings underlined the perceived impact of dehydration on organ function and recovery. The quantitative findings revealed a gap in standard practice in that 20% of older patients still needed timely hydration assessments. Qualitative evidence supporting this finding points to the influence of understaffing and time constraints on proper evaluation and monitoring.

Furthermore, quantitative and qualitative data showed staff pressures and time limits showed problems in correctly filling fluid charts and determining hydration status. The triangulated data gave a thorough picture of the difficulties in hydration assessment, underlining the significance of early hydration risk assessment and diagnosis while accentuating systemic problems such as resource

shortages and inadequate documentation. It also showed that there is no formal diagnosis of dehydration in MOP wards.

3.7 Conclusion

In this mixed-method study, the data triangulation of quantitative and qualitative studies repeatedly highlights the significance and advantages of hydration risk assessment in older inpatients. The hydration assessment was considered essential for patient outcomes and well-being. The findings also underscore problems and shortcomings in the current approach and the need for formal and objective diagnosis of dehydration on MOP wards. Some patients required prompt hydration assessments and were not evaluated instantly, highlighting standard procedure flaws. The capacity to appropriately monitor patients' hydration status was substantially impacted by understaffing. Due to staff pressures and time restraints, fluid intake and consumption reporting needed to be more accurate and complete. These results showed that these issues must be addressed for proper hydration risk assessment, documentation and objective diagnosis in MOP wards. The findings of this mixed-methods study have indicated the need for increased hydration education, accurate hydration risk assessment techniques such as Bioelectrical Impedance Analysis (BIA), patient attribute consideration, and staff-related problems. These could be used with the current trust's hydration risk assessment.

3.8 Key Insights of this Chapter

Phase 1: Quantitative Analysis

1. **Prevalence of Dehydration Risk:** All 50 older patients admitted to MOP wards were found to be at risk for dehydration. This highlights an alarming prevalence of dehydration among older inpatients on MOP wards.
2. **Timeliness of Hydration Risk Assessments:** For 80% of the patients, the hydration risk assessment was completed within 24 hours of admission to MOP wards. However, 20% of the patients were not assessed within this timeframe, highlighting a delay in the initial assessment process, which can be crucial for patient outcomes. Among the patients not evaluated within the first 24 hours, 14% were assessed on the second day, 2% on the fifth day, and 4% after the sixth day. This indicates a gap in timely hydration risk assessments.
3. **Inefficient Record Keeping:** Most fluid balance sheets needed to be completed, with 80% showing insufficient data for patients with high dehydration risk.
4. **Absence of Objective Dehydration Assessment:** There is currently no formal diagnosis of dehydration on MOP wards, relying instead on subjective clinical judgments.

Phase 2: Qualitative Analysis

1. **Challenges associated with staffing and time constraints:** Participants' interviews revealed that understaffing and time constraints severely impacted the ability to assess and monitor patients' hydration status effectively.
2. **Reliance on Subjective Assessments:** The absence of objective diagnostic tools was further highlighted, with participants relying on patients' verbal reports and subjective observations, suggesting a gap in current practices.
3. **Complexity in Identifying Mild Dehydration:** Participants expressed the difficulty in identifying mild dehydration in older patients, as existing health conditions can mask symptoms.

Integration and Implications:

1. **Triangulation of Data:** By combining quantitative and qualitative data, the study comprehensively understood the current hydration risk assessment and related patient care practices on MOP wards. This approach reduced the likelihood of drawing inaccurate conclusions based on a single data source, thereby addressing the 1st research question of this PhD programme.

Need for Systematic Improvements: The present study highlights the necessity for improved hydration education among MOP staff, the development of objective dehydration assessment tools, and the need to address staff-related issues to enhance dehydration care in MOP wards.

Chapter 4 Bioelectrical Impedance Analysis in the Assessment of Hydration Status

4.1 Clinical and Historical Background

Bioelectrical Impedance Analysis (BIA) is a rapid and non-invasive means of predicting total body water that exploits the electrical properties of tissues[27]. BIA can detect alterations in hydration status by measuring electrical current changes known to be affected by the body's water content and electrolyte status in the body[145]. The earliest use of bioelectrical impedance focused on the relationship between impedance measures with water and electrolyte content of the body, as well as its link with other variables such as blood flow, basal metabolic rate and thyroid function. Thomasset [146] was the first to use electrical impedance to estimate total body water content using needles inserted into the subcutaneous tissue. However, this was soon followed by the less invasive use of surface electrodes, which were more popular and ethically acceptable to volunteers[147]. However, surface electrodes also co-existed with limitations as high currents and voltages were required to promote the stability of inject currents that were used to measure impedance[27]. Single frequency measures of impedance at 50 kHz were first utilised by Nyober (1959) and Hoffer et al. (in 1969) to estimate total body water (TBW) using the impedance index, which is based on the volumetric relationship between impedance and a conductor. Multifrequency bioimpedance analysers, which measured resistance and reactance at a set of selected frequencies to create impedance plots, were first used by Thomasset in 1962 to determine the proportion of extracellular water in TBW[148]. Experiments with electrical impedance resulted in a greater understanding of the relationship between body water content and impedance measurements; by the early 1990s, the first single- and multi-frequency BIA analysers, as well as bioelectrical impedance spectroscopy (BIS), had been commercially produced to permit use for clinical and academic purposes (Table 6). Such analysers were portable, thus allowing measurement at the point-of-care, whilst also being non-invasive and producing reliable results[27]. These analysers also permitted the analysis of large amounts of data from multi-frequency bioelectrical impedance without the need for biomedical engineers to interpret the data.

Table 6 Clinical measures that can be assessed using BIA [149]

	Single frequency bioelectrical impedance analysis (SF-BIA)	Multi-frequency bioelectrical impedance analysis (MF-BIA)	Bioelectrical impedance spectroscopy (BIS)
Total fat free mass (FFM)	Yes	Yes	Yes
Total fat mass (FM)	Yes	Yes	Yes
Total body water (TBW)	Yes	Yes	Yes
Extracellular Water (ECW)	No	Yes	Yes
Intracellular Water (ICW)	No	Yes	Yes
Body cell mass (BMC)	No	Yes	Yes
Central and Peripheral FFM & FM	Yes	Yes	No
Total abdominal fat and visceral fat	No	Yes	No

4.2 Principles of Bioimpedance Measurement

4.2.1 Impedance Measures

The primary measures of BIA include the resistance (R), reactance (Xc), impedance ratio and phase angle (PhA), and it is essential to understand how these are derived. The resistance of a material is proportional to its length or height and inversely proportional to the cross-sectional area. Despite the human body lacking a uniform shape/composition, the conductivity can never be constant; thus, a simple relationship can be derived between the impedance quotient $\left(\frac{\text{length}^2}{\text{resistance}}\right)$ and the volume of contained water. The distance from the wrist to the ankle is usually used in practice to inform BIA measurements (Figure 4.1), which alters the relation between lean mass (around 70% of water) and the impedance quotient. However, due to marked variances in the composition and geometry of the

human body, the calculations of BIA must be matched to a coefficient that can account for this variable. Further complexity is observed as the body confers two forms of resistance to electrical current: capacitive resistance, known as reactance, and resistive resistance, usually referred to as resistance. Impedance is a measure of both, although measurements can be affected by anatomical variations in body shape, differences in body segments or series, and field inhomogeneity[27].

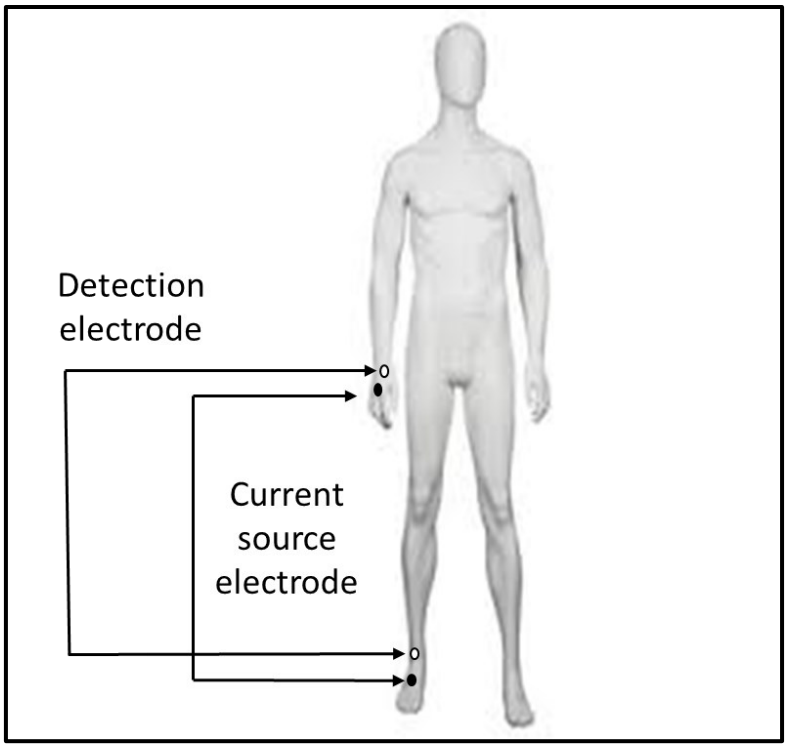


Figure 4.1 Placement of electrodes typically used in BIA [27]

Capacitance results from the electrical activity of cell membranes and membrane potentials, whilst resistance arises from intracellular and extracellular fluid current. The phrase impedance reflects a composite of the reactance and resistance. Although measuring at very low and high currents are impractical, resistance is determined using predicted frequencies via Cole-Cole plots as shown in Figure 4.2. The relationship between capacitance and resistance is important as it can reveal variances in nutritional and hydration status in response to changes in the electrical properties of tissues. The phase angle of the Cole-Cole plot is one means to determine the relationship between capacitance and resistance, which has been used to generate patterns of clinical conditions and physiological states[27]. Phase Angle is the most widely reported impedance measure studied in the clinical setting as it has been shown to be highly predictive of impaired clinical outcomes and mortality in a variety of diseases.

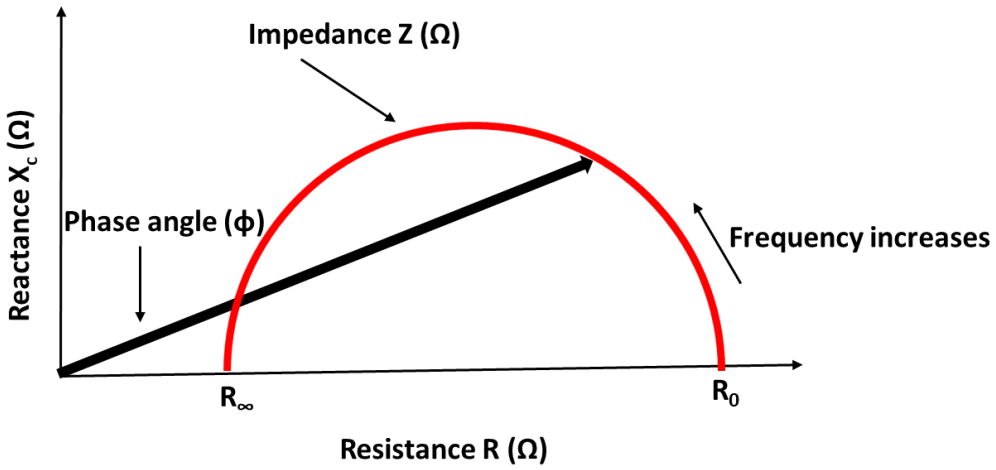


Figure 4.2 Cole-Cole plot deriving the phase angle to elicit the relationship between, impedance, resistance and frequency of an applied current [27]

The phase angle is the ratio of the arc tangent of reactance to resistance (Figure 4.2), determined at the Characteristic Frequency (Fc) which is the frequency at which reactance is greatest (usually between 25-75 kHz). Many devices do not directly determine the Fc and report the phase Angle at 50 kHz. The utility for assessing the extent of dehydration is limited due to variances in composition, hydration and cellular characteristics such as integrity, permeability and capacitance[150]. The generic interpretation of phase angle is that high values represent a greater reactance for any given resistance and, therefore, are suggestive of cell membrane integrity and high body cell mass. In contrast, lower values suggest impaired cell membrane integrity, low body cell mass and cellular loss/death[151]. In healthy adults, age, sex and Body Mass Index (BMI) act as determinants of the phase angle, which decreases with increasing age and is generally higher in men due to high body muscle mass as well as in those with high BMI due to increased amount of fat and muscle cells. Changes in phase angle can be due to changes in reactance (Figure 4.3), resistance (Figure 4.4), or both. These changes are visually expressed in the form of Cole-Cole plots, which are semi-circular plots allowing the extrapolation of resistance and reactance at theoretical zero and theoretical infinite frequencies, allowing determination of changes in phase angle with changes in resistance and reactance across the frequency range of the applied current[152].

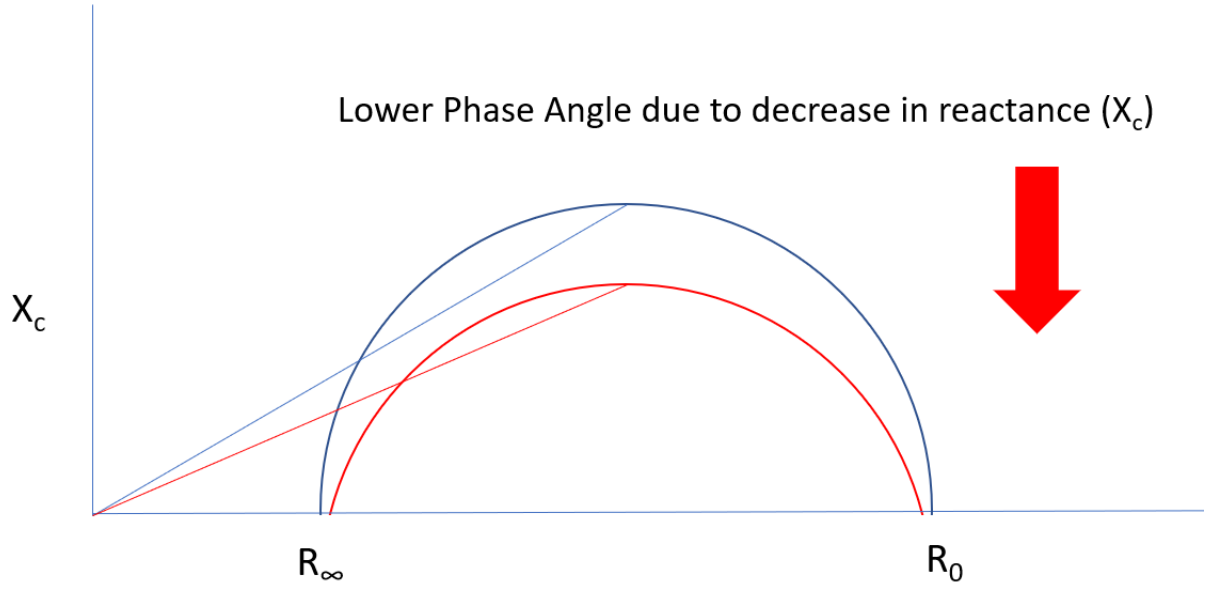


Figure 4.3 Cole-Cole plot showing the relationship of phase angle with reactance (X_c). Phase angle lowers with decrease in reactance, in states of critical illness

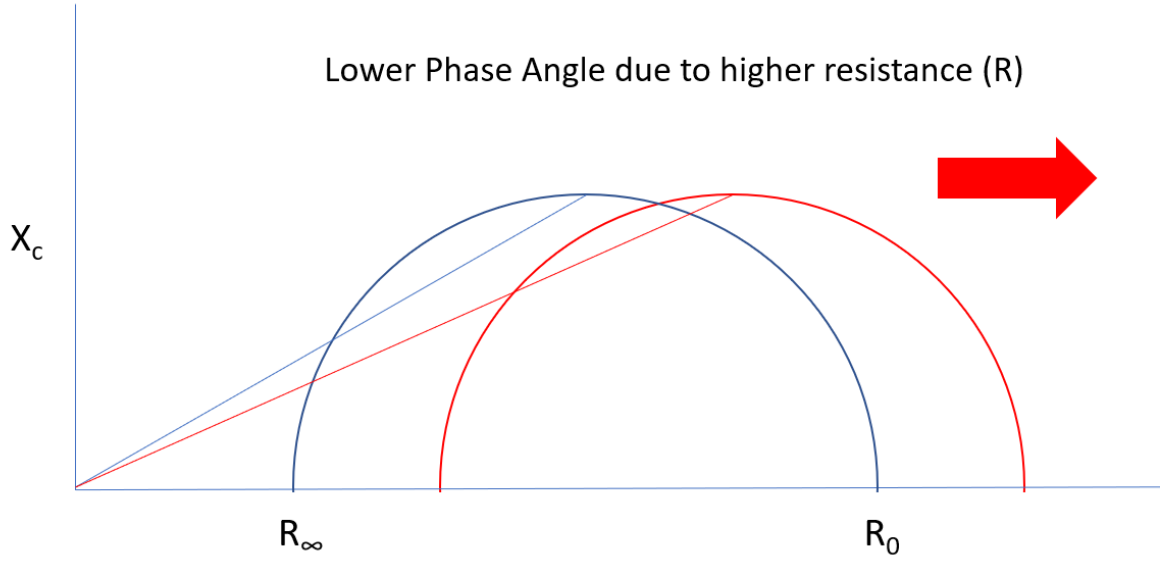


Figure 4.4 Cole-Cole plot depicting the relationship of phase angle with resistance (R). Increased resistance lowers the phase angle, in states of dehydration

Another BIA parameter that can provide information regarding hydration status is the Impedance Ratio, which is the ratio of impedance at 200 kHz to that at 5 kHz (or other alternatives of high and low frequency)[150]. The Impedance Ratio can provide information about the ratio of extracellular water to total body water regarding its compartmental distribution. However, there is a paucity of clinical studies to affirm its validity and reliability[150]. In general terms, it is reported that high impedance ratios reflect over-hydration states, as may occur in cardiac and renal impairment, whilst low ratios reflect dehydration states, with the threshold to discriminate these states being 1.0[153].

Despite these assumptions, there have been few studies conducted to correlate Impedance Ratio with dehydration states and thus, there is uncertainty whether measurement in routine practice would prove useful for detecting low-intake dehydration in older adults[154].

4.2.2 Using Impedance Measures to Derive Estimates of Hydration

Currently, the gold standard method of TBW measurement is the tracer dilution technique, in which deuterated water (D_2O) in orally administered, and the exchange of labelled hydrogen atoms is measured from normal hydrogen atoms in carboxyl, hydroxyl, and amino acid groups. This isotopic dilution technique is expensive and time consuming compared to BIA[155]. The methods of BIA include single, multi- and segmental BIA, localised BIA, bioelectrical spectroscopy and vector analysis. Single-frequency BIA, usually at 50 kHz, is used to estimate the resistance of extracellular and intracellular water and fat-free mass but it cannot be reliably used to differentiate the differences in intracellular water. This reduces the validity of single-frequency BIA for detecting changes in total body water across various states of hydration. Other limitations to BIA, in general, are related to the theoretical and empirical equations that have been used to derive BIA indices[27]. In multi-frequency BIA with various frequencies ranging from 0-500 kHz, estimates of fat-free mass, total body water, intracellular and extracellular water can be derived, and with superior accuracy to that of single-frequency BIA[156,157]. However, some authors have found that the method has limited ability to determine changes in body water content across extracellular and intracellular compartments within older adults and thus, both single- and multi-frequency BIA are not always accurate in determining total body water in response to deviances in hydration status[145,157]. This is because the equations used to calculate total body water content are centred around euhydration. Thus, are not valid for eliciting water content during dehydrated or over-hydrated states.

Research suggests that the poor accuracy of BIA for altered hydration states is related to the differences in electrolyte balance across body compartments as this influences the movement of water between the intracellular and extracellular compartments, and as a result, the resistance[27]. The inaccuracy of BIA for determining hydration status is particularly poor in patients observing acute changes in fluid and electrolyte dynamics/shifts[158]. The Cole-Cole model has been found to provide accurate measures of extracellular and intracellular water during acute fluid shifts but only for multi-frequency BIA[159]. In contrast, electrolyte shifts during acute fluid therapy are associated with marked BIA measurement error of 15-20% for intracellular and extracellular water estimations, which decreases its value in clinical practice where such errors could lead to under- or over-treatment and patient harm[160]. The value of multi-frequency BIA has been supported in a meta-analysis where single-frequency BIA was found to grossly over-estimate total body water in healthy persons compared to no over-estimation using multi-frequency BIA[161].

4.2.3 Deriving Estimates of Body Composition

Due to the variances in the resistance of tissues to electrical current, BIA can be used to derive estimates of body composition, primarily fat-free mass and body cell mass; the former reflecting all body content that excludes adipose tissue and the latter representing metabolically active tissue but one that changes during catabolic states (Figure 4.5)[27]. However, accuracy in determining body cell mass is complicated, particularly in altered hydration states due to dynamic changes in the extracellular fluid compartment. Due to the sensitivity of single-frequency BIA to changes in intracellular water but not to extracellular water, the method has limited use in determining fat-free mass or total body fat during abnormal hydration states[162]. The utility of BIA in measuring body cell mass has also been impeded by difficulties in deriving the equations needed to account for inter-individual variances in the hydration of lean muscle[27].

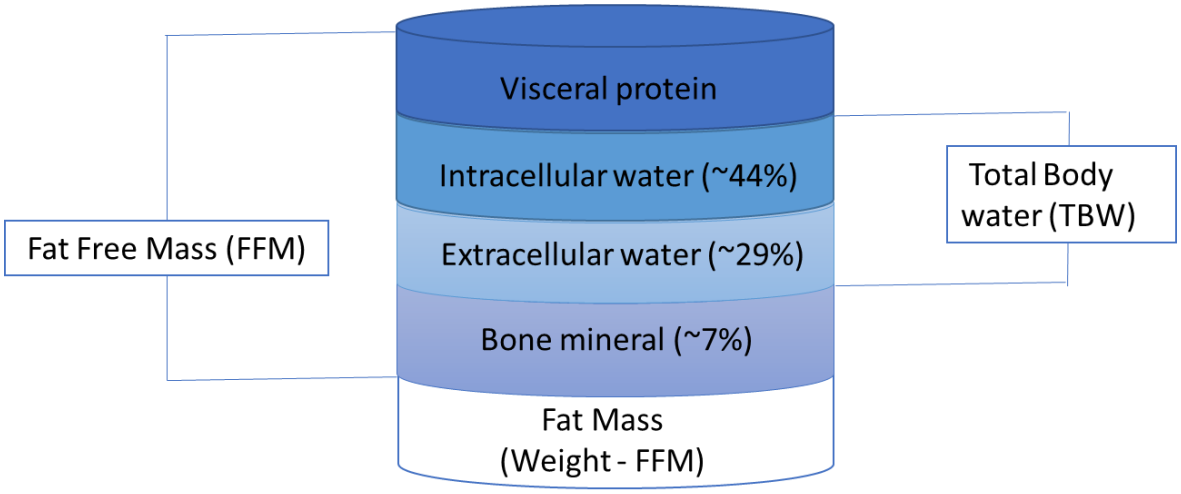


Figure 4.5 Schematic of body composition compartments [27]. Fat-free mass includes total body water, visceral proteins and bone minerals.

Estimates of body cell mass and extracellular water using BIA have yielded considerable differences and thus, have proven unreliable for clinical use thus far[163]. One of the critical problems with BIA for measuring body composition is its indirect nature of measurement. BIA fails to measure composition per se and measures electrical responses of the body via resistance upon exposure to electrical current and translates said resistance into a prediction of composition based on theoretical equations[164]. The fat-free mass is generally derived based on assumptions that the hydration fraction of this tissue is 0.73, but this is based on healthy adult populations and, thus, cannot be reliably applied to older population groups or account for variances in the resistivity of different tissues and resistivity variances in relation to composition field[164]. The advantages and disadvantages of utilising BIA to determine TBW are highlighted below (Table 7):

Table 7 Advantages and Disadvantages of BIA in determining TBW [234]

Advantages	**Disadvantages**
Non-invasive and safe to use, generally inexpensive	Based on assumptions of the 2-component model-reliant on regression equations for determining body composition variables
Limited participant input, no risk of respondent bias	Measurements can be affected by hydration status, validity of measurements also influenced by demographic factors such as age, biological sex, ethnicity, body size due to source of reference data
Valid and precise method for determining TBW and ECW in normal-weighted individuals and healthy individuals	Limited in severe obesity to correctly estimate TBW due to the effect of increased adipose tissue on the assumed resistivity of the ECW
Estimated determination of TBW correlates well with other measures such as dilution methods	Wide limits of agreement with small mean differences compared to tracer dilution techniques for estimating ECW and TBW-this leads to poor sensitivity of BIA in individual assessment of fluid volume

4.3 Clinical Applications of BIA in Hydration Research

An abundance of research has evaluated and reported upon the clinical utility of BIA in deriving measures of body composition and hydration status within varied population groups ranging from young children to older people and across varied physiological and diseased states[23]. The specific clinical applications of BIA, as reported across the literature, have included the assessment of nutritional and hydration status, to derive measures of body composition and to evaluate lymphoedema[150]. Regarding the use of BIA in deriving information about body composition, evidence has shown that people with obesity and in states of fluid overload observed excessively hydrated fat-free mass, but due to overexpansion of extracellular water in some conditional states, the fat-free mass can be overestimated[23]. Similar issues of fat-free mass over-estimation have also been

observed in patients with advanced solid cancers, with estimates observing marked variation between different BIA devices[165].

The parameters obtained through BIA have also been suggested to provide important prognostic information, but due to the poor reliability of equations used to derive impedance indices, the clinical application of BIA for such purposes has not been popular[166]. Other researchers have found that derivation of the fat-free mass index (calculated as the predicted fat-free mass in kg/height in cm2) can provide helpful information regarding the risk of adverse outcomes[150]. In one example, van Venrooij, et al. [167] defined a low-fat free mass index at <14.6 kg/m2 in women and <16.7 kg/m2 in men and found that patients having such values observed a significantly higher rate of post-operative infections and a longer length of hospital stay. However, bioelectrical impedance spectroscopy (BIS) was found to provide a more accurate measure of the fat-free mass index among patients who had undergone abdominal surgery compared to the use of single-frequency BIA, which overestimated fat-free mass index to a significant degree[168].

An additional clinical application of BIA has included the evaluation of lymphoedema, a pathological state characterised by anatomically localisation and collection of fluid in the extracellular space which is normally drained by the lymphatic system. Studies have been able to utilise measures of the extracellular to intracellular water ratio to help detect early lymphoedema in breast cancer patients[169,170]. The early detection of the expansion of extracellular volume has permitted the diagnosis of early lymphoedema in this population group. However, this has been due to bioelectrical impedance spectroscopy (BIS) which has more favourable sensitivity for detecting changes in extracellular water[169].

Further evidence has explored the utility of BIA for monitoring fluid changes in patients with dialysis-dependent renal failure and as a result, using the derived parameters to guide dialysis management[150]. In such cases, estimates of dry weight are critical as they are used to inform the ultrafiltration rate or the rate of fluid removal during dialysis, which, in the absence of accurate derivation, could lead to under-filtration and hypervolaemia and, in turn, sequelae of fluid overload[171]. On the contrary, underestimates of dry weight may lead to excess filtration and hypovolaemia, which can increase the risk of hypotensive shock, cardiac arrhythmias and venous thromboembolism that confer direct threats to life[171]. Conventionally, dry weight has been estimated using physical examination findings and blood pressure, but some studies have shown that BIA, and in particular bioelectrical impedance spectroscopy (BIS), can yield reliable measures of dry weight; however, one of the fundamental limitations is that the approach has not been able to produce estimates of whole body drug weight[172].

4.4 Applications of BIS in Current Research

In this project, BIS will supplement conventional and recommended means of identifying low-intake dehydration in older inpatients to determine whether the technology could improve the identification when diagnostic uncertainty exists. Previously, a growing body of evidence has evaluated the diagnostic value of BIA to find that the technique is more accurate than conventional clinical assessment and laboratory hydration tests[30,31]. However, as noted above, variances in body shape and segments, field heterogeneity, and resistivity of various body cells and tissues can limit the accuracy of BIS[23].

The current project utilised the ImpediMed Bioimpedance Spectroscopy SFB7® research device. This multi-frequency BIA device can scan 256 frequencies from 3 to 1000 kHz and measure fluid status and tissue composition using Cole modelling with Hanai mixture theory. With this device, raw impedance data can also be accessed, which is essential since most BIS devices provide derived measures of reactance and resistance, with which assessment of hydration status in older patients is not secure. BIS measures determined from the SFB7 device have been validated against DXA and isotope dilution analysis. The SFB7 device is linked with the BioImp Body Composition Analysis Software, which can analyse and display the multi-frequency whole-body bioimpedance data.

Estimates of TBW, ICF, and ECF from BIS are often derived based on assumptions that fail in states of altered hydration. Therefore, these estimated values alone do not provide enough clinical data to predict or quantify the extent of dehydration[23,27]. One of the critical research areas in this PhD programme is that BIS using raw data values may offer a solution for this practical issue, which will be explored in chapters 5 and 6. The current project focuses on the adjunctive role of BIS alongside existing current local hydration risk assessment methods used at Southampton General Hospital to identify low-intake dehydration in older patients using the raw measured and reported values (i.e., Resistance, Reactance and Phase Angle), especially in cases of clinical uncertainty.

The next chapter systematically explores current literature to determine what is already known about using BIA to detect low-intake dehydration in older people in acute settings. This systematic review provides a foundation to answer my second research question of whether BIS can augment existing approaches and improve the detection and management of low-intake dehydration in the older adult population.

4.5 Key Insights of this Chapter

1. **Evolution of Bioelectrical Impedance Analysis (BIA):** This chapter discusses the BIA's evolution from its inception as an invasive method to its role as a non-invasive, where it is a portable, convenient, and practical tool for assessing hydration status and body composition.
2. **BIA Technologies:** The chapter discusses single-frequency, multi-frequency, and bioelectrical impedance spectroscopy (BIS) methodologies. These technologies differ in their capacity to assess various body composition elements such as total body water and fat-free mass.
3. **Principles of Bioimpedance Measurement**: Key BIA measures include resistance, reactance, and phase angle as essential measurements, with each parameter providing specific insights into body composition and hydration**.**
    a. **Resistance (R):** Measures the opposition to the flow of an electric current through body water and is inversely related to total body water.
    b. **Reactance (Xc):** Reflects the capacitive properties of cell membranes and tissue interfaces, indicating cell membrane integrity and body cell mass.
    c. **Phase Angle (PA):** Derived from the arctangent of reactance divided by resistance, serving as an indicator of cellular health. It is used as a predictive tool in various clinical settings.
4. **Importance of Primary Measurements over Regression Equations in Clinical Settings:** The chapter emphasises the significance of using primary BIA measurements (R, Xc, and PA) in clinical settings. It points out that reliance on regression equations can be unreliable, as they may not hold in clinical settings where hydration states or nutritional status are altered. Direct measurements provide more reliable and accurate data, which is crucial for patient assessment and decision-making.

Chapter 5 Detection of Low-Intake Dehydration Using Bioelectrical Impedance Analysis in Older Adults in Acute Care Settings: A Systematic Review

5.1 Introduction

This chapter provides a systematic review of my PhD thesis, which aims to aggregate and review the available empirical evidence to examine the utility of impedance measures using BIA for detecting low-intake dehydration in older adults in acute care settings.

The chapter is divided into five sections. The first three sections cover the review method used and present the literature review findings. The fourth section provides a critical interpretation of the review. The fifth section deliberates the justification for the proposed review.

5.2 Review Question

The question for this review was:

> ***What is the utility of Bioelectrical Impedance Analysis (BIA) to detect low-intake dehydration in older adults admitted to acute care hospital facilities?***

This review question was developed using the population, intervention, comparison and outcome framework (Table 8). The utility of using BIA to detect low-intake dehydration in older adults admitted to acute care hospital facilities was assessed in this systematic review.

5.3 Method

5.3.1 Data Search

A systematic search of existing literature was conducted using the electronic databases Ovid MEDLINE and EMBASE, CINAHL (EBSCO), Web of Science Core Collection (indexes SCI Expanded, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI), and Cochrane Central and CDSR. The search terms, syntaxes, and Boolean operators used for database searching are detailed in Table 8 by the accepted population, exposure/interest, outcomes, and setting (PE/IOS) framework[173]. Details of the search strategy for one database are included in Appendix K.

Table 8 Search strategy informed by the PE/IOS framework

PE/IOS	Search Terms and Boolean Combinations
Population	'Geriatrics' OR 'aged' OR 'aged subject' OR 'frail elderly' OR 'old* adult*' OR 'old* person*' OR 'old* people' OR 'old* patient*' OR 'old* m#n' OR 'old* wom#n' OR 'old* age' OR 'elder*' OR 'old* male*' OR 'old* female*' OR 'old* population*' OR 'geriatric*' OR 'elderly people' OR 'elderly person' OR 'ageing' OR 'aging' OR 'senior citizen*'
Exposure/interest	'Bioelectrical impedance analysis' OR 'bioelectrical' OR 'electric impedance' OR 'impedance' OR 'BIA' OR 'reactance' OR 'resistance' OR 'bioimpedance' OR 'bioimpedance analysis' OR 'electrical' OR 'phase angle' OR 'ohmic' OR 'capacitance'
Outcomes	'Hydrat*' OR 'dehydrat*' OR 'euhydrat*' OR 'rehydrat*' OR 'body water' OR 'body fluid*' OR 'hypohydrat*' OR 'fluid* balance*' OR 'fluid* imbalance*' OR 'fluid* measur*' OR 'fluid* monitor*' OR 'water* volum*' OR 'water* intake' OR 'water* balance*' OR 'water* imbalance*' OR 'water* measur*' OR 'water* monitor*' OR 'fluid* deficit*' OR 'fluid* manag*' OR 'liquid* manag*' OR 'liquid* volum*' OR 'liquid* intake' OR 'liquid* balance*' OR 'liquid* imbalance*' OR 'liquid* measur*' OR 'liquid* monitor*'
Setting	'Hospital*' OR 'clinical care' OR 'acute care' OR 'hospitalisation'

The literature was searched for randomised controlled trials and observational cross-sectional, cohort, and case-control designs. Search results were limited to publications in peer-reviewed journals in the English Language, with a time limit from inception till May 2022, and publications which reported on each of the PE/IOS components. The inclusion criteria were male and female older adults (defined as age ≥65 years), as this is the usual age threshold to represent the population group of older adults most affected by dehydration. Such adults had to have low-intake dehydration measured using BIA during the receipt of care within a hospital setting. Studies were not limited by publication date or geographic setting, as it was pertinent to include all relevant evidence. Peer review was considered necessary to identify and evaluate evidence of sufficient scientific and ethical rigour[174], peer review details were determined from the journal website or databases indexing the journal. The criteria for publications in the English language were necessary to comprehend and collectively analyse the reported outcomes without the need for translation. Studies among children and younger adults were excluded from the review because of the low rate of low-intake dehydration among these population groups. Finally, outcomes regarding the value of BIA for detecting low-intake dehydration had to comprise indices of diagnostic accuracy, such as sensitivity and specificity, as these are widely used among diagnostic accuracy reviews and are amenable to pooled statistical analyses[175]. The inclusion and exclusion criteria are presented in Table 9.

Table 9 The inclusion and exclusion criteria used in the review

Study Characteristics (PE/IOS)	Inclusion Criteria	Exclusion Criteria
Research design	Randomised controlled trials and observational studies, including cross-sectional, cohort, and case-control studies	Secondary review research, animal, laboratory-based, and qualitative studies, editorials, letters, case series, and case reports
Publication date	No restriction	-
Language	English	Other languages
Peer-reviewed research	Journals	Articles not subject to peer review
Geographical region	No restriction	-

Study Characteristics (PE/IOS)	Inclusion Criteria	Exclusion Criteria
Study quality	No restriction	-
Population	Older adults aged ≥65 years with low-intake dehydration (plasma osmolality ≥295 mOsm/kg)	Younger adults aged 18–64 years or children aged <18 years Older adults with euhydration or plasma osmolality <295 mOsm/kg
Exposure/interest	Hydration status measured using BIA	-
Outcomes	Diagnostic value, including measures of sensitivity, specificity, total accuracy, and/or positive or negative predictive values	Outcomes irrelevant to the research question
Setting/context	Hospital or other acute healthcare facilities	Community care facilities

BIA: bioelectrical impedance analysis; PE/IOS: population, exposure/interest, outcomes, and setting.

Studies were selected using the usual filtering process of title/abstract and full-text screening, with citations managed using Clarivate Analytics® EndNote X9 referencing software[173]. The process of study screening and selection was supervised by Dr Stephen Wootton (SAW) and Dr Stephen Lim (SL) who reviewed the results from study filtering at the title/abstract and full-text stages. In case of any uncertainty, studies were either included or excluded after supervisor review. The results of the study selection are presented in the Results section and in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram in Figure 5.1[176,177].

5.3.2 Data extraction

The data required for critical appraisal and results synthesis was extracted using pre-developed electronic proformas taken from the Cochrane Handbook for Systematic Reviews and adapted to suit the construct of interest[178]. Data extraction was further reviewed by my supervisor SL, and any discrepancies were discussed with SAW to reach a consensus.

5.3.3 Quality assessment

The quality of eligible studies was assessed using the Cochrane Risk-of-Bias Tool for Randomised Controlled Trials and a modified version of the Cochrane tool for non-randomised studies[179,180]. The risk of bias for each study was rated in accordance with Cochrane guidelines as either low, high, or unclear; judgements regarding external validity are noted in the discussion section of this chapter. Data regarding the diagnostic utility of BIA included consideration of pooled meta-analyses, which would have been conducted using the Cochrane Collaborations RevMan® v5.3 software®. However, the outcome data were not amenable to meta-analyses due to the lack of reporting of true positives, true negatives, false positives, and false negatives. As only one study in the review reported

diagnostic accuracy indices, a consistent analytical approach was achieved in the form of narrative synthesis to describe the value of BIA for detecting low-intake dehydration[181].

5.4 Results

5.4.1 Study Selection

Following the search for literature using the defined strategy, a total of 2,743 studies were retrieved. Before screening for titles/abstracts, 758 duplicates were discarded. The remainder 1,985 studies were screened for titles/abstracts, and 1,968 studies were excluded as they either did not study the research outcomes related to BIA or older patients or were presented as posters in conferences. This left 17 articles for full-text review, out of which further 13 studies were excluded for the following reasons: 1) evaluation of BIA used among older adults in non-hospital or non-acute setting (7 studies)[31,157,182-186]; 2) unclear outcomes regarding the diagnostic value of BIA for low-intake dehydration in older adults (2 studies)[187,188]; 3) evaluation of BIA used among younger adults and/or children (4 studies)[30,189-191]. The remaining four studies met each of the inclusion criteria and were therefore deemed eligible for review as shown in Figure 5.1.

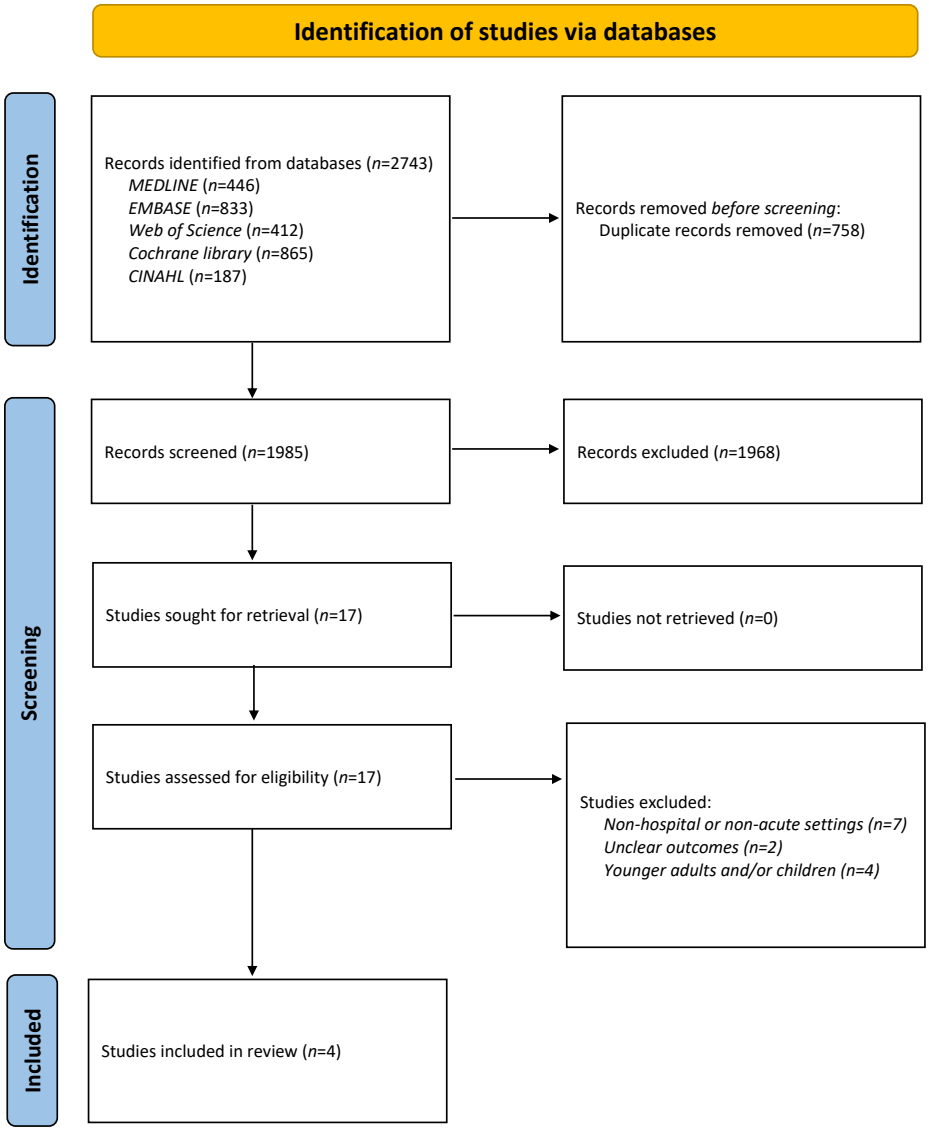


Figure 5.1 PRISMA flow diagram

5.4.2 Study Characteristics

The research designs of the four studies (Table 10) identified for collective review[29,155,192,193] comprised two single-centre prospective observational cohort studies[29,192], a multi-centre prospective cohort study[193] and a randomised non-controlled study[155].

Table 10 The selected studies included in the current review

Author and Year	Design	Setting	Participants (sample size)	Bioelectrical Impedance Analysis	Comparators
Jones, et al. [29] (2015)	Prospective, observational cohort (single centre)	Australia	Subjects (*n*=61) admitted to the ICU who received mechanical ventilation and with an expected hospital stay of ≥48 hours. Patients with dehydration had a mean age of 66 years. Sex: Female (38%) and male patients (62%).	Bioelectrical impedance vector analysis (Renal EFG BIVA™ Technology; EFG Diagnostic, Belfast, UK). Impedance of 50 kHz. Pairs of electrodes were placed on the dorsum of the wrist and the ipsilateral ankle.	A comparator was not used.
Kafri, et al. [192] (2013)	Prospective, observational cohort (single centre)	United Kingdom	Older adults (*n*=27) admitted to hospital with acute stroke. Patients with dehydration had a mean age of 73.5 years. Sex: Not reported.	Multi-frequency BIA (Maltron BioScan® 920-2; Maltron International, Essex, UK). Impedance of 5 kHz, 50 kHz, and 100 kHz. Pairs of electrodes were placed on the talus and the third and fifth digits of the foot and the third and fifth knuckles of the hand and the wrist.	Serum osmolality was analysed using freezing point depression (295–300 mOsm/kg) (i.e. impending dehydration), with current dehydration being ≥301 mOsm/kg. Serum osmolarity (mOsm/L) was calculated from combined concentrations of serum sodium, potassium, glucose, and urea ([2×Na+]+[2×K+]+urea+glucose) (i.e. 295–300 mOsm/L [impending dehydration], with dehydration at the time of the study of ≥301 mOsm/L).
Powers, et al. [155] (2009)	Randomised non-controlled study	United States	Older adults (*n*=32) admitted to medical and surgical wards. Patients with dehydration had a mean age of 77.1 years. Sex: Female (63%) and male patients (37%).	Single-frequency BIA (Real-Time RJL Systems® Analyser, Clinton Township, Michigan, USA). Impedance of 50 kHz. Pairs of electrodes were placed on the dorsal surfaces of the right hand and foot proximal to the metacarpal, phalangeal, and metatarsal phalangeal joints. One additional pair of electrodes were applied at the pisiform bone of the right wrist and between the medial and lateral malleoli of the right ankle.	TBW was determined by $^{2}H_2O$ dilution, and ECW was measured by using sodium bromide (NaBr) dilution. The participants provided baseline blood samples. To measure TBW, the participants were asked to drink water containing $^{2}H_2O$ at an amount of 30 mg/kg of body weight. To measure ECW, the participants were asked to drink water containing NaBr at an amount of 70 mg/kg of body weight. A second blood sample was obtained 3–4 hours after the oral dose. Plasma was separated from the blood samples. Isotope ratio mass spectroscopy was used to determine $^{2}H_2O$ in the plasma. TBW was calculated using the following equation: TBW = [$^{2}H_2O$dose/($^{2}H_2O$ 3 h – $^{2}H_2O$ 0 h)]/1.04. To measure ECW, NaBr dilution was assayed by using a high-performance liquid chromatography anion-exchange method after serum ultrafiltration. The equation used for the ECW calculation was: ECW = [Br Dose/(Br dose 3 h – Br dose 0 h)] × 0.90 x 0.95. ICW was calculated as TBW – ECW.

Author and Year	Design	Setting	Participants (sample size)	Bioelectrical Impedance Analysis	Comparators
Ritz [193] (2001)	Prospective observational cohort (multi-centre)	France	Older adults (*n*=169) admitted to geriatric wards for acute medical problems across six hospitals. Patients with dehydration had a mean age of 81.4 years. Sex: Female (64%) and male patients (36%).	Multi-frequency BIA (Analycor-3®; Spengler, Cachan, France). Impedance of 5 kHz, 50 kHz, and 100 kHz, with current of 400 μA. Pairs of electrodes were placed on the distal end of the third metacarpal bone and the distal end of the second metatarsal bone. One additional pair of electrodes was applied between the styloid processes of the radius and ulna and between the two malleoli of the ankle.	Dilution measurements of deuterated water ($H_2{}^{18}O$) for TBW and Br dilution for ECW. The patients were considered dehydrated if they had plasma sodium levels of ≥142 mmol/L, and they were considered euhydrated if their plasma sodium concentrations were ≤135 mmol/L. At baseline, overnight fasting (approximately 12 h) was required, and the participants provided plasma and urine samples to determine the natural abundance of $H_2{}^{18}O$ enrichment and Br concentration. An amount of 2% of $H_2{}^{18}O$-enriched water (approximately 50 g) was orally administered to the subjects, and 20 g of potassium Br syrup (containing approximately 1 g of Br) was given to half the participants. After an interval of 4–5 hours, the plasma and urine samples were collected. The following equation was used to calculate ECW after considering the mean Br plasma concentration 4 and 5 hours after the dose: ECW = 0.90 × 0.95 × (Br dose)／[delta(Br plasma)]. Br dose = the dose given and delta (Br plasma) = the difference in mean plasma concentration between the administration of the dose and the baseline concentration.

$^2H_20$: deuterium oxide; Br: bromide; EBW: extracellular water; ICU: intensive care unit; NaBr: sodium bromide; TBW: total body water; $H_2{}^{18}O$: water enriched with oxygen-18

A summary of the findings of the four studies is presented in Table 11. The populations and sample sizes were as follows: older adults (n=61) admitted to the intensive care unit who received mechanical ventilation and had an expected length of stay of ≥48 hours[29], older adults (n=27) admitted to hospital with acute stroke[192], older adults (n=32) admitted to medical and surgical wards[193], and older adults (n=169) admitted to geriatric wards for acute medical problems across six hospitals[155].

Table 11 A summary of the findings of the four included studies

Author and Year	BIA Equipment/Protocol	BIA data (R [Ohm/m]; Xc [Ohm/m] and Pa [degrees])	Measure of Hydration Status	Descriptive Findings
Jones, et al. [29] (2015)	Bioelectrical impedance vector analysis (Renal EFG BIVA™ Technology; EFG Diagnostic, Belfast, UK). Impedance of 50 kHz. Pairs of electrodes were placed on the dorsum of the wrist and the ipsilateral ankle. The measurements were taken twice daily (in the morning and afternoon) for the first five days of each patient's stay in the ICU or until ICU discharge, where the patients were positioned horizontally and placed in the supine position for ≥2 minutes.	Dehydration (*n*=14): R = 321.0 Xc = 43.6 Pa = 9.1 Euhydration (*n*=22): R = 314.0 Xc = 29.6 Pa = 5.5 Overhydration (*n*=25): R = 224.0 Xc = 16.5 Pa = 3.8	A quantitative estimation was made of TBW volume as a percentage of fat-free body mass. Dehydration (TBW of ≤72% of fat-free body mass). Euhydration (TBW of 73–74% of fat-free body mass). Overhydration (TBW of ≥75% of fat-free body mass).	BIA was used to categorise the patients according to hydration status using TBW volume thresholds of ≤72% (signifying dehydration), 73–74% (reflecting normal hydration), and ≥75% (indicating overhydration). While no direct measures of diagnostic accuracy were reported given the lack of a comparator group, the results showed that BIA reliably identified dehydration based on positive physiological responses to fluid challenges and maintenance fluid therapy. Dehydration, identified using BIA, was associated with a non-significant increase in the requirement for renal replacement therapy (p=0.800), length of ICU stay (p=0.870), length of hospital stay (p=0.220), admission to intensive care (p=0.890), and the rate of hospital mortality (p=0.550) compared to normally hydrated subjects (all p>0.05).
Kafri, et al. [192] (2013)	Multi-frequency BIA (Maltron BioScan® 920-2; Maltron International, Essex, UK). Impedance of 5 kHz, 50 kHz, and 100 kHz. Pairs of electrodes were placed on the talus and the third and fifth digits of the foot and on the third and fifth knuckles of the hand and the wrist. The participants fasted for at least two hours and were asked to remove any jewellery and to micturate if they wished before the BIA measurements were taken. Two consecutive measurements were taken over a couple of seconds within 20 minutes of the blood samples being taken while the subjects were in the supine position. The recordings were repeated a few minutes later. An average of the two consecutive measurements was calculated. The first data set was used in the event of variation of ≥3%. Height, weight, biological sex, age, and ethnicity were entered into the MF-BIA device.	Not reported.	A quantitative estimation was made of (1) TBW volume as a percentage of body weight, (2) ICW as a percentage of TBW, and (3) ECW as a percentage of TBW using MF-BIA (using published equations for older adults).	The accuracy of BIA varied with the threshold of TBW volume congruent with dehydration. The highest sensitivity (100%) was observed for TBW volume of 55% with low corresponding specificity (i.e. of only 14%). The highest specificity (91%) was observed for a TBW volume of 45%; however, the corresponding sensitivity was only 17%. The positive and negative predictive values were 25–33% and 79–100%, respectively. Optimal accuracy with a modest sensitivity and specificity (62–67%) was observed for a TBW volume threshold of 52%.

Author and Year	BIA Equipment/Protocol	BIA data (R [Ohm/m]; Xc [Ohm/m] and Pa [degrees])	Measure of Hydration Status	Descriptive Findings
	BIA outputs (the mean of the two readings) were used to calculate TBW (L) and ECW (L) using published equations for older people. TBW, ECW, and ICW were calculated as body weight percentages using equations specifically developed for older adults (rather than those already programmed in the device). TBW was estimated using the Vaché equation: TBW = (2.896)+(0.366*height^2/R100)+(0.137*weight)+(2.485*G) R100 = impedance at 100Hz, and G = gender, with a value of 1 for men and 0 for women. ECW was estimated using the Visser equation: ECW (Women) = (1.7) + (0.2*height^2)/(R5)+(0.057*weight). ECW (men) = (4.8) + (0.225* height^2)/(R5).			
Powers, et al. [155] (2009)	Single-frequency BIA (Real-Time RJL Systems® Analyser, Clinton Township, Michigan, USA). Impedance of 50 kHz. Pairs of electrodes were placed on the dorsal surfaces of the right hand and foot proximal to the metacarpal, phalangeal, and metatarsal phalangeal joints. One additional pair of electrodes was applied at the pisiform bone of the right wrist and between the medial and lateral malleoli of the right ankle. The participants were placed in the supine position, with their arms and legs abducted at an angle of 30–45°. Overnight fasting was required.	Not reported.	R, Xc, Ht, wt, biological sex, age, and amount of exercise were entered into a software programme called Cyrus. TBW and ECW were estimated using the BIA device.	The use of BIA was associated with small inter-individual variability in relation to the accurate measurement of TBW volume percentage (4.1%), compared to the reference tests, which suggests that the method feasibly identified dehydration and changes in hydration status. ECW volume, measured using BIA, was not significantly different to that measured using NaBr (p=0.430).
Ritz [193] (2001)	Multi-frequency BIA (Analycor-3®; Spengler, Cachan, France). Impedance of 5 kHz, 50 kHz, and 100 kHz, with current of 400 µA. Pairs of electrodes were placed on the distal end of the third metacarpal bone and the distal end of the second metatarsal	Not reported.	A quantitative estimation was made of TBW and ECW as a percentage of body weight.	Sufficient comparability was observed between BIA and the reference tests in measuring TBW volume; notably, the method was able to discriminate between dehydration and normal hydration based on a TBW volume of 0.25–0.39 L. In this regard, average TBW volume in normally hydrated subjects was 0.69–0.83 L, considerably higher than that in dehydrated subjects.

Author and Year	BIA Equipment/Protocol	BIA data (R [Ohm/m]; Xc [Ohm/m] and Pa [degrees])	Measure of Hydration Status	Descriptive Findings
	bone. One additional pair of electrodes was applied between the styloid processes of the radius and ulna and between the two malleoli of the ankle. The measurements were taken on both sides of the body. Overnight fasting (approximately 12 h) was required. The measurements were taken after resting for at least 30 minutes and up to five hours post the administration of the $H_2{}^{18}O$ and Br doses.		TBW was estimated at 50 kHz and 100 kHz using the following equations: TBW (l) 2.896 0.366 Ht^2 = + ⁄ I100 + 0.137 wt + 2.485G TBW (l) 3.026 0.358 Ht^2 = + ⁄ I50 + 0.149 wt + 2.924G. ECW was estimated at 5 kHz using the following equations: ECW (Segal,1) = -6.1 + 0.284 Ht^2/I5 + 0.112 wt ECW (Visser, men,1) = 4.8 + 0.225 Ht^2/I5 ECW (Visser, women,1) = 1.7 + 0.2 Ht^2/I5 + 0.057 wt. In all the equations, Ht was measured in centimetres, and wt in kilogrammes. I signifies 'impedance', and G 'gender' (with values of 0 and 1 for women and men, respectively).	

BIA: bioelectrical impedance analysis; Br:, bromide; ECW: extracellular water; Ht: height; ICU: intensive care unit; ITW: intracellular water; MF-BIA: multi-frequency bioelectrical impedance analysis; NaBr: sodium bromide; Pa: phase angle; R: resistance; TBW: total body water; wt: weight; Xc: reactance; I: impedance

The mean age of subjects across the studies ranged between 63 and 80 years; the study of subjects with a mean age of 63 years reported by Jones, et al. [29] was included due to the predominance of older adults in the cohort. Patient hydration status was ascertained using the following techniques: bioelectrical impedance vector analysis[29], multi-frequency BIA[192,193], and single-frequency BIA[155].

BIA outcome measures used to determine hydration status differed between studies and included TBW percentage, intracellular water percentage, extracellular water percentage, and extracellular:intracellular water ratio. Only one study[192] reported diagnostic accuracy indices, as noted in the meta-analysis and narrative synthesis subsections.

5.4.3 Quality Assessment

As no studies included in the review were randomised controlled trials, the Risk of Bias for Non-Randomised Studies tool was used to inform the risk of bias among the observational studies[194]. A summary of the assessments is provided in Table 12. Overall, three studies were rated as having a high risk of bias[155,192,193], whilst the remaining study observed a low risk of bias[29]. Specific insight into the factors leading to such judgements of quality is provided below, in accordance with the recommendations of Mallen, et al. [194].

Table 12 Critical appraisal of the quality of the included studies using the Cochrane ROBINS-I tool [195]

Included Studies	Selection Bias	Confounding Bias	Classification of Exposure Bias	Missing Data Bias	Outcome Measurement Bias	Reporting Bias	Overall Risk of Bias
Jones, et al. [29]	L	L	L	L	L	L	L
Kafri, et al. [192]	U	L	L	L	H	H	H
Powers, et al. [155]	L	L	L	L	H	H	H
Ritz [193]	L	L	L	L	H	H	H

*U: unclear; H: high; L: low

Two of the studies[29,193] recruited subjects using consecutive sampling techniques, which is a credible approach to avoiding selection bias in non-randomised observational studies, given that there is no risk of selectivity in including or excluding participants with characteristics that may skew measured outcomes. Of the two other studies, Powers, et al. [155] utilised random sampling, while the sampling technique needed to be sufficiently described by Kafri, et al. [192], leading to low and unclear selection bias risk judgements, respectively. However, as each studied different specific populations, the external validity (generalisability of the findings to all older patients) is poor. In this regard, Jones, et al. [29] restricted subjects to those admitted to the intensive care unit and who were expected to be

ventilated for longer than 48 hours, while Kafri, et al. [192] included subjects with incident stroke, which co-existed with extensive exclusion criteria, thus impairing external validity to the general older population. In contrast, Ritz [193] and Powers, et al. [155] included older adults admitted to medical and surgical wards for various clinical reasons and with minimal exclusion criteria offering broader generalisability to other older adult populations. Sample size also affected the external validity of most studies[29,155,192] in this review, with only one study[193] attaining a reasonably sized representative sample (i.e. 169 subjects).

The studies included in this review were judged to have a low risk of confounding bias, as the authors accounted for multiple demographic and clinical factors in the statistical analyses, which were considered important or potential influencers of hydration status. There was also a minimal risk of misclassification bias across all studies in this review, given that evidence-based thresholds were used to categorise subjects into hydration status categories (euhydrated, dehydrated, and over-hydrated). Similarly, there was a low risk of outcome measurement bias due to the homogenous derivation of hydration status based on calculations of TBW through BIA. However, the study by Jones, et al. [29] was the only one to denote/report on the raw data measures for BIA, including resistance, reactance, and phase angle, and thus was considered to have a low risk of reporting bias. While the other three studies in this review did not report on the raw data measures but used these to derive the predicted values of TBW, the risk of reporting and measurement biases were high, as this might have affected the overall accuracy in identifying the hydration status of the participants for the following reason: the raw data measures are independent of regression equations or weight and can be carried out in situations where BIA assumptions are not valid for estimating body fluid compartments.

5.5 Narrative Synthesis

In In the study conducted by Kafri, et al. [192], the authors determined the diagnostic accuracy of BIA for dehydration by comparing BIA-derived TBW estimates with plasma osmolality measurements. The diagnostic accuracy was found to vary markedly depending on which threshold of TBW was used to define dehydration. The highest sensitivity (100%) was observed for a TBW percentage threshold of 55%, although the corresponding specificity was only 14%. The positive and negative predictive values were 25% and 100%, respectively. In contrast, the highest specificity (91%) was observed for the TBW percentage threshold of 45%, although the corresponding sensitivity was only 17%. The positive and negative predictive values were 33% and 79%, respectively. Similar observations were found when diagnostic accuracy was based on intracellular and extracellular water percentages and extracellular-to-intracellular water ratios, with progressive increases in sensitivity and progressive decreases in specificity when the threshold values increase. The most desirable balance of accuracy

was observed at a TBW percentage threshold of 52%, which yielded a modest sensitivity (67%) and specificity (62%).

Powers, et al. [155] found that when compared to estimates of TBW by deuterium dilution and BIA-derived estimates of TBW were comparable with only a small mean difference in TBW percentage (4.1%) with modest inter-individual differences suggesting that the two approaches to estimating TBW were comparable in detecting differences in hydration status, and both were far superior to estimates of TBW derived using conventional predictive approaches using anthropometry.

Ritz [193] also compared BIA-derived estimates of TBW against estimates of TBW by deuterium dilution in a large multicentre trial in patients with differing degrees of hydration from dehydrated, euhydrated and overhydrated. He found that TBW could be estimated accurately by BIA and whilst there was a small difference in the estimated TBW, this difference was not affected by hydration status and concluded that BIA could be used to monitor changes in fluid balance across a range of hydration disorders.

Finally, in the study reported by Jones, et al. [29], the authors used bioelectrical impedance vector analysis to classify patients into three categories of hydration status using TBW percentage thresholds of ≤72% (signifying dehydration), 73–74% (indicating normal hydration), and ≥75% (denoting overhydration). They found higher resistance, reactance, and phase angle values in dehydrated than in euhydrated and overhydrated patients; values that differed progressively from states of overhydration to dehydration and reflected the changes in hydration status with therapeutic intervention. The authors also found that dehydration ascertained using bioelectrical impedance vector analysis was associated with non-significant increases in the need for renal replacement therapy and admission to the intensive care unit, intensive care unit and hospital lengths of stay, and the rate of hospital mortality when compared to normally hydrated subjects (all $p>0.05$).

5.6 Discussion and conclusion

This systematic review sought to explore the diagnostic utility of BIA for the detection of low-intake dehydration among older adults admitted to acute care facilities. Of the four studies that met the inclusion criteria identified, only Kafri, et al. [192] reported the diagnostic accuracy of a BIA-derived estimate of TBW against a clinical measure of dehydration (osmolality). The studies by Ritz [193] and Powers, et al. [155] compared the BIA-derived estimates of TBW against those derived by deuterium-dilution. While finding some degree of concordance between the different approaches to estimating TBW, they did not compare them against other clinical measures. Finally, Jones, et al. [29] reported differences in impedance values in those they categorised as dehydrated compared to those who

were eu/overhydrated. They adopted a qualitative approach using vector analysis findings demonstrating changes in the vector with fluid replacement but again made no comparison against clinical measures. Taken together, the scarcity and quality of published studies and the heterogeneity of observations do not permit any firm conclusion as to the diagnostic utility of BIA in detecting low-intake dehydration in older people in the acute clinical setting.

Some support in using BIA to detect dehydration may be provided by studies in younger adults and children or in non-acute clinical settings or in the community. The search strategy revealed several such studies but were not included in the final evaluation as they did not meet the inclusion criteria. Of particular interest, Shimizu, et al. [185] showed that resistance measures using BIA could derive thresholds to discriminate dehydration from normal hydration in a cohort of adults from an outpatient department. The authors found that those adults identified as dehydrated using clinical assessment had a higher resistance than those normally hydrated and that resistance correlated well with plasma osmolality and other laboratory biomarker measurements. Similarly, Dal Cin, et al. [188] found that BIA could detect dehydration induced by furosemide therapy in a small series of young adults with normal health. In adults with renal disease, O'Lone, et al. [196] demonstrated that multi-frequency bioimpedance spectroscopy in peritoneal dialysis patients was an independent predictor of patient survival, whilst Park, et al. [197] have demonstrated the clinical usefulness of bioimpedance analysis for assessing volume status in patients receiving maintenance dialysis.

In contrast, Rikkert, et al. [157] showed that the sensitivity of BIA for detecting dehydration among community-dwelling older adults was only 14% when compared to a reference comparator comprising a composite of clinical examination, laboratory tests, and changes in weight. Finally, a recent Cochrane review reported by Hooper, et al. [6] evaluated various measures to detect dehydration in older adults, including BIA, but was primarily conducted among populations attending non-hospital or non-acute settings and so would not have been included in this review. The review concluded that clinical assessment measures of hydration status had greater feasibility, cost-effectiveness, and speed than that derived using BIA.

Based on the limited evidence included in this review, measured impedance values appear to change with altered hydration status, but the diagnostic utility of detecting low-intake dehydration in older people in the acute care setting remains unclear. This review has several limitations. Firstly, the literature search comprised an informed series of sources and an extensive series of terms; however, there is a residual risk that one or more studies were precluded from the review. Additionally, there were only four studies that met the inclusion criteria, which, together with marked methodological heterogeneity, precluded inter-study comparisons and meta-analysis. Finally, variances in outcomes across the studies could have resulted from a difference in BIA equipment and/or a lack of quality control or calibration of the instruments.

Whilst severe dehydration may be readily identified in the acute setting using conventional clinical assessments, those with less overt or early dehydration may be overlooked, undiagnosed and untreated. Future primary research should seek to explore the usefulness of raw BIA measures as an adjunct to aid diagnostic accuracy, especially when there is clinical uncertainty, in older adults in high-risk settings such as acute care. Further work on this PhD programme would have greater value if the measured values of resistance, reactance and phase angle are reported in addition to the derived estimates of body water and report how they relate to clinical measures of hydration used in routine care.

5.7 Key Insights of this Chapter

1. **Objective:** The chapter systematically reviews the utility of Bioelectrical Impedance Analysis (BIA) for detecting low-intake dehydration in older adults in acute care settings.
2. **Methodology:** A literature search was conducted across multiple databases. Studies were selected based on specific inclusion and exclusion criteria, focusing on older adults (aged ≥65 years) with low-intake dehydration measured using BIA in hospital settings.
3. **Findings:** The systematic review aimed to evaluate the diagnostic utility of Bioelectrical Impedance Analysis (BIA) for detecting low-intake dehydration among older adults in acute care settings. It included four studies, each with different methodologies and focus areas.
4. **Comparative Analysis:** Among the studies reviewed, only Kafri et al. reported the diagnostic accuracy of a BIA-derived estimate of Total Body Water (TBW) against a clinical measure of dehydration (osmolality). The studies by Ritz and Powers et al. compared BIA-derived TBW estimates against those derived by deuterium-dilution, finding some concordance but not comparing them against other clinical measures. Meanwhile, Jones et al. reported on impedance value differences in dehydrated versus euhydrated/overhydrated patients, yet without comparison to clinical measures.
5. **Limitations and Quality Assessment:** The limited number of studies, methodological heterogeneity, and variable risk of bias among the studies highlighted in the review limit the conclusiveness regarding the utility of BIA in this context.
6. **Conclusion:** The evidence of using BIA in this context is not robust enough to draw firm conclusions. Future research should focus on the utility of raw BIA measures and explore their relation to clinical measures of hydration.

Chapter 6 An Evaluation of the Feasibility and Acceptability of Performing a Study to Identify Low-Intake Dehydration in Hospitalised Older People on Medicine for Older People (MOP) Wards through Concurrent Use of Bioimpedance Measurements and Existing Hospital Risk Assessment Tools

6.1 Chapter Introduction

Dehydration is a highly prevalent and burdensome problem that disproportionately affects older hospitalised patients due to their age- and comorbid-risk of excess fluid loss and insufficient fluid intake, which results in a net fluid deficit[198]. The prevalence of dehydration among older populations has varied by geographic region and patient settings but has been reported to be as high as 39% among nursing home residents and approximately 25% for hospitalised patients[10]. In a recent report published by the Scientific Advisory Committee on Nutrition (SACN)[15], it was cited that one-third of all older people admitted to emergency departments are dehydrated. In the hospital setting, empirical evidence highlights that dehydration is not adequately treated[9,126]. El-Sharkawy, et al. [9] reported that 37% of older people admitted to the hospital were dehydrated, and 48 hours later, 62% of these patients remained dehydrated. The Francis Report[8] also highlighted that the nursing care failures at Mid Staffordshire NHS Foundation Trust which resulted in significant patient harm, included inadequate hydration care. A lack of hydration management standards continues to be a problem within the NHS[127].

In clinical practice, dehydration means a deficiency in total body water (TBW). There is no universally accepted definition of the presence or severity of dehydration[17]. The recent European Society for Parenteral and Enteral Nutrition (ESPEN) guidelines refer to the most prevalent form in older adults as ‘low-intake’ dehydration, thus signifying the primary cause to be insufficient drinking[46].

Early and accurate detection of low-intake dehydration, and prompt identification of those who are at a higher risk of low-intake dehydration are key steps in preventing further complications. Addressing low-intake dehydration and initiating prompt management plans are likely to reduce excess morbidity and mortality, particularly among older persons who represent an already at-risk group for poor outcomes following or during hospitalisation[9]. Diagnosis of dehydration has

traditionally depended upon clinical assessments of hydration status, such as the extent of skin turgor, moisture of mucous membranes and checking for physiological responses to hypovolaemia, such as tachycardia and reductions in blood pressure from baseline values. However, these measures are poorly reliable and tend to only occur in those who are severely dehydrated[199]. Moreover, other clinical presentations may also present with similar signs such as tachycardia and hypotension, thus making it difficult to ascertain if patients truly have low-intake dehydration. In patients with early or minor dehydration, clinical assessment methods are markedly insensitive, as evidenced and outlined by the findings of the qualitative interviews with Medicine for Older People (MOP) staff in previous chapters, and reliance upon examination is associated with delays in instigating hydration therapy and increased risk of complications[200].

Bioelectrical Impedance Analysis (BIA) is a relatively simple and rapid method as mentioned previously that can be used to detect alterations in hydration status through measuring changes in current that is known to be affected by water content and electrolyte status in the body[145]. BIA directly measures the resistance of the body to electrical current, denoted by R, which depends on the body height and lean body mass; and capacitance or reactance, denoted by Xc, which represents the resistance arising from cell membranes[27]. R and Xc can be used to derive the phase angle, which is a biomarker of cellular health and has clinical implications in several diseases[27].

The service evaluation study performed prior as part of a mixed-methods study, as shown in Chapter 3, found that hydration status is not consistently assessed in clinical practice, nor is it incorporated into a formal diagnosis. Whilst the hydration assessment tool supports decision-making in identifying risk factors for dehydration, patients are often not formally diagnosed as having low-intake dehydration. In the service evaluation study, 40/50 (80%) patients were assessed by the clinical team using the local Trust's hydration assessment tool within 24 hours of admission; however, the exact time after admission when it was filled was not even recorded in the assessment form. There was a wide discrepancy regarding assessment times for the remaining patients: 7 (14%) were assessed on day 2; 1 (2%) on day 5; and the rest of 2 (4%) patients were assessed on or after day 6. All 50 patients were found to be at risk for dehydration; moreover, those recognised at risk for severe dehydration and needing fluid balance monitoring through a 24-hour fluid sheet were not adequately assessed and managed for dehydration. There was a high proportion of missing or incomplete hydration and fluid balance charts, especially for seriously ill patients.

The service evaluation study highlighted a need for improvement in assessing hydration for older patients, as under-recognition and mismanagement of dehydration in this age group can significantly increase the morbidity and mortality risks. An objective, standardised and quantifiable approach is required to identify low-intake dehydration in these patients. Considering the practical challenges of accurate assessment of hydration status in older people, primary research should seek to explore the

usefulness of bioimpedance variables as an adjunct to identify those at greater risk and aid diagnostic accuracy, especially when there is clinical uncertainty.

This feasibility study was conducted following up on the service evaluation study and qualitative interviews with the MOP medical and nursing staff. It was conducted to determine whether such a study would be feasible and acceptable for identifying low-intake dehydration in older adults through the concurrent use of bioimpedance measurements and local hydration risk assessment tool. The study also aimed to determine whether directly measured BIA values such as resistance and reactance independent of changes in body weight, correlated with the dehydration risk category assessed by the local hydration assessment tool.

6.2 Methods

6.2.1 Study Objectives

The primary objective of this study was to determine the feasibility and acceptability of performing a study that would examine the concurrent measurement of hydration status in hospitalised older adults using a) the existing hospital risk assessment tool for dehydration; and b) Bioelectrical Impedance Analysis (BIA), specifically Bioelectrical Impedance Spectroscopy (BIS). This feasibility of performing this study was determined by the recruitment rate of patients, the quality of collected data, and the data collection that would inform the calculation of power and sample size. Acceptability was determined by patient acceptance of the BIA measurement procedure, and by recording reasons which precluded patient participation in BIA measurement after giving informed consent for the study.

Secondary objectives included determining the effect size of measured BIA values and their correlation with clinical and demographic patient characteristics, and to determine factors precluding BIA analysis in older adult patients.

To achieve these objectives, a feasibility study was conducted on participants from Medicine for Older People (MOP) wards at University Hospital Southampton. Ethical approval for this feasibility study was first granted by the University of Southampton, Faculty of Medicine Ethics Committee via the Ethics and Research Governance Online II system (ERGO II ID 79301) and the East of England - Cambridge South Research Ethics Committee (REC reference: 23/EE/0067) and the Health Research Authority were then granted through the Integrated Research Application System (IRAS) (IRAS ID 321556) (Appendix L). The study was conducted under clinical supervision by a consultant geriatrician (Dr Stephen Lim).

6.2.2 Patient Selection

Participants were identified and recruited from MOP wards at University Hospital Southampton (UHS). I approached the nurse in-charge of the MOP wards, introduced myself, and asked for a list of patients in the ward who did not have impaired capacity. I was joined by Dr Stephen Lim (academic supervisor and consultant geriatrician) in the beginning. After obtaining the list, I approached each patient, introduced myself, and then explained the study both verbally and through the written information sheet. Patients who agreed to participate were then asked to sign a consent form and were provided a copy of the same. Patients were informed of their right to withdraw from the study at any time and were ensured about data confidentiality. I carried this out in all MOP wards in UHS over a period of one month in April 2023. This time period allowed me to collect data from enough patients to meet the sample size requirements, and also did not pose any additional burden on a busy clinical service. Patients with a known history of severe dementia who were unable to provide consent, as well as patients with a life expectancy of less than 48 hours, were excluded from the study. Based on National Institute for Health Research (NIHR)[201], the study recommendations regarding sample sizes for feasibility trials, the minimal recommended sample size was 24 patients, which was met as 25 patients were eventually recruited in the study.

6.2.3 Data Extraction Methods

Data extraction was performed after screening admitted patients in MOP wards for eligibility using the hospital's CHARTS (electronic medical record) system. I screened patients' medical records and consulted the nurse in charge of the ward to confirm eligibility for inclusion before approaching the patient. Patients were then explained about the study objectives and provided a written Patient Information Sheet (PIS) (Appendix M) and were asked to sign a consent form (Appendix N), a copy of which was provided to them. They were assured regarding confidentiality and right to withdraw from the study, as described in patient selection section. All patient records were stored in a password-protected file in the hospital computer in compliance with the hospital's information governance policies.

Two data extraction and collection forms were utilised to gather the feasibility questions data (Appendix O) and the general and clinical demographic information from the patient's medical records (Appendix P) including their age, biological sex, height, weight, marital status, usual place of residence, date and time of Admission, reason for admission, current clinical diagnosis, comorbid conditions, and number of current medications. Information regarding hydration status as determined by the hospital hydration assessment tool, as well as certain clinical indicators such as frailty (determined using the Clinical Frailty Scale (CFS)); mobility status; presence of delirium (based on clinical diagnosis or 4AT score); malnutrition (determined by the Malnutrition Universal Screening

Tool (MUST) score); and presence of acute kidney injury were also inputted in the data extraction sheet. I discussed every patient with the room ward nurse to ensure that their hydration risk assessment recorded on the local hydration care tool reflected their actual clinical status and was updated accordingly. Retrospectively, I reviewed the patient information data again to determine osmolarity measures (such as sodium, potassium, urea and glucose values). Plasma osmolarity was calculated using the Khajuria and Krahn equation (Osmolarity = 1.86 x (Na+ + K+) + 1.15 x glucose + urea + 14 (all measured in mmol/L)). None of the patients had directly measured plasma osmolality values available, as this is usually done only in medical conditions such as hyponatraemia, and not routinely done to determine dehydration in routine clinical practice.

6.2.3.1 Bioimpedance Spectroscopy

After documenting the feasibility questions and patients' clinical demographic information, patients underwent bioimpedance spectroscopy (BIS) to determine bioimpedance measures. This was performed using the ImpediMed SFB7® (Bioelectrical Impedance Spectroscopy (BIS)) device. Device usage and procedure were guided by the user manual provided by ImpediMed and National Institute for Health and Care Research (NIHR) Southampton Biomedical Research Centre developed by Dr Kesta Durkin (Appendix Q), and prior to use a calibration check was performed. Three consecutive measurements were taken for all patients to determine a mean value accounting for any measurement errors and to ascertain data quality, and the collected data was displayed using the BioImp® PC Software. Prior to electrode application, patient's age and biological sex as well as accurate height and weight (to the nearest 0.5 cm and 1 kg respectively) were entered in the device. To perform the measurements, skin sites at right wrist and right foot were cleaned for 15 seconds using alcohol-based wipes, and 2 electrodes each, spaced 5 cm apart were placed on both sites with the patient supine according to the device usage instructions. Measurement accuracy was ensured by asking patients to remove any watches, jewellery, or stockings which could interfere with the electrodes, and to ensure good skin contact with electrodes. Electrode leads were then connected to the device to obtain the measurements—this process did not require any exposure beyond the electrode placement sites, and patient privacy was ensured throughout the process.

Data from the ImpediMed SFB7® analyser was uploaded in an anonymised format to the University computer and was coded using a unique patient identifier. Recorded measurements were screened using a minimum frequency of 5kHz and maximum frequency of 500kHz with a rejection limit of 2%, therefore allowing for a higher percentage of data inside the fitted curve radius with minimisation of the standard error estimate (SEE) and data artefacts. The recorded data included directly measured variables such as resistance (R) and reactance (Xc); reported or calculated variables such as phase angle (PhA); and derived variables such as total body water (TBW), intracellular fluid (ICF), extracellular fluid (ECF) and fat free mass (FFM).

Findings from the current dataset were compared against reference ranges for normal values of R_{50}, Xc_{50} and PhA_{50} for patients aged >70 years (the cohort selected in this study) stratified by biological sex and BMI. These normal reference ranges were derived from population studies conducted by Bosy & Westphal et al[202,203]. The reference ranges are presented in Table 13 below:

Table 13 Stratified reference values for BIA measured resistance, reactance, and phase angle at 50kHz for older people aged >70 years

Biological sex	**BMI (kg/m2)**	**R_{50}[202] (Mean±SD)**	**Xc_{50}[202] (Mean±SD)**	**PhA_{50}[203] (Mean±SD)**
Females	**18.5-24.9**	597.3 ± 65.7	53.4 ± 9.9	5.1 ± 0.84
	25-29.9	558.4 ± 60.4	51.3 ± 9.1	5.2 ± 0.78
	30-34.9	518.5 ± 58.5	47.9 ± 8.6	5.2 ± 0.75
	35-39.9	479.0 ± 53.1	44.0 ± 8.3	5.2 ± 0.84
	>40	443.3 ± 51.0	39.4 ± 7.4	5.0 ± 0.72
Males	**18.5-24.9**	524.3 ± 59.9	46.6 ± 7.8	5.1 ± 0.86
	25-29.9	470.6 ± 53.6	44.7 ± 8.2	5.4 ± 0.77
	30-34.9	442.6 ± 47.0	42.5 ± 6.9	5.5 ± 0.76
	35-39.9	406.6 ± 48.7	38.5 ± 6.3	5.4 ± 0.73
	>40	372.7 ± 39.9	32.9 ± 6.7	5.0 ± 0.87

BMI=body mass index; R_{50}=Resistance at 50kHz; Xc_{50}=Reactance at 50kHz; PhA_{50}=Phase angle at 50kHz; SD: Standard Deviation

An overview of this data shows that females have higher ranges of resistance and reactance for all categories of BMI. Resistance and reactance in both biological sexes progressively decrease as the BMI increases; on the contrary, phase angle increases as BMI increased from average weight to obese but declined sharply in older people with BMI>40, irrespective of biological sex.

6.2.4 Data Analysis

Data analysis was performed by entering the demographic and clinical data in IBM Statistical Package for Social Sciences (SPSS) software version 28. Data from the ImpediMed device was imported in the

university computer as a Microsoft Excel sheet—from this sheet only the mean values of measured and reported variables (i.e., R, Xc and PhA) at 50kHz frequency for each patient were entered and analysed in the SPSS sheet. This was done because these variables remain unchanged by the assumptions used to calculate derived values such as TBW, ICF and ECF, and therefore predict an accurate estimation of hydration status in ill patients.

Qualitative variables were analysed and presented as frequency (percentages), while quantitative variables were analysed and presented as mean±SD. Non-parametric tests of significance were applied to the dataset, with the level of significance being p value ≤0.05 and the confidence interval for all associations set as 95%. Categorical variables were correlated using the Chi square test, while quantitative variables were correlated using Spearman's rank coefficient. Independent samples Kruskal Wallis-H test was used to determine the association between MUST or CFS categorisation and measured BIA variables. such as mean R50 or X_c50 values.

To adjust for the effect of patient factors such as age, gender and BMI on BIA measured variables, the values of measured variables were expressed as standard deviation scores (SDS). After determining the mean values for resistance, reactance, and phase angle, values for these variables above the mean score for each variable were expressed as positive SDS, while values below the mean were expressed as negative SDS. The SDS values were then compared against calculated or predicted plasma osmolarity values to determine any relation. Based on the principle of normal distribution, 96% of the values would be likely to fall within ±2 SD of the mean.

6.3 Results

In this section, the results of this study are presented in three parts:

a. Feasibility of doing this study

b. Acceptability of making all of the measurements in the study including BIA

c. BIA results and their association with clinical factors

6.3.1 Feasibility

Feasibility was assessed by the recruitment rate of patients, the quality of collected data, and the collection of data that would inform the calculation of power and sample size.

6.3.1.1 Participant Recruitment

A total of 124 patients were admitted to the five MOP wards at UHS over the observation period and were considered for inclusion in the study. Of these, 70 were ineligible as they either did not meet the inclusion criteria or were too clinically unwell or unable to participate in the study due to confusion, low mood and inability to communicate. A total of 54 eligible patients were approached for participation in the study, out of which 25 were finally recruited, with a recruitment percentage of 46.29%. The main reasons for exclusion are highlighted in Figure 6.1:

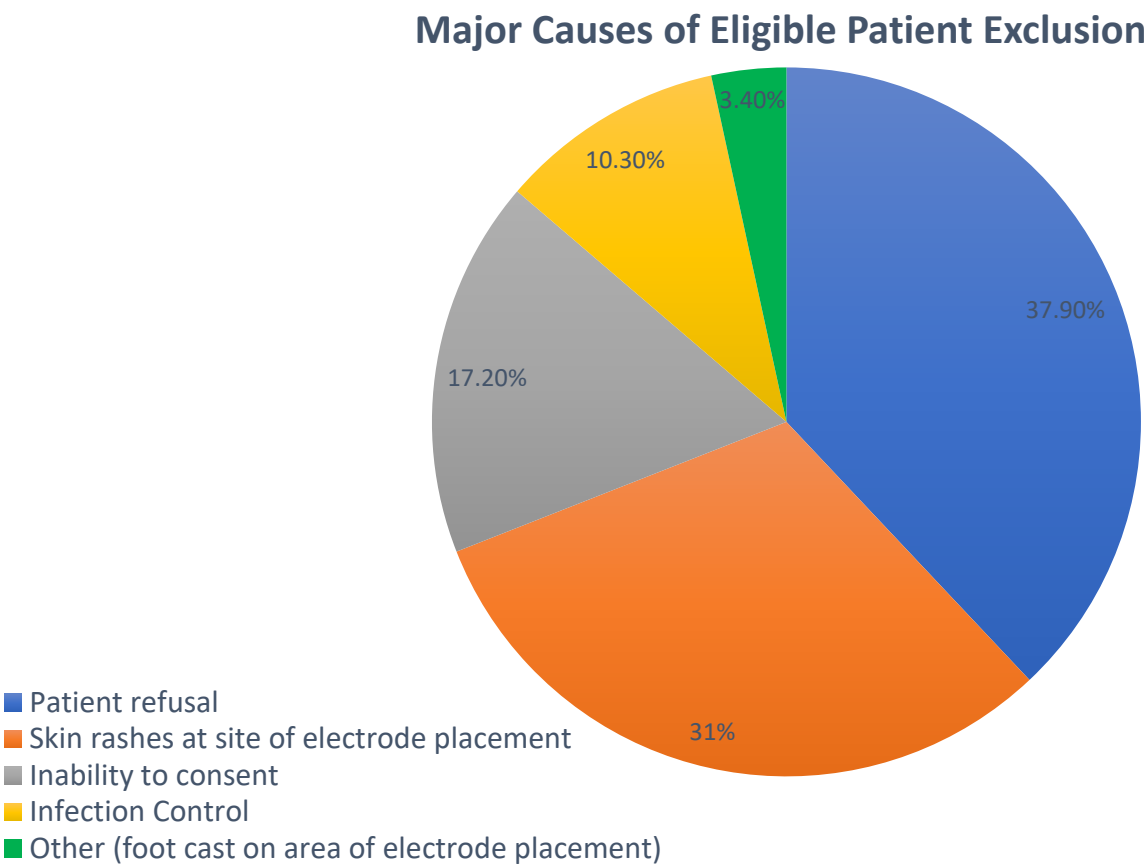


Figure 6.1 Major causes for exclusion of eligible patients

6.3.1.2 Demographic and Clinical Characteristics

There was a female preponderance in the selected patients (n=17, 68%), with average age being 86.76±4.35 years. Table 14 highlights the key demographic characteristics of the included patients, as well as their major co-morbid conditions:

Table 14 Demographic and Clinical Characteristics of Study Participants

Patient Characteristics	Mean±SD or n (%)
Marital Status	
Single	8 (32%)
Married	9 (36%)
Widowed	8 (32%)
BMI (kg/m^2)	26.34±6.25
Healthy (18.5-24.9 kg/m^2)	12 (48%)
Overweight (25-29.9 kg/m^2)	6 (24%)
Obese (30-39.9 kg/m^2)	6 (24%)
Severely obese (≥40 kg/m^2)	1 (4%)
Usual Residence	
Private home living alone	12 (48%)
Private home with friends or relatives	12 (48%)
Shelter/supported accommodation	1 (4%)
Comorbid Conditions	
Hypertension	18 (72%)
Diabetes Mellitus	14 (56%)
Cardiovascular Disease	15 (60%)
Stroke or transient ischemia attack (TIA)	6 (24%)
Kidney disease	13 (52%)
Liver disease	2 (8%)
Asthma	15 (60%)
Chronic Obstructive Pulmonary Disease (COPD)	15 (60%)
Mobility Status	
Walking independently	5 (20%)
Walking with assistance (stick/frame)	17 (68%)
Only transfer from bed to chair	3 (12%)

The most common cause of admission was feeling unwell (n=10, 40%), followed by shortness of breath (n=8, 32%), falls (n=6, 24%), and back pain (n=1, 4%). A majority of the patients faced respiratory issues in the form of lower respiratory tract infection (LRTI) including pneumonia or infective exacerbation of bronchiectasis (n=8, 32%); 6 (24%) of the patients had renal issues including acute kidney injury (n=4, 16%) or urinary tract infection (n=2, 8%), while the rest of the patients had

hypotension (n=4, 16%), acute confusion (n=2, 8%), sepsis (n=1, 4%), or myocardial infarction (n=1, 4%). Polypharmacy was common in the included patients, with the average number of medications per day being 10.5±2.8.

Most patients were at low risk of malnutrition (n=20, 80%) as evidenced by a MUST score of 0; only 2 (8%) patients were at medium risk while 3 (12%) were at high risk of malnutrition. However, all of the patients were clinically frail based on the clinical frailty score (CFS), with categorisation as mild (n=6, 24%), moderate (n=9, 36%), severe (n=8, 32%) and very severe (n=2, 8%). A significant number of patients (n=13, 52%) were diagnosed with delirium either based on clinician judgment or the 4AT assessment.

6.3.1.3 Quality of Collected data

The issue of concern raised in Chapter 3 was whether it would be possible to a) collect sufficient detailed information from the routine approach to assessing hydration status on all patients included in the study and b) impedance measurements. This section considers the assessment of hydration status using routine methods whilst the BIA assessment is discussed in section 6.3.3.

6.3.1.3.1 Hydration Assessment Using Routine Methods

Hydration assessment had already been conducted by the nursing staff for all the included patients (n=25) at the point of observation in this study. Most of the patients were started on a hydration chart (n=18, 72%) or a hydration chart as well as a 24-hour fluid balance chart (n=6, 24%).

These 24 patients were all deemed to be at higher risk of dehydration because of their age (>75 years old). Those 6 patients who required a 24-hour fluid balance chart were deemed to have an even higher risk of dehydration, as assessed by the hydration assessment tool.

Only one patient (4%) did not require any further action after hydration assessment, as they were medically fit and awaiting discharge. Table 15 highlights the decision categorisation based on hydration assessment:

Table 15 Risk categorisation based on the hydration assessment tool.

Risk factor	**n (%)**
Factors to start hydration chart only	
Dry mucous membranes, dry lip, skin turgor, sunken eyes	0
Difficulty handling cups/cutlery, unable to pour their own drinks	3 (12%)
Age over 75	24 (96%)
Respiratory rate more than 25 bpm	1 (4%)
Oral diuretics	0
Febrile patients (Temperature > 38° C)	0
Delirium and/or dementia	5 (20%)
Constipation	1 (4%)
Diabetes	14 (56%)
Decreased appetite	3 (12%)
Thickened fluids	1 (4%)
Consuming clear or free fluids only	0
Long term catheter	1 (4%)
Factors to support starting 24-hour fluids balance chart	
Acute Kidney injury and/or sudden decrease in urine output (<0.5mls/kg/hr)	2 (8%)
Sepsis or NEWS2 ≥ 3	0
IV fluids/NG/PEG feed or TPN	0
IV Diuretics	4 (16%)
Diarrhoea/High stoma output	0
Post Op < 48hrs. (excluding day case)	0

Nil by mouth > 6 hours	0
Fluid restriction (excluding long term restrictions e.g., dialysis)	1 (4%)
IV chemotherapy	0
High drainage wounds	0
Increased vomiting/High NG output	0
Short term catheter removed < 24 hours	1 (4%)
Requested by Clinical team	1 (4%)

There was no association between medium and high risk of malnutrition (p=0.316) as well as mobility status (p=0.954) and need of starting 24-hour fluid balance chart. Patients who were moderately or severely frail and had delirium were found more likely to be monitored using 24-hour fluid balance chart, indicating higher prevalence of risk factors for severe dehydration; however, these associations were also statistically insignificant (p>0.05). No significant association was present between marital status or place of residence with hydration status (p>0.05).

These results suggest that the quality of hydration assessment was sufficiently secure to enable the comparison with the impedance results.

6.3.2 Calculated Plasma Osmolarity

After retrospective data collection for values of urea, glucose, serum sodium and potassium, plasma osmolarity was calculated for all of the patients using the Khajuria and Krahn equation. The mean plasma osmolarity was 297.49±9.14 mOsm/L. With the cutoff value of 295 mOsm/L to define low-intake dehydration, 14/25 patients (56%) had high plasma osmolarity values >295 mOsm/L, indicating low-intake dehydration. Only one patient had significant hyponatremia (123 mmol/L) and had an overall normal plasma osmolarity. None of the patients had plasma osmolarity below 275 mOsm/L, indicating hypo-osmolar state.

Calculated osmolarity was also plotted against patient risk stratification as per the dehydration assessment tool (Figure 6.2):

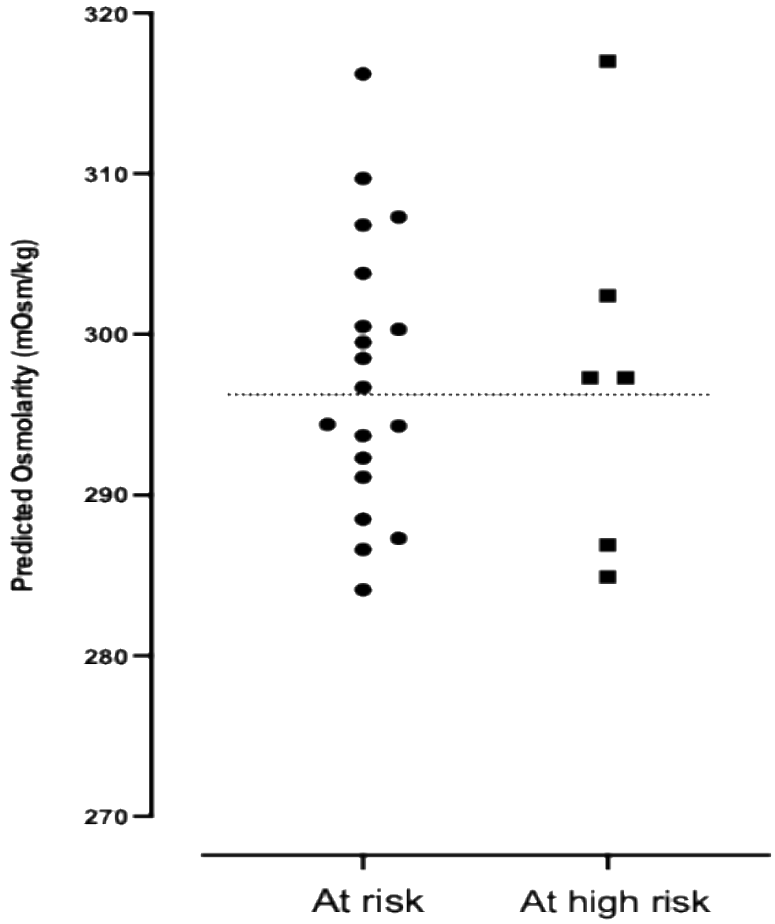


Figure 6.2 Scatter plot of calculated osmolarity with risk stratification for dehydration. While most of the patients with osmolarity >295 mOsm/L were categorised as either at risk or at high risk by the risk stratification tool, some patients deemed at risk or at high risk did not have low-intake dehydration as evidenced by normal osmolarity values-thus indicating that the hydration assessment tool can only screen for but not diagnose dehydration.

The association between plasma osmolarity and phase angle is described later in the section 6.3.4.

6.3.3 Acceptability

Acceptability was determined as the patient acceptance of the BIA measurement procedure, and by recording reasons which precluded patient participation in BIA measurement after giving informed consent for the study.

All the participants of the study (n=25, 100%) agreed that they would accept bioimpedance analysis (BIA) in the future, with no objections noted after gaining consent. This observation would suggest that the BIA measurement was acceptable and could be used to enable the comparison with the routine hydration assessment.

6.3.4 Bioelectrical Impedance Analysis (BIA) Data

BIA data was obtained using the SFB7 device as outlined in the methodology. This included directly measured values of resistance (R) and reactance (Xc), which were used to report the phase angle (PhA). The Impedance Ratio (IR), a marker of the relative distribution of ECW:ICW (R_5/R_{200}), was also reported. These values were determined at multiple frequencies of the applied current ranging from 5 kHz to 500 kHz. However, only the values obtained at 50 kHz are reported here as peak reactance was reported at this frequency on the Cole-Cole Plot. Three repeated measurements were performed for all patients, and the mean values R and Xc at 50 kHz were determined. The phase angle at this frequency (PhA_{50}) was calculated directly by the BIA device using the values of resistance and reactance through the formula $\frac{Xc}{R} x \frac{180°}{\pi}$. Data for BIA variables and calculated or predicted plasma osmolarity were normally distributed for both genders, as determined by Shapiro-Wilk test (p values >0.05).

The mean R_{50} was 557.93±126.16, while the mean Xc_{50} was 33.52±8.79, mean PhA_{50} was 3.47±0.78 and mean IR was 0.87±0.02. BIA findings stratified by gender for the current dataset are presented below (Table 16):

Table 16 BIA data for study participants. All values are represented as mean ± SD (min, max).

Variable	Females (n=17)	Males (n= 8)
Predicted Osmolarity (mOsm/kg)	297.0 ± 9.5 (284, 317)	298.6 ± 8.8 (287, 316)
Resistance at 50 kHz (Ω)	590 ± 141 (335, 926)	489 ± 36 (446, 541)
Reactance at 50 kHz (Ω)	34.4 ± 9.0 (15.5, 48.5)	31.7 ± 8.7 (20.3, 47.3)
Phase Angle (degrees)	3.37 ± 0.72 (2.1, 4.80)	3.71 ± 0.94 (2.6, 5.1)
Resistance at 5 kHz (Ω)	632 ± 148 (353, 983)	529 ± 45 (463, 601)
Resistance at 200 kHz (Ω)	557 ± 136 (319, 882)	459 ± 34 (424, 515)
Impedance Ratio	0.88 ± 0.02 (0.83, 0.92)	0.86 ± 0.03 (0.82, 0.91)
Resistance at 50 kHz SD Score	0.19 ± 2.1 (-3.46, 5.08)	0.43 ± 0.97 (-1.08, 1.93)
Reactance at 50 kHz SD Score	-1.84 ± 0.93 (-3.77, -0.48)	-1.64 ± 1.25 (-2.97, 0.70)
Phase Angle at 50 kHz SD Score	-2.19 ± 0.87 (-3.57, -0.53)	-2.08 ± 1.10 (-3.64, -0.52)

Figure 6.3 represents the distribution of R_{50}, Xc_{50}, PhA_{50} and IR in the current dataset. Increasing trend of R_{50} value and decreasing trend of Xc_{50} value were associated with dehydration in the Bosy-Westphal, et al. [202] dataset and decreasing trend of PhA50 was associated with dehydration in the Bosy-Westphal, et al. [203] dataset.

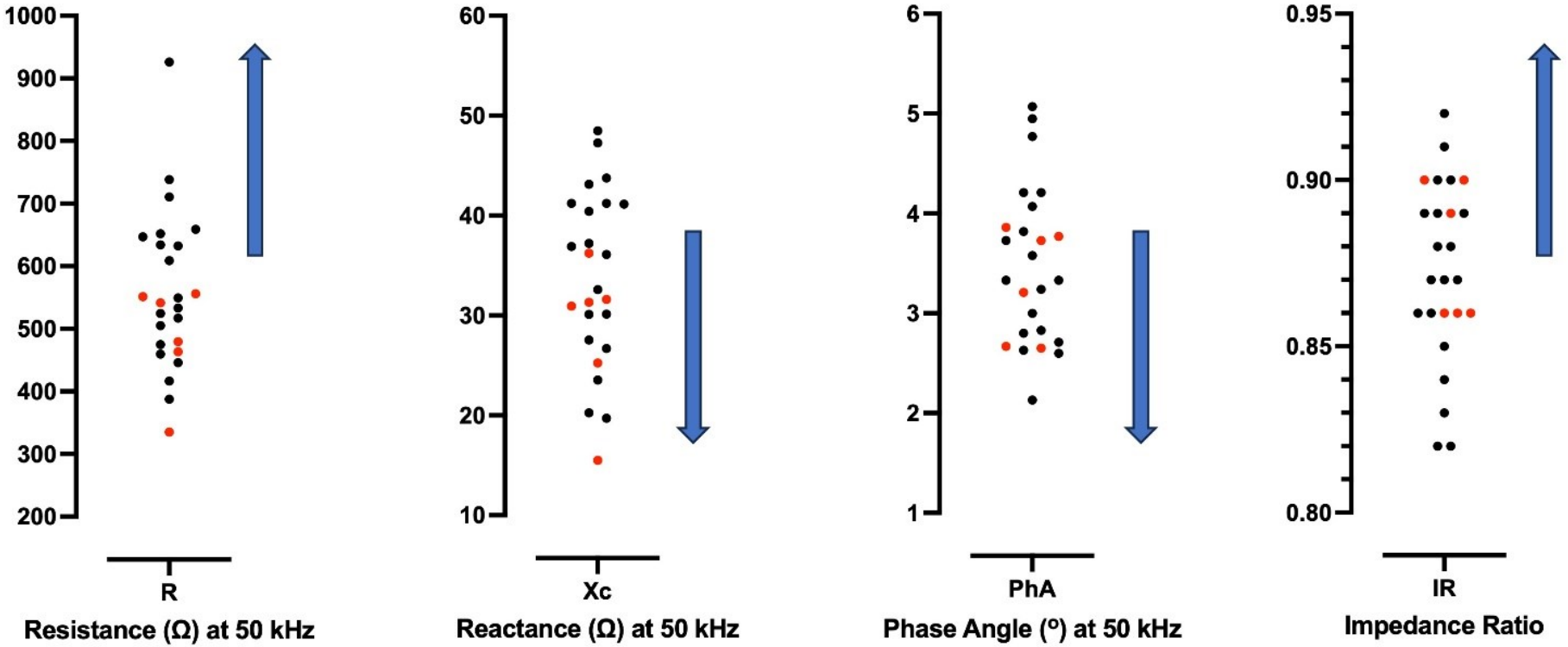


Figure 6.3 Dot plot of R_{50}, Xc_{50}, PhA_{50} and IR representing patient distribution in the current feasibility study dataset —patients with highest dehydration risk requiring 24-hour fluid balance charts are highlighted in red and a trend toward the likelihood of dehydration is highlighted in blue in the current dataset. This trend is derived from the reference values of Bosy-Westphal, et al. [202] and Bosy-Westphal, et al. [203], whose data showed that dehydration is associated with an increasing trend of resistance, and decreasing trend of reactance and phase angle.

Figure 6.4 represents the distribution of SDS values for PhA50, R50, and Xc50 in the current patient dataset, stratified according to biological sex.

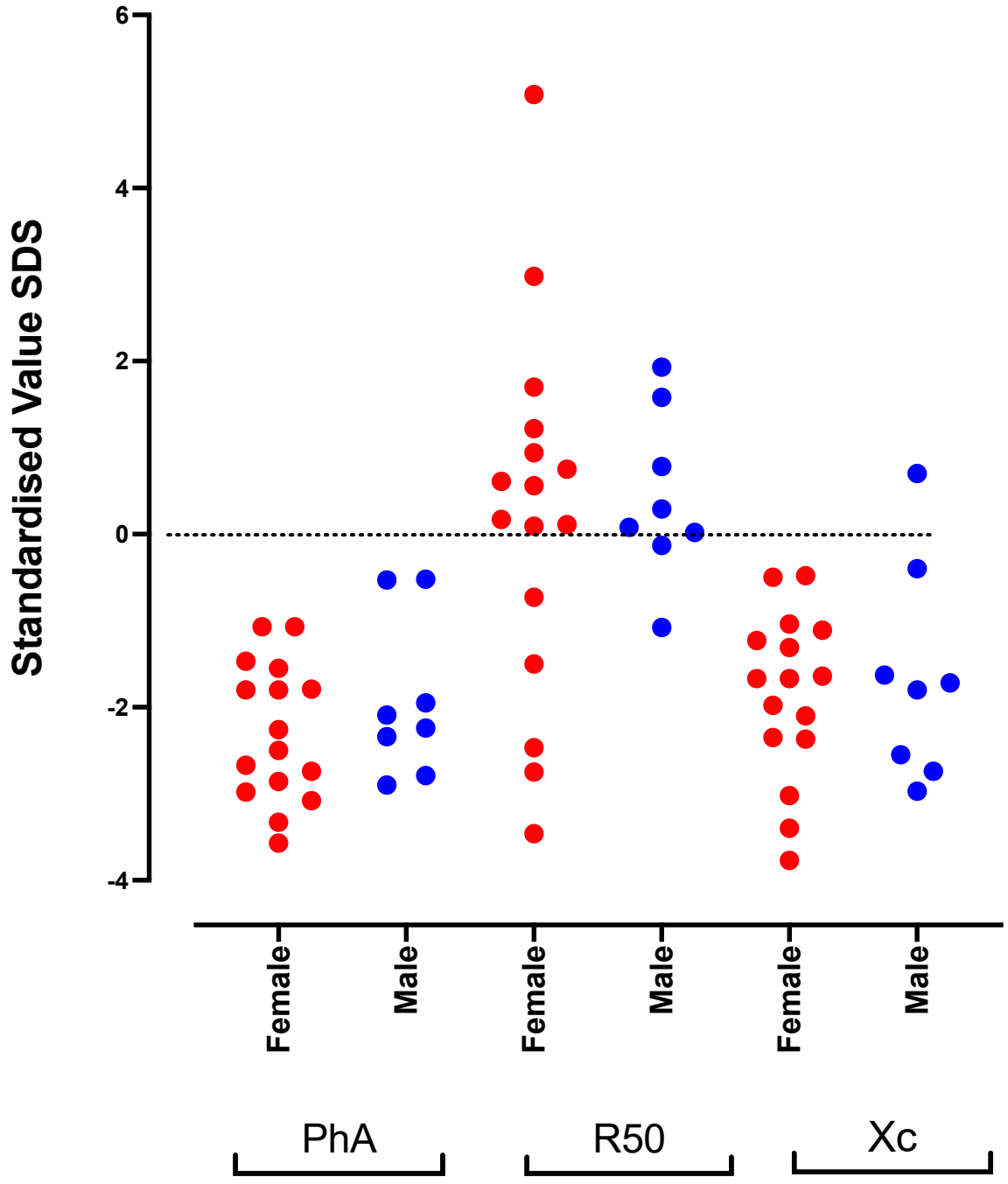
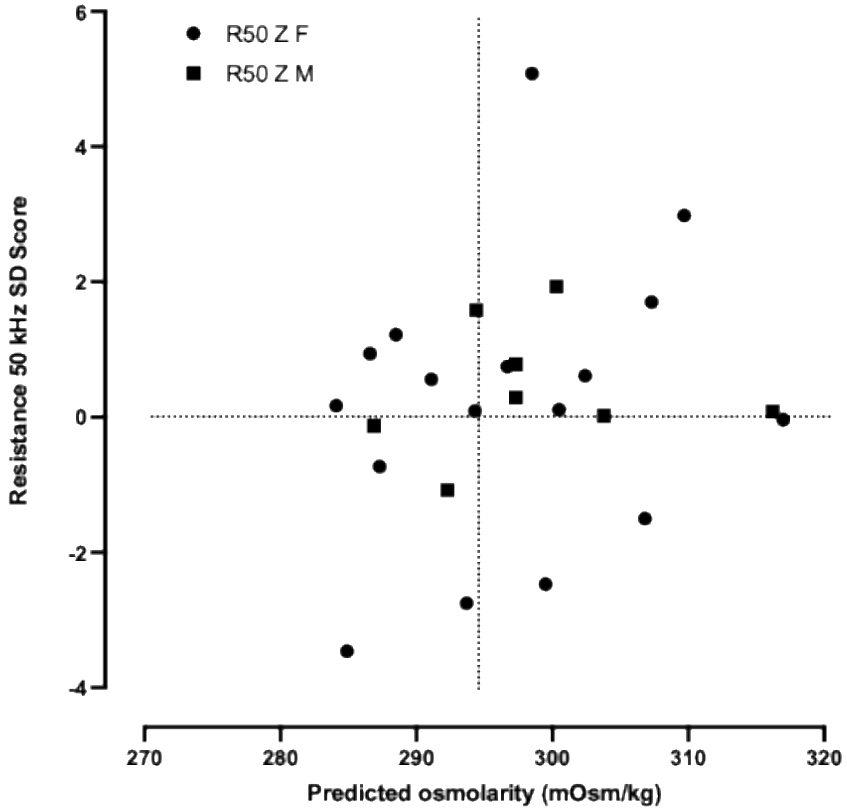
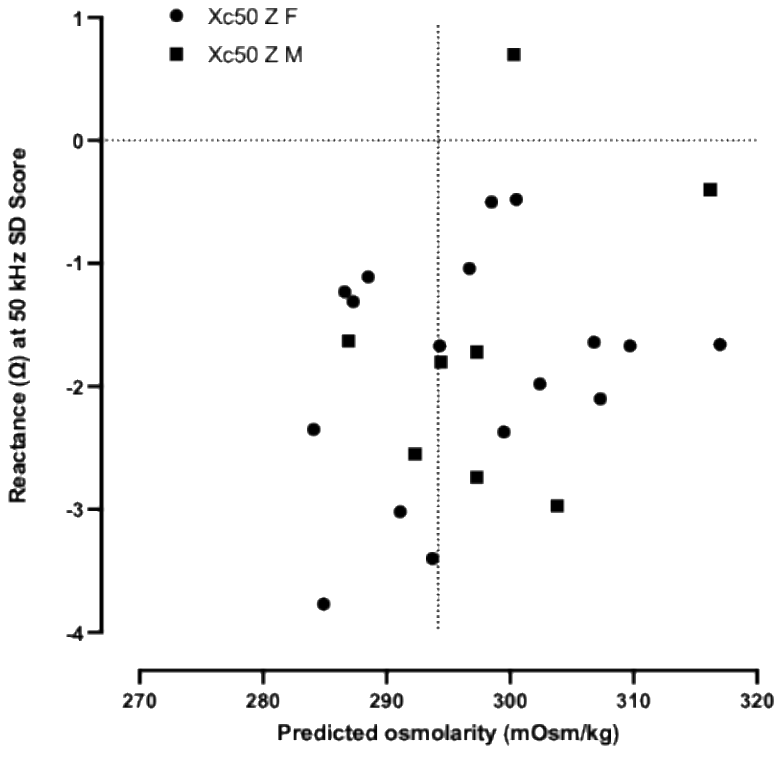


Figure 6.4 Distribution of SDS values for PhA50, R50, and Xc50 in the current patient dataset, stratified according to biological sex. The majority of R50 values were between 0 to +2 SDS, whereas all PhA50 values were below 0 SDS in both biological sexes. Variability in distribution of SDS values for BIA measures is demonstrated throughout the dataset but the values appear comparable for both biological sexes.

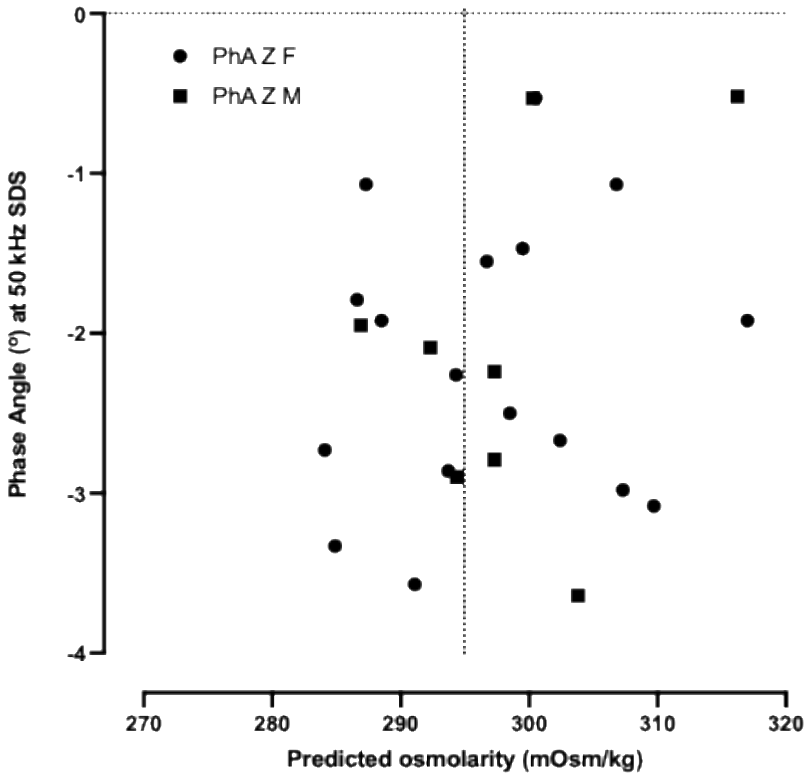
Plotting SDS for resistance, reactance, and phase angle at 50kHz against calculated plasma osmolarity showed high variability in distribution of values for both males and females beyond the normal reference limit (Figure 6.5):



(a)



(b)



(c)

Figure 6.5 Distribution of SDS values for resistance, reactance, and phase angle at 50 kHz for calculated plasma osmolarity values. (a) For patients with plasma osmolarity >295 mOsm/kg, R50 SDS values were mostly within +2 SD from the mean; (b) and (c) for patients with calculated plasma osmolarity >295 mOsm/kg, Xc50 and PhA50 values lied below the mean, with variability in distribution.

Impedance ratio had a non-significant and negative correlation with plasma osmolarity (ρ=-0.231, p=266); plotting this relation showed variable distribution of impedance values for males and females with plasma osmolarity >295 mOsm/kg, although most of the impedance values were higher than 0.85, as represented in Figure 6.6.

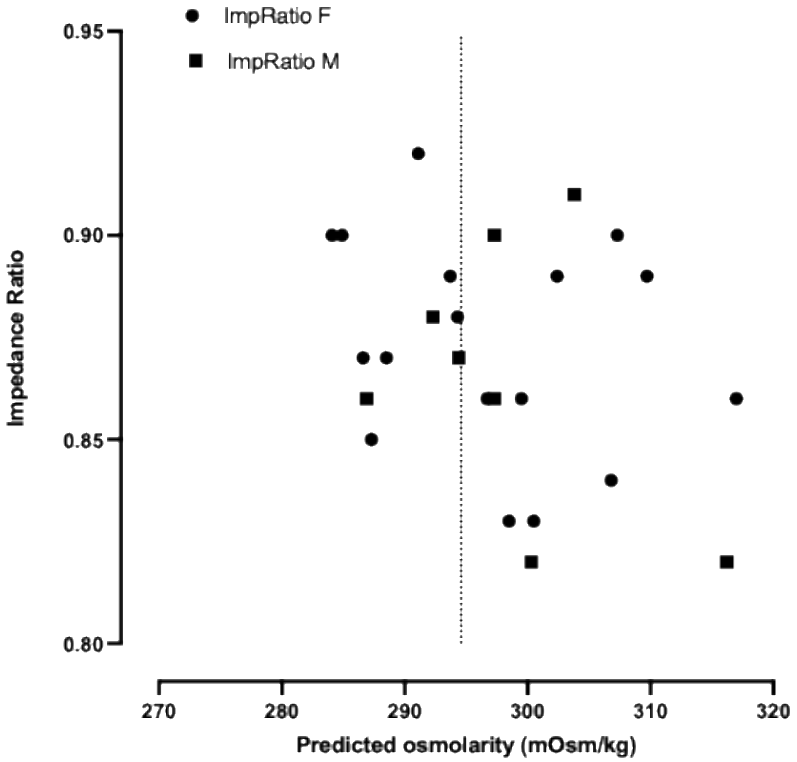
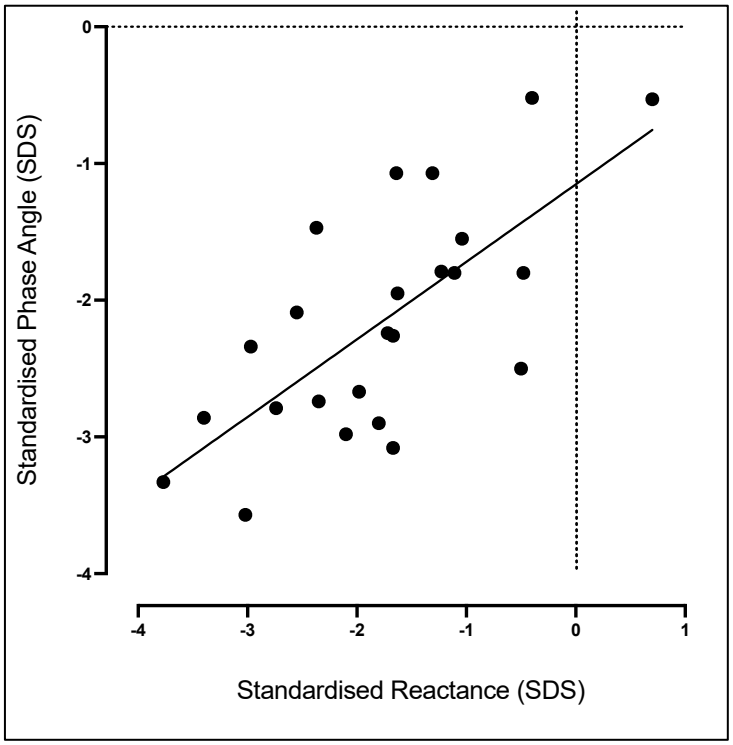


Figure 6.6 Impedance ratio for males and females against predicted osmolarity values. For dehydrated individuals (osmolarity >295 mOsm/kg), impedance values were variable but mostly >0.85.

A strong positive correlation was present between Xc_{50} and PhA_{50} (ρ=0.640, p=0.001), where a weakly negative and insignificant correlation was present between R_{50} and PhA_{50} (ρ=-0.188, p=0.367). Plotting PhA_{50} against R_{50} and Xc_{50} showed that changes in PhA_{50} were primarily dependent on changes in Xc_{50}, as PhA_{50} did not vary significantly with changes in resistance (Figure 6.7).

(a)



(b)

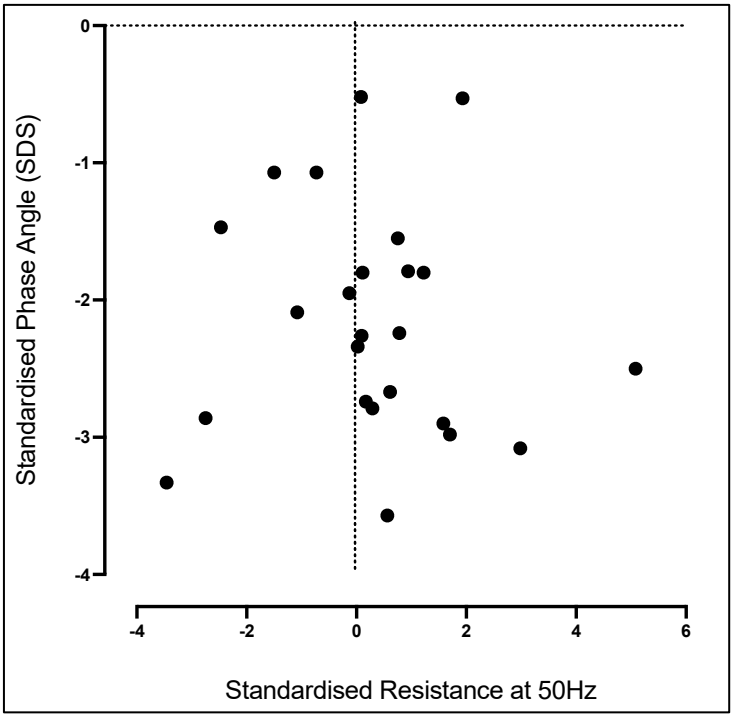


Figure 6.7 (a and b) Changes in PhA50 SDS values are primarily dependent on changes in Xc50 (a) rather than changes in R50 (b). There is a strong positive correlation between phase angle and reactance, whereas the correlation between R50 and PhA50 values is weakly negative and statistically non-significant.

There was no significant association of measured BIA values with decision categorisation on the dehydration risk assessment tool. Figure 6.8 represents the distribution of PhA50 values for the patients as categorised by the risk assessment tool.

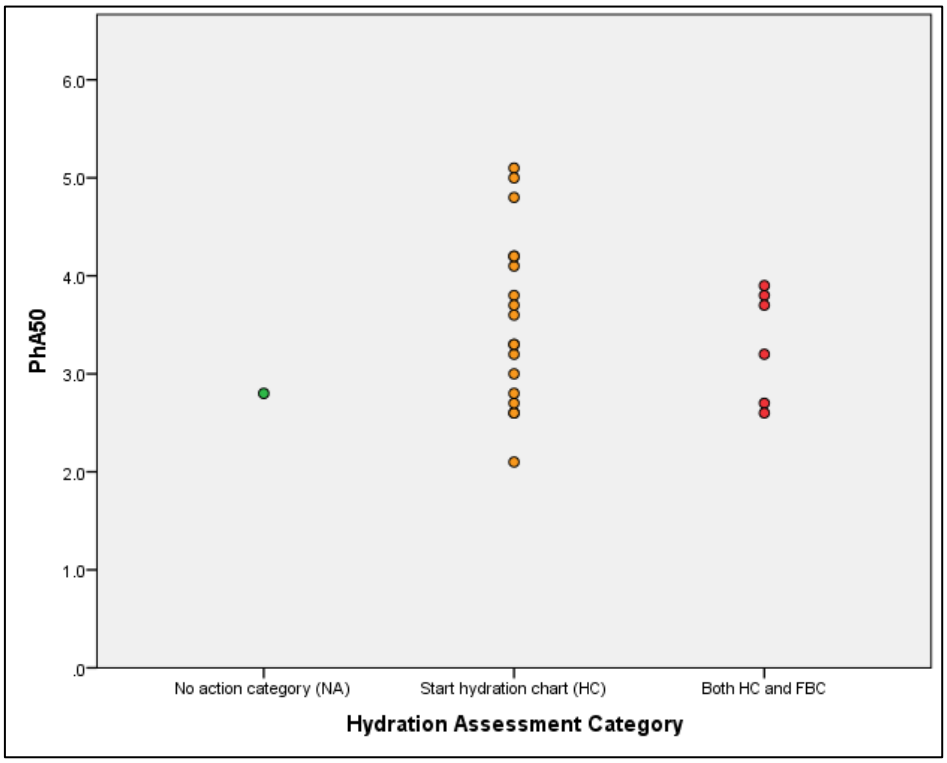


Figure 6.8 PhA50 values for patients in various categories, with colour coding to represent no risk of dehydration (green); moderate risk of dehydration (amber); and high risk of dehydration (red). HC=Hydration chart; FBC=Fluid balance chart. This chart also demonstrates that risk stratification based on the hydration assessment tool is only for screening possible dehydration and does not reflect actually dehydrated patients.

Similarly, no significant association was present between BIA data measures of R_{50}, Xc_{50} and PhA_{50}, and patient's clinical status for mobility, malnutrition (measured by MUST) or frailty (measured using CFS) ($p>0.05$, CI 95%) as determined by the independent samples Kruskal-Wallis test. There was a moderately strong positive correlation of R_{50} values with mobility status and MUST scores, and a strong correlation with frailty, indicating that R_{50} increased in malnourished and frail individuals, and in those with reduced mobility. Xc_{50} was only moderately positively correlated with malnutrition with the correlation being statistically significant, whereas PhA_{50} was moderately negatively correlated with mobility status and frailty without significance of the correlation (Table 17).

Table 17 Correlation of BIA variables with categories for mobility, malnutrition and frailty

Grouping Variable	**R_{50}**	**Xc_{50}**	**PhA_{50}**
Mobility Status	0.351	-0.155	-0.349
Malnutrition (MUST Score)	0.422*	0.476*	0.024
Frailty (CFS)	0.515	0.033	-0.255

*Correlation is significant at p values <0.05. Values presented are of the Spearman correlation coefficient r_s; MUST: Malnutrition Universal Screening Tool; CFS: Clinical Frailty Scale

The differences in PhA_{50} appeared to be primarily dependent on differences in Xc_{50} values rather than differences in R_{50} values.

6.4 Discussion

Evaluation of new complex interventions in areas of health and social care practice is performed in accordance with the Medical Research Council (MRC) framework, the four main tenets of which include development or identification of the intervention; assessment of feasibility and acceptability; evaluation using the most appropriate method to address research questions; and implementation of the successfully tested health innovation in clinical practice[204]. In the context of my study, the use of BIA as an adjunct to the existing Trust's hydration assessment tool to detect low-intake dehydration in hospitalised older adults represents novel use of a pre-existing medical device, and therefore must be evaluated according to the tenets of the MRC framework (Figure 6.9).

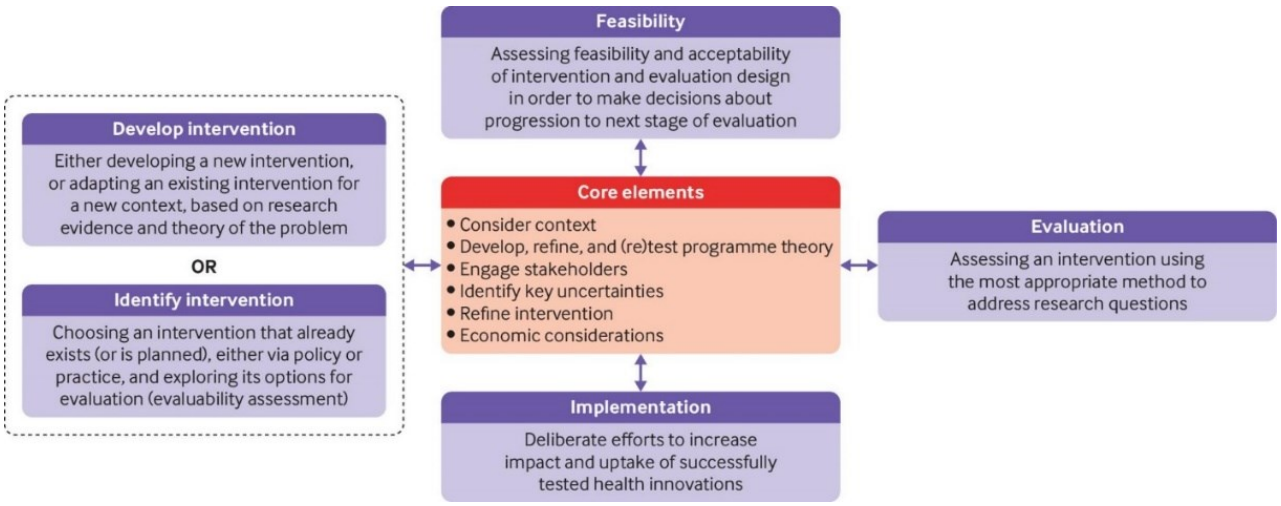


Figure 6.9 The MRC framework for developing and evaluating complex interventions. The present study explores feasibility and acceptability of the intervention. Adapted from Skivington, et al. [204]

Conducting a feasibility study allows to assess progression criteria related to either the evaluation design (such as reducing recruitment uncertainty, collecting data, retaining participants, and determining outcomes) or the intervention itself (such as acceptability, optimal delivery, cost effectiveness, or capability of care providers to deliver the intervention)[204]. As recruitment in clinical research can be difficult for novel interventions, feasibility studies need to evaluate recruitment potential and barriers[205,206]. In my feasibility study, the recruitment percentage was only 46.29%, and one of the major reasons for low recruitment from the eligible patient group was patient refusal (37.9%). It is also worth noting that the current admitted older patients are the most seriously ill due to the site's capacity and capabilities. As most patients on MOP wards are above 75 years of age, they are all at risk of dehydration. Whether they are dehydrated is dependent on diagnosis via objective measures such as serum osmolality, which was not available to be compared against.

Feasibility studies can also be used to estimate the sample size for further studies by determining the variance (i.e., standard deviation) of the outcome variable[206]. This is valid when the feasibility study is constructed to test both clinical outcomes and methodological components simultaneously and is a smaller-scale version of a large, randomised study[206]. The current study focuses on determining the acceptability of BIA and not on methodological components for a randomised trial to evaluate this intervention; consequently, pre-study sample size calculations are not reported. For the same reason, the current study focuses on descriptive statistics rather than hypothesis testing for effectiveness, due to the lack of a control arm and a powered sample size[206-208].

A major cause of eligible patient exclusion in my study was the presence of a skin condition such as rash on the site of electrode placement. Cutaneous infections, rashes, or altered skin temperature can alter electrical transmission between the skin and electrodes and can impact BIA results[209]. Geriatric patients have a high prevalence of dermatological conditions, especially dry skin, which can predispose to rashes and infections[210]. It is therefore important for staff to be able to recognise skin conditions that contraindicate BIA measurements, and future studies can also explore how to counteract this problem when performing BIA in a population where these conditions are highly prevalent. While conducting this study, I encountered problems with skin contact and electrode placement in 4 of the eligible patients; however, I resolved this after adjustment and replacement of the electrodes, and therefore the relevant data was not excluded from the analysis.

The feasibility of using BIA to detect hydration or nutritional status in clinical practice has been explored in different populations. A study conducted on the feasibility of using BIA for assessing hydration status and fluid distribution during the peri-operative period of acute high-risk abdominal (AHA) surgery showed a significant correlation between BIA measurements (such as absolute fluid overload), and cumulative fluid balance, changes in weight, and presence of post-operative clinical complications[211]. This study signifies an important role for BIA in assessing and guiding fluid management in the perioperative phase. Another population in which multifrequency BIA (MF-BIA) is recommended to assess body composition is patients undergoing maintenance haemodialysis[212]. A qualitative study exploring patient and staff perceptions to the use of BIA in this population found high levels of acceptability and patient satisfaction with the BIA measurement process: the measurements required minimal staff effort or burden and they motivated patients to change behaviours to maintain lean muscle mass[213]. However, the study highlighted perceived staff barriers towards BIA, such as knowledge of understanding and evaluating BIA data, and utilising scarce staffing resources for a new intervention. These concerns would also be applicable to the present study's geriatric population. Studies among older people have shown a high mean patient to registered nurse or healthcare assistant (HCA) ratio with low mean time for care[214]. This highlights the effect scarce staffing resources could have on the introduction of a new intervention.

Dehydration is also closely linked with frailty and malnutrition. Frailty in cognitively intact older adults has been linked with a higher risk of low-intake dehydration[215]. Dementia and cognitive impairment have also been linked with a higher prevalence of dehydration in older adult population[216]. The present study found similar findings, as frail patients or those with delirium were found more likely to have risk factors for severe dehydration and, therefore, were monitored more frequently using a 24-hour fluid balance chart. Malnutrition often overlaps with low-intake dehydration in older patients[108,217]; however, only a small subset of patients in this study had moderate or severe risk of malnutrition evidenced by MUST scoring, and therefore no significant association between the two could be determined.

As a secondary outcome, this study also explored correlation between BIA-measured direct and derived values of R_{50}, Xc_{50}, and PhA_{50}, with plasma osmolarity and risk categorisation on the hydration assessment tool but did not find any significant association. Dehydration is usually associated with high resistance and low reactance and phase angle values[29, 31]; measurements of R_{50}, Xc_{50} and PhA_{50} are independent of changes in body weight and regression equations, and therefore have less measurement and reporting bias compared to derived values which are body weight dependent. Also, raw BIA measurements can be carried out in situations in which BIA assumptions are not valid to estimate body fluid compartments and body composition[218]. Consequently, these direct measures are more valuable in critically ill patients as they do not rely on body weight and fluid homeostasis for their calculation[219].

Patient factors can also significantly influence BIA measurements. Age, biological sex, height and BMI are major patient factors influencing directly measured BIA variables. Bioimpedance measurements must be interpreted in the context of reference data and cut-off values for these patient factors. The current reference data utilised by the ImpediMed SFB7 device, used in this thesis, is based on results from a German database using a similar, but different impedance device, and stratifies values for phase angle and impedance vector components by age, biological sex, and BMI[202,203]. To account for these possible confounders, SDS values for resistance, reactance and phase angle were plotted against plasma osmolarity after stratifying the data for biological sex, as illustrated in figures. While significant variability was demonstrated by these plots, the current study was relatively underpowered to explore these effects, and a larger powered prospective study to compare these findings would be needed, especially if directly measured serum osmolality is utilised instead of calculated or predicted osmolarity for objective diagnosis of dehydration.

Current literature on phase angle changes during dehydration is conflicting: phase angle alone is insufficient for determining hydration state, and all BIA raw measures (reactance, resistance, and phase angle) should be interpreted simultaneously to get a better view of the hydration state[220].

Albeit from a small sample, this data trend in the feasibility study emphasises on the relationship between reactance and phase angle, which has been reported elsewhere as well[219].

A significant limitation of the current study was the lack of a confirmed diagnosis of dehydration at the time of initial data collection. At the time of initial data collection, patients had only been risk stratified for dehydration based on the trust's hydration risk assessment tool and had not been objectively diagnosed with dehydration based on serum osmolality values. Retrospective determination of osmolarity did not show any significant correlation of calculated osmolarity with the hydration risk categories, impressing the fact that the hydration assessment tool is only for screening purposes and cannot be used as a replacement for objective dehydration diagnosis via plasma osmolarity calculation. Furthermore, as the data for electrolyte values to determine osmolality values was collected retrospectively from patient records after this thesis project had been finished, there is a possibility that certain relevant patient factors, (such as transient hyperglycaemia contributing to raised osmolarity) could have affected the calculated osmolarity results. Data collection for this study was reliant on nursing assessment of hydration assessment and risk categorisation; this raises the possibility of patients having been misclassified. Moreover, it is also possible that patients who were deemed to be at higher risk of dehydration received extra prompting and care to drink more, thereby this may influence the impedance analysis results. These limitations are significant but do not influence the primary objectives of this feasibility study.

The present study also has other limitations. The causes for patient refusal from the eligible patient group were not explored due to study constraints. This feasibility study was an observational cross-sectional model with no comparator arm; furthermore, the small sample size precluded a validity and reliability analysis of BIA against current objective measures of determining dehydration. The feasibility study did not undertake any economic modelling to explore whether a full-scale randomised trial to evaluate the role of BIA in objectively determining dehydration in older adults would be beneficial enough to warrant the financial costs. Due to time constraints, this study could not incorporate a qualitative evaluability assessment of clinical staff to determine whether an intervention such as BIA would be feasible for staff to perform; whether they would accept a new intervention that could potentially be time consuming; what additional levels of training they would require to perform this intervention and interpret its results; and what perceived barriers they would face when implementing this intervention. Based on the feasibility study results, BIA-measured (R and Xc) and reported (PhA) values may offer insight into patients' hydration status; however, an adequately powered prospective observational study, which includes serum osmolality and a more secure reference range of normally hydrated individuals of the same age, gender, and BMI is required to determine how useful bioimpedance measures are for objective determination of dehydration. This is further explored as a proposed future study in the next chapter.

Nevertheless, this study also has strengths related to the quality of collected data. All included patients in the study were screened appropriately using the hydration risk assessment tool, and BIA with three consecutive measurements was performed successfully for all the patients, with the obtained data meeting the predefined acceptance/rejection criteria for secure impedance as per the rejection limit used by the software. This study highlights that BIA is an acceptable intervention for older patients admitted to MOP wards. A larger sample, early access to newly admitted patients for eligibility screening, and the use of quantitative measures of hydration such as serum osmolality would be required to determine the true association of BIA measured resistance, reactance, and phase angle with hydration status in these patients and to reduce any bias introduced by measures undertaken once the risk assessment is completed (such as rehydrating patients or encouraging high risk patients to drink more). Furthermore, performing bioimpedance vector analysis (BIVA) and determining changes in phase angle (PhA) from admission to different setpoints during hospital stay, especially at the time of discharge (i.e. Medically Optimised For Discharge (MOFD)), could further help in determining the true value of BIA for measuring low-intake dehydration in older adults. Comparison with a non-hospitalised and normally hydrating cohort from the community would also be important in this regard, as discussed later in future directions in the next chapter.

6.5 Conclusion

Dehydration is prevalent in older hospitalised patients and is associated with significant morbidity. Bioimpedance analysis is an acceptable modality for use in older patients to determine low-intake dehydration. Its use can be precluded by skin conditions at the site of electrode placement. BIA measures such as resistance, reactance, and phase angle do not depend on body weight and can be used for determining dehydration without risk of bias due to patient characteristics.

6.6 Key Insights of this Chapter

1. **Bioimpedance Analysis (BIA) Introduction:** The study introduces BIA, with a focus on Bioelectrical Impedance Spectroscopy (BIS) using the ImpediMed SFB7 device. It explores how BIA measures body resistance and reactance, and how the phase angle derived from these measurements could offer a more reliable indicator of hydration status compared to traditional methods.
2. **Prior Service Evaluation Study Outcomes (Chapter 3):** Previous service evaluation highlighted significant inconsistencies in the clinical practice of hydration assessment. This emphasises the need for improved, objective methods to accurately identify low-intake dehydration, particularly in older patients.
3. **Feasibility Study Aims:** The core objective was to evaluate the feasibility and acceptability of doing a study that would examine the concurrent measurement of hydration status in in hospitalised older adults through the use of BIA as an adjunct tool for identifying low-intake dehydration in older adults in Medicine for Older People (MOP) wards.
4. **Methodology and Recruitment Process:** The study adhered to specific inclusion and exclusion criteria for patient recruitment, focusing on consent and ethical considerations. The target minimum recruitment of 24 patients, recommended for feasibility trials, was exceeded with 25 patients recruited.
5. **Data Collection and Analysis Procedures:** The study involved data collection including demographic details, clinical data, and hydration status indicators. BIA measurements were taken thrice for each patient to ensure accuracy. Analysis focused on recruitment rate, data quality, and patient acceptance of the BIA procedure.
6. **Findings from Data Analysis:** Statistical analysis of the data revealed no significant association between BIA measurements and the trust's hydration assessment tool categorisation. The study explored correlations between BIA measurements and various clinical factors such as mobility status, malnutrition (MUST score), and frailty (CFS).
7. **Patient Acceptability of BIA:** High levels of patient acceptance for the BIA procedure were observed, indicating its potential feasibility for future application.
8. **Acknowledged Limitations and Future Research Directions:** The study acknowledges its limitations, including the absence of a control arm and the lack of objective dehydration measures such as directly measured plasma osmolality. The chapter suggests directions for future research to address these limitations.
9. **Conclusions:** The chapter concludes that BIA, while accepted and potentially effective for assessing dehydration in older hospitalised patients, requires further research to validate its efficacy and to facilitate its integration into clinical practice.

Chapter 7 General Discussion and Conclusion

This thesis has explored various facets of hydration assessment to diagnose low-intake dehydration in older patients on MOP wards. Dehydration in these patients is often overlooked but is a significant and preventable contributor towards numerous complications. While medical staff are cognisant of the importance of proper hydration assessment and care to prevent dehydration, they are often constrained by time and resources in providing adequate hydration care. Bioimpedance analysis is a bedside technique that can be utilised to assess and monitor changes in body water and electrolytes. However, evidence of the feasibility, acceptability, and clinical validity of BIA in comparison to gold-standard diagnostic tools for dehydration (serum osmolality) needs to be determined. While this study explored and found BIA to be feasible and acceptable by older patients, there is scope for further research with sufficient quality and power to determine the clinical validity of using directly determined BIA measures of phase angle, resistance and reactance to diagnose dehydration as well as to monitor its resolution in routine clinical practice.

7.1 Summary of the Project

This thesis project explored the current approaches to detecting low-intake dehydration in a cohort of medically fit for discharge older adult population on the MOP wards and the possible value of bioimpedance analysis in determining low-intake dehydration. Given the significant burden of dehydration in the older adult population, current means of determining dehydration, such as reliance on physical signs and symptoms or laboratory-measured indices, are unreliable and cannot be used to diagnose dehydration objectively. Plasma osmolality is currently considered a marker for confirming dehydration. However, directly measured osmolality is rarely performed on the MOP wards, and calculation of plasma osmolarity to diagnose dehydration is also often not determined even though the constituent biochemical measures are available. Caveats of these current means of determining dehydration were discussed in Chapter 2.

Chapter 3 of this thesis aimed to determine the current scale of low-intake dehydration on MOP wards based on the use of the pre-existing hydration risk assessment tools at University Hospital Southampton. It also qualitatively explored the factors attributing to the poor hydration status of older adults and the challenges staff face in diagnosing dehydration and preventing it. As a possible adjunct to the current means of determining the risk of dehydration, this thesis explored the role of bioimpedance analysis across chapters 4 and 5. While Chapter 4 provided a foundation for the basis of BIA in assessing hydration status, chapter 5 explored currently available literature systematically

to gather current evidence on the utility of BIA in determining low-intake dehydration in older adults in acute care settings and its diagnostic value.

With this rationale, a feasibility study was conducted on the MOP wards to determine whether it was feasible to conduct a study in a 'real-world' clinical setting that included BIA measurements concurrently alongside conventional routine approaches to screen for the risk of dehydration. There was a need to determine whether staff and patients on a busy ward would be willing to consent and participate in such a study and consider BIA measurements whilst they were receiving routine care. This feasibility study was needed to determine the possible numbers of patients who might meet the inclusion and exclusion criteria, those who would consent, and those in whom it was possible to obtain concurrent measures of clinical data, screening tool, and BIA measurements, as well as the likely effect size and variability to aid in the design of adequately powered studies in the future. The findings of this study, presented in Chapter 6, show that it was possible to conduct such a study, that the design and measures were acceptable for staff and patients, and that it would be feasible to use this approach in future studies of utility and effectiveness. This final chapter summarises the relevant findings of this thesis. It presents a methodology for such a future study and post-hoc power calculations to aid sample size determination and selection for future studies.

7.2 Interpretation of Study Findings in the Context of Available Literature

7.2.1 Current Approach for Screening and Identifying Dehydration

There is strong consensus within the European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines to screen all older people for low-intake dehydration whenever they encounter the healthcare system or if an unexpected change in clinical condition occurs; periodic screening should be undertaken if older people are malnourished or at risk of malnutrition[46]. This stems from observations that low-intake dehydration can affect 1 out of 4 older people[19] and leads to poorer outcomes in older people than those who are well-hydrated[221].

While the ESPEN guidelines recommend directly measured serum or plasma osmolality to diagnose low-intake dehydration, they also note that older adults or informal carers can use hydration risk assessment tools. However, periodic osmolality measurements should still be carried out concurrently[46,222]. Hydration risk assessment tools are frequently utilised in the NHS to screen for dehydration; risk categorisation is conducted, and patients are stratified as having no risk, low to moderate risk (requiring regular fluid monitoring charts), or high risk (requiring 24-hour fluid intake and output charts). This thesis describes a mixed-methods study (Chapter 3), the quantitative part of which assessed compliance on the Medicine for Older People (MOP) wards for timely completion of

the hydration risk assessment tool used in UHS, and what is currently being conducted on MOP wards. This service evaluation highlighted three aspects: firstly, serum osmolality was not highlighted anywhere in the hydration assessment tool or recorded in the patient notes; secondly, there was overall excellent compliance with completing the hydration chart for patients at moderate to severe risk (100% completion rate); and thirdly, patients who were identified at severe risk had a suboptimal record of monitoring via the 24-hour fluid balance chart (20% completion rate). As this was a service evaluation study, it did not evaluate the performance and accuracy of the hydration assessment tool against serum osmolality measurements for screening for dehydration. Indeed, the validity of such tools for screening for dehydration in older people is still being determined when compared with the ESPEN reference standard of osmolality[198].

Drawing on the service evaluation study (Chapter 3), it was clear that severely at-risk patients were receiving inadequate monitoring. This issue was evident in the low (20%) completion rate of the 24-hour fluid balance charts. Based on these findings, informal discussions were held with the MOP wards' clinical team, who acknowledged the gaps in hydration monitoring identified by the mixed-methods study. To address these gaps, a quality improvement (QI) protocol (Appendix R) was developed following discussions with Dr Edward Hewertson, a specialist in Quality Improvement and Hydration in the MOP department, focusing on enhancing the accuracy and completeness of record-keeping in MOP wards, specifically the thorough documentation of 24-hour fluid balance sheets for patients in critical dehydration categories. The protocol involves targeted training sessions for staff, emphasising the importance of complete and accurate record-keeping. As the protocol was developed near the end of the current PhD programme, it was fed back to my field supervisor, Dr Stephen Lim, so that it could be implemented into routine clinical practice to improve hydration care for older adults. Easy-to-follow guidelines for fluid balance sheets are anticipated to be introduced following this protocol alongside regular audits to ensure compliance with documentation standards. A supervisory system where senior staff periodically review records for completeness and accuracy will also be established. Spanning twelve months, this project would include phases of training, audits, feedback, and ongoing improvement using the Plan-Do-Study-Act (PDSA) model cycles for iterative testing of changes to improve the quality of systems[223,224]. Expected outcomes are enhanced documentation accuracy and completeness, improved patient care through better monitoring of hydration status, and a culture valuing precise record-keeping. Responsibilities are also divided among the Nursing/Dietitian Project lead, Nursing Staff and the Local QI team. This protocol could significantly enhance patient hydration care and documentation accuracy in MOP wards.

The qualitative section of the mixed-methods study in this thesis explored views and experiences of medical staff working on the MOP wards regarding hydration assessment, current standards of hydration care, and limitations towards the timely recognition and management of dehydration.

Medical staff were aware of common risk factors and symptoms of dehydration, as well as real-life contributing factors on MOP wards for dehydration and the consequent adverse effects such as delirium, acute kidney injury, and delayed discharge, While strategies to ensure hydration care such as ensuring provision and accessibility of fluids were present on the MOP wards, staff were constrained by the lack of standard diagnostic or evaluation tools, by difficulty in recognition of mild or early dehydration, and by patient factors and inadequacy of staff training and expertise to recognise, stratify, and prevent dehydration. Therefore, limitations exist in the current approach towards diagnosing and managing dehydration in MOP wards, as identified by the mixed-methods study, which triangulated and integrated study data from qualitative and quantitative analyses.

7.2.2 Possible role of Bioimpedance Analysis

The ESPEN guidelines advise against using bioelectrical impedance to assess hydration status in older adults as it has not yet been considered a diagnostic measure[46]. However, the evidence quoted in the guidelines comes only from a systematic review on water-loss dehydration, which analyses just five studies that utilised BIA[6]. This has several caveats: firstly, as acknowledged within the original systematic review, there is variability of device usage for conducting bioimpedance analysis between studies included in the review, which confounds any generalisable conclusion. Secondly, the included studies relied on estimated BIA parameters of total body water (TBW), intracellular fluid (ICF) and extracellular fluid (ECF), the calculation of which is reliant on assumptions which are frequently violated in sick and hospitalised patients as in the systematic review reported in chapter 5[225]. Only one of the five studies correlated total body resistance (TBR) directly measured by BIA with the evidence of fluid imbalance in long-term facility residents and found TBR to be comparable with clinical and laboratory findings in identifying the risk of hypovolaemia in long-term facility residents, who were mostly older people[182].

Largely randomised controlled trials using BIA are needed to assess low-intake dehydration in older adults. This lack of evidence underlies why BIA may have been dismissed for hydration status assessment without significant scientific evidence proving it may play a role in augmenting clinical decision-making. This presumption is further supported by small-scale studies: a population cohort study comparing the predictive value of hydration assessment using BIA versus biochemical parameters (blood urea nitrogen (BUN): creatinine ratio) for prolonged hospitalisation and poor discharge destination (other than home) in older patients with stroke or fragility fracture found BIA to accurately determine poor hydration status as well as better predict clinical outcomes or discharge destination for older adults compared with BUN/Creatinine[226]. While one study showed low concordance between clinical judgment and BIA for determining hydration status in acutely ill geriatric patients[220], this low concordance can be explained by the presence of electrolyte

abnormalities in older adults, which can influence BIA measurements independent of fluid changes and thus limit the application of predictive equations generated by whole-body BIA models[227]; as well as by the variance of body composition (in terms of fat mass and fat-free mass) in older adults, which can impact interpretation of TBW for determination of hydration status[228]. The systematic review reported in this thesis (Chapter 5) noted that current literature primarily emphasises the quantitative determination of TBW, ICF or ECF as fat-free body mass (FFM) or total body weight percentages to determine dehydration[29,155,192,193].

Bioimpedance Vector Analysis (BIVA) could also offer further insight as it is not dependent on variances in body composition and eliminates the assumptions used in regression equations or theoretical models to determine body water composition. Although BIVA was not used in the PhD programme due to time constraints and training, it utilises directly measured resistance and reactance values normalised for standing height. The values are plotted on a bivariate graph to calculate a vector: the length of this vector relates to fluid content. In contrast, the direction refers to the phase angle and indexes hydration status[229]. Since BIVA relies on classifying hydration by determining vector length from directly measured resistance and reactance values standardised for standing height, it does not have the caveats associated with using theoretical and predictive regression models for assessing hydration present in BIS or single-frequency BIA. The present thesis also utilises these directly measured values as opposed to predicted values for hydration measures, which can be limited by regression error of the prediction equation, technical errors in reference method, biological variability, and limitations of the bioelectrical volume model, and can under or over-estimate hydration[229]. BIVA has been utilised in clinical studies to stratify and differentiate older patients based on changes in their hydration status due to diseases or medications[230]. A study in critically ill patients determined that changes in phase angle and vector length determined by BIVA can partially reflect hydration status changes[219] and that changes in phase angle depend more on changes in reactance and less on changes in resistance, as shown in the feasibility study analysis (Chapter 6). BIVA has also been used to assess the direction of changes in fluid volume for correlating hydration status with physical signs and symptoms of advanced cancer, and it has shown increased symptom severity in lower states of hydration[231]. A neurologically impaired paediatric population study showed that bioelectrical characteristics identified by BIVA, such as increased resistance or reactance, were compatible with impaired hydration status and identified dehydration effectively compared to clinical and laboratory data[232].

BIVA has mainly been used in research studies, and there needs to be more real-world data of sufficient quality and power to compare its feasibility to determine hydration status, especially when compared to serum osmolality. BIVA does not directly quantify the degree of hydration as is the case with BIS and single-frequency BIA and only allows qualitative classification (under, standard, and

over-hydration) and ranking of change in hydration (i.e., more or less after treatment)[229]. Feasibility of clinical interventions depends on a multitude of factors: there must be a clear rationale to use a new intervention; the intervention must be valid and reliable with low variability of observations[204]; it must be acceptable to service users as well as staff members; it must be cost-effective against existing measures[204]; and its implementation should be evidence-based, leading to improved patient or public health outcomes[233]. BIVA needs to be evaluated for its feasibility and its benefit for patient care through further research[229].

The research reported in this thesis aimed to provide a rationale for using BIA and to assess the feasibility and acceptability of performing a study that would examine the use of BIA to identify low-intake dehydration in older adults in MOP wards in conjunction with the existing hydration risk assessment tool. BIA is a non-invasive bedside test making it easier and quicker to conduct and interpret than directly determining serum osmolality. BIA could also have implications in medicine for older people beyond the hospital, such as in care homes or residential facilities, as blood tests to determine serum osmolality may be less readily available in the community compared to hospitals.

This research showed that almost all older people admitted to MOP wards are at risk for moderate to severe dehydration. While a service evaluation study conducted in MOP wards showed that these patients are readily stratified based on their risk of dehydration on admission into MOP wards, the hydration assessment tool cannot diagnose dehydration. Adding BIA to this assessment would help to categorise patients as dehydrated or not dehydrated objectively and could also help confirm the resolution of dehydration in these patients. BIA was also found to be acceptable by all the participants: this is especially important as patients are more likely to be willing to undergo measurements they deem acceptable, which can impact overall clinical outcomes and the effectiveness of the intervention[234,235].

7.2.3 Challenges with BIA Use

No studies have explored the cost-effectiveness of using BIA as a bedside tool to determine dehydration. Dehydration is associated with substantive healthcare costs in older adults: it can lead to extended hospital stays and increased readmission rates. It can also contribute to increased severity of other diseases, leading to increased morbidity and mortality, which carry increased costs[236,237]. Any interventions leading to earlier recognition of dehydration could likely prevent these consequences, thereby decreasing overall healthcare costs resulting directly and indirectly from dehydration[237]. In the UK in 2015, excess healthcare costs from malnutrition and dehydration were estimated at over £13 billion per year[13]. BIA could potentially help offset these costs by better recognising and treating dehydration. A cost-effectiveness analysis for multifrequency BIA (MF-BIA) use in guiding fluid management in dialysis-dependent chronic kidney disease patients showed that

the probability of BIA-guided fluid management being cost-effective was 59% at a threshold of £20,000 per quality-adjusted life year (QALY) gained[238]. Determining the cost-effectiveness of BIA for dehydration recognition alone would require further large-scale studies in an older adult population.

Improving hydration is not directly listed as a quality indicator in the recent Commissioning for Quality and Innovation (CQUIN) 2022/23 Guidance[239]. However, specific quality indicators can be related to improving hydration, for instance, CCG8 (Supporting patients to drink, eat and mobilise as soon as possible after surgery) and PSS2 (Achieving high-quality Shared Decision-making (SDM)) conversations in specific specialised pathways to support recovery). Improved recognition of dehydration in older people can encourage staff to ensure adequate hydration measures for all admitted patients, and SDM in this regard involving nurses, dietitians, family members, carers, and doctors can enhance the recovery of these patients. It has been shown that hospital staff can often make assumptions regarding the ability of patients to eat or drink: a qualitative study in dementia patients showed that shared decision-making for hydration decisions can help to outline stepwise treatments and guide future decisions[240]. This presents another potential area where BIA-led bedside screening and diagnosis of dehydration can help inform decision-making around hydration. However, this also raises the question of healthcare professionals' acceptability of BIA.

Using BIA in MOP wards also poses some unique challenges. In contrast to other bedside devices such as ECG machines or cardiac monitors, BIA is separate from the routine training and education of nurses and other healthcare professionals. During the qualitative element of the mixed-methods analysis of hydration assessment in MOP wards (Chapter 3), staff training and experience emerged as a significant theme, alongside workplace and time constraints that all NHS staff face already. Implementing BIA would require additional staff training, dedicated time off work for training, competency assessment for using BIA, and ensuring staff can interpret BIA data to identify dehydration. Adding BIA as an adjunct to the hydration assessment tools used widely within the NHS would also need to be separately evaluated regarding staff perception and impact on workload and time management. In busy MOP wards where all patients would be categorised as being at risk of dehydration due to their age, feasibility studies would need to be undertaken to identify whether BIA should be used for every patient as part of routine assessment or for more select patient groups. These challenges are not unique to BIA: integrating any new intervention into clinical practice can be impacted by organisational factors, the level of responsiveness of intervention to the needs of the target population, issues associated with obtaining funding and a reasonable timeframe for implementation of the intervention[241].

7.3 Impact of Patient Factors on BIA Results

As discussed in Chapter 6, age, biological sex, height, and BMI are major patient factors influencing the directly measured BIA variables. Bioimpedance measurements need to be interpreted in the context of reference data and cut-off values for these patient factors, which are presented for the population cohort in the feasibility study in Chapter 6. Interestingly, these reference ranges do not account for ethnicity and only depict findings from one Western European population. Significant differences between phase angle values for various ethnic groups have been reported in the literature: African Americans and Hispanics reported higher reference phase angle values than Caucasians and Asians. However, this variance was non-significant after regression analysis accounted for age and sex[242]. Other studies have also demonstrated ethnic differences in phase angle cut-off values[243]. Recently, data has been needed to develop a large and diverse multi-country dataset of BIA raw measures[244]. Therefore, patient factors should also be considered before conclusions regarding the hydration status of individuals are made based on BIA results.

7.4 Strengths and Weaknesses

While the current thesis provides an overview of the current literature on BIA use for dehydration assessment and the feasibility of carrying out such a study in MOP wards in a large university hospital, it also has several limitations, mainly due to the constraints imposed by the COVID-19 pandemic. Due to the lack of literature on the role of raw BIA measures in assessing dehydration, there were no standardised values for these measures in dehydration adjusted for age, biological sex or BMI to compare the current data. Only a small sample size was assessed during the feasibility study, and a more extensive power study could highlight any significant relationships between patient characteristics and BIA measures. BIVA was not utilised due to a lack of evidence-based assessment of its role in objectively assessing dehydration in the current literature and due to time constraints and the required training. While conducting the feasibility study, simultaneous qualitative data collection from healthcare staff was not performed to consider whether BIA would be a suitable intervention in a busy MOP ward. The mixed-methods study and the feasibility study were conducted on one occasion within a single hospital, and so the findings are not necessarily transferable to other occasions, wards, or hospitals. Previous work has demonstrated that screening practices and the management of dehydration conducted on other hospitals show the same challenges.

Moreover, given the current cost-of-health crisis prevalent in the NHS, financial and economic modelling was not undertaken to determine the costs of BIA as a bedside assessment tool to identify dehydration. As highlighted previously, patients in the collected dataset were at risk but not

objectively diagnosed with dehydration. Therefore, a correlation between dehydration prevalence and BIA measures could not be performed.

However, this thesis also has several strengths. Due to the mixed-methods service evaluation study, a comprehensive overview of current hydration practices and staff knowledge, experiences and perceptions was recorded. Significant findings from the service evaluation led to developing a quality improvement protocol for assessing dehydration practice, which is expected to be implemented soon. Findings from the feasibility study highlighted that BIA is an acceptable intervention for older patients admitted to MOP wards. The following section explores future research directions to reinforce these findings and build a practical rationale for the utility of using both BIA and local hydration risk assessment tools in dehydration assessment and screening for older patients.

7.5 Future Work and Studies

The research reported in this thesis primarily focused on highlighting, through an extensive narrative and systematic literature review, as well as a mixed-methods study, that dehydration is highly prevalent in older adult patients admitted to MOP wards. Despite a dismissal of the role of BIA in screening and identifying dehydration in the ESPEN guidelines, directly measured and reported BIA values such as resistance, reactance, and phase angle have potential to be important determinants of dehydration. That research to measure their diagnostic validity is feasible and acceptable to patients. However, this present research uncovered several facets of BIA measurement in older people that have previously been underexamined and need to be explored by future research.

Future studies can utilise several methods to examine the role of BIA in determining the hydration status of older people. The first step in this direction could be directly comparing BIA measured and reported values of resistance, reactance, and phase angle versus serum osmolality to identify dehydration in this population cohort accurately. Currently, the sensitivity and specificity of BIA-measured values as a diagnostic tool against the gold standard measurement of serum osmolality are still being determined; this falls beyond the scope of the work reported in this thesis. Determining the reliability of BIA would be essential before it is evaluated for use in clinical settings, especially as a stand-alone measure.

There is no published and secured data on BIA value measures and serum osmolarity from normally hydrated population of older adults in the community. Based on presently available reference ranges from the Bosy and Westphal et al. data set[202,203], and the BIA findings from the current feasibility study, I conducted a theoretical post hoc power calculation using an online power calculator (https://clincalc.com/Stats/Power.aspx) to determine the sample size of an adequately powered future study to determine the reliability and validity of BIA values for phase angle compared against

serum osmolarity for diagnosing dehydration. Using endpoint mean values (for PhA50) from an ordinarily hydrated population aged >70 years (reference value taken from the Bosy and Westphal dataset) of 5.3 ± 0.8, as well as endpoint mean values from the current dataset of hospitalised older adults with mean PhA50 of 3.5 ± 0.8, I determined that a sample size of at least 40 participants would be required for each of two groups (control group of ordinarily hydrated individuals and case group of dehydrated older adults) to account for both changes in effect size (difference between both endpoint mean values) as well as changes in variability (standard deviation values for either endpoint mean).

Based on this sample size calculation, a future study should involve a reference group, and a group of hospitalised cases. The reference group can be selected from the community and includes older adults living in residential or nursing homes, sheltered accommodations, or in their own homes. The reference group should typically include hydrated individuals (as determined by serum osmolality). The participants should undergo simultaneous objective assessment of hydration status based on clinical signs and symptoms, measured serum osmolality, as well as BIA measured resistance, reactance, phase angle, and impedance ratio variables. The control group should include hospitalised older adults. This group should undergo an assessment using routine hydration assessment tools. It should also undergo testing for serum osmolality and BIA measurements at the time of hospital admission, after any intervention to correct dehydration (if diagnosed with dehydration), and at the point of discharge to the community. Doing so would allow us to determine the validity of BIA in determining dehydration by direct comparison with the gold standard of serum osmolality. It would also enable determining whether BIA can monitor or predict response to treatment for dehydration. These measurements on repeat occasions can allow a much more detailed comparison of the reliability and validity of BIA against serum osmolality. Once this data is collected, 2-way ANOVA can be analysed with repeated measures to determine any significant effects by group, over time, or significant effects based on both group and time. This data can also be used to assess the impact of individual characteristics such as age, biological sex, or BMI via post-hoc statistical analysis. The data can also be used to correlate impedance ratio with PhA50 to determine whether participants are well and usually hydrated or whether they are sick, dehydrated, or both.

Future studies should also determine factors that could confound BIA-measured values in older people. The present feasibility study explored if mobility status, clinical frailty, or increased risk of malnutrition could impact BIA measures: R50 values were strongly correlated with increasing frailty. In contrast, Xc50 was moderately correlated with increased malnutrition risk. Epidemiological studies should explore the impact of ethnicity, underlying disease conditions, effects of polypharmacy, and the role of environmental factors alongside known patient factors of BMI, age, and biological sex to determine possible confounders of BIA measurements for assessing hydration status.

BIA measurements in this thesis showed little inter-individual variability, highlighting their reproducibility. Since the measurements were all made on the same device in the feasibility study, future research can explore whether different devices exhibit significant variability when determining directly measured BIA variables. It would also be interesting to consider what possible adjustments can be made to make the use of BIA universal: some patients with skin conditions precluding wrist-ankle measurements can have ankle-ankle or wrist-wrist measurements undertaken, and the correlation between values from different electrode placement techniques should be examined as well.

A major next step would be determining the acceptance of BIA among nursing and other healthcare staff. Previous research has shown that significant challenges impede the implementation of evidence-based practices, such as lack of time and motivation, lack of resources and training, lack of skill to use evidence-based research findings, and lack of incentives[245]. As highlighted previously, nursing staff must be trained during their educational years to undertake BIA measurements. They will require formal training to use BIA which would add to the already excessive healthcare costs. Critical barriers to training nurses and healthcare professionals include staff shortages, poor provision of training and support, lack of IT literacy and infrastructure, and variability in management's support for staff training[246]. Under these circumstances, a separate feasibility analysis from a staff perspective would need to be undertaken to determine whether BIA can be implemented in MOP wards and whether this would be a time-efficient measure.

Future studies can audit current implementation standards for checking older people's serum osmolality to determine low-intake dehydration. Despite insistence from the ESPEN guidelines to check serum osmolality even in patients who are routinely screened using a hydration assessment tool, it is unclear how widely this standard is followed, and the current CQUIN guidance also needs to emphasise this screening. Low levels of compliance with implementing this standard could indicate underlying feasibility issues. They could offer an exciting insight into how BIA could better supplement the diagnosis of dehydration as an adjunct to hydration risk assessment tools because of its portability, ease of use, and non-invasive nature.

Finally, a cost-effectiveness assessment would also need to be undertaken. Early dehydration recognition and management could be cost saving as they could prevent unnecessary hospitalisations and increased morbidity in older people. However, given the current financial constraints faced by the NHS and the contention that technological change is a significant driver of increased economic cost[247,248], it would be essential to rationalise the benefits of using raw BIA measured and reported values backed by sound scientific evidence before a widespread implementation is planned.

7.6 Recommendations for Clinical Practice

This thesis explored various facets of current hydration assessment and management practices and the role of adjunct methods such as BIA in aiding these practices. Based on the findings, especially from the service evaluation (chapter 3) and the feasibility (chapter 6) studies, several recommendations can be made for clinicians caring for older people.

While screening for dehydration is routinely performed on MOP wards, results from the service evaluation study showed that this is only sometimes consistent. Furthermore, inconsistency was also noted when calculating the results of the hydration assessment tool. While the hydration risk assessment tool is simple and practical to use, staff may only sometimes be trained thoroughly to stratify patients correctly. This can lead to a delay in the recognition and management of dehydration. This thesis also noted that a formal diagnosis of low-intake dehydration was not recorded for patients: this increases the possibility that dehydration could be under-recognised, especially in older patients who often have multiple clinical issues. Therefore, clinicians should raise awareness regarding dehydration and try to implement local hydration assessment policies within the wards, similar to how venous thromboembolism (VTE) assessment is stressed.

Clinicians should also consider using directly measured serum osmolality or predicted serum osmolarity to diagnose low-intake dehydration in older people. Considerable evidence for this recommendation has been made by ESPEN guidelines. Auditing practises of hydration assessment, as recommended in section 7.5, as well as emphasising the importance of hydration assessment and prevention of dehydration in teaching sessions for healthcare professionals, is also an important step that clinicians can undertake. Given that all older adults, by default, are at risk of dehydration as assessed by the hydration risk assessment tool, clinical judgment is critical to distinguish between older adults who require encouragement to drink only versus those who may need assisted hydration support. Educating and training healthcare professionals to exercise this judgment can play an instrumental role in the clinical setting.

Clinical care's key focus on managing dehydration should revolve around whether recommendations are being followed, whether patients are consistently screened, whether screening leads to action and diagnosis, and whether actions taken effectively correct osmolality levels and fluid balance.

7.7 Conclusion

Older adults in MOP wards are at high risk of moderate to severe dehydration. While present tools to assess hydration used locally can stratify the risk of dehydration, they cannot objectively identify low-intake dehydration. The proposed addition of bioelectrical impedance analysis to hydration assessment on MOP wards was feasible and acceptable in the feasibility study conducted as part of this thesis. Studies with higher power and studies comparing BIA with the current standard of diagnosing dehydration, i.e., serum osmolality, need to be undertaken to determine the clinical applicability of BIA in diagnosing dehydration and determining dehydration resolution. This thesis also explored current service provision for hydration assessment on the MOP wards, as well as medical staff's knowledge and experience of hydration assessment and real-world issues encountered during dehydration assessment; based on these, a protocol for quality improvement in hydration assessment and care was developed which could be conducted by a dedicated researcher or a junior doctor, who could take this protocol forward and implement it.

List of References

1. Jéquier E, Constant F. Water as an essential nutrient: the physiological basis of hydration. *European journal of clinical nutrition* 2010;64(2):115-23.

2. Popkin BM, D'Anci KE, Rosenberg IH. Water, hydration, and health. *Nutrition reviews* 2010;68(8):439-58.

3. Delpire E, Gagnon KB. Water homeostasis and cell volume maintenance and regulation. *Current Topics in Membranes* 2018;81:3-52.

4. Hickson M, Bulpitt C, Nunes M, et al. Does additional feeding support provided by health care assistants improve nutritional status and outcome in acutely ill older in-patients?—a randomised control trial. *Clinical Nutrition* 2004;23(1):69-77.

5. Armstrong LE, Kavouras SA. Thirst and drinking paradigms: Evolution from single factor effects to brainwide dynamic networks. *Nutrients* 2019;11(12):2864.

6. Hooper L, Abdelhamid A, Attreed NJ, Campbell WW, Channell AM, Chassagne P, et al. Clinical symptoms, signs and tests for identification of impending and current water-loss dehydration in older people. Cochrane Database Syst Rev. 2015 Apr 9;(4).

7. Hodgkinson B, Evans D, Wood J. Maintaining oral hydration in older adults: a systematic review. *International journal of nursing practice* 2003;9(3):S19-S28.

8. Francis R. *Report of the Mid Staffordshire NHS Foundation Trust public inquiry: executive summary*: The Stationery Office; 2013.

9. El-Sharkawy AM, Watson P, Neal KR, et al. Hydration and outcome in older patients admitted to hospital (The HOOP prospective cohort study). *Age and ageing* 2015;44(6):943-47.

10. Paulis SJ, Everink IH, Halfens RJ, et al. Prevalence and risk factors of dehydration among nursing home residents: a systematic review. *Journal of the American Medical Directors Association* 2018;19(8):646-57.

11. Warren JL, Bacon WE, Harris T, et al. The burden and outcomes associated with dehydration among US elderly, 1991. *American journal of public health* 1994;84(8):1265-69.

12. Xiao H, Barber J, Campbell ES. Economic burden of dehydration among hospitalized elderly patients. *American Journal of Health-System Pharmacy* 2004;61(23):2534-40.

13. England NHS. Commissioning excellent nutrition and hydration 2015-2018. *A Report by NHS England* 2015.

14. Campbell N. Dehydration: why is it still a problem? *Nursing times* 2011;107(22):12-15.

15. van Dijk M, Cullum A, Swan G, et al. An overview of the Scientific Advisory Committee on Nutrition's position statement on nutrition and older adults living in the community. *British Journal of Nutrition* 2021;126(8):1164-67.

16. Care Quality Commission. Time to listen in NHS hospitals: dignity and nutrition inspection programme. *National Overview (London: Care Quality Commission, 2011)* 2013.

17. Lacey J, Corbett J, Forni L, et al. A multidisciplinary consensus on dehydration: definitions, diagnostic methods and clinical implications. *Annals of medicine* 2019;51(3-4):232-51.

18. Thomas DR, Cote TR, Lawhorne L, et al. Understanding clinical dehydration and its treatment. *Journal of the American Medical Directors Association* 2008;9(5):292-301.

19. Parkinson E, Hooper L, Fynn J, Wilsher SH, Oladosu T, Poland F, et al. Low-intake dehydration prevalence in non-hospitalised older adults: Systematic review and meta-analysis. Clin Nutr. 2023 Aug;42(8):1510-1520. doi: 10.1016/j.clnu.2023.06.010.

20. Hooper L, Bunn DK, Abdelhamid A, et al. Water-loss (intracellular) dehydration assessed using urinary tests: how well do they work? Diagnostic accuracy in older people. *The American journal of clinical nutrition* 2016;104(1):121-31.

21. Taylor K, Jones EB. Adult dehydration. 2020.

22. Khajuria A, Krahn J. Osmolality revisited—deriving and validating the best formula for calculated osmolality. *Clinical biochemistry* 2005;38(6):514-19.

23. Kyle UG, Bosaeus I, De Lorenzo AD, et al. Bioelectrical impedance analysis—part II: utilization in clinical practice. *Clinical Nutrition* 2004;23(6):1430-53.

24. Kant AK, Graubard BI, Atchison EA. Intakes of plain water, moisture in foods and beverages, and total water in the adult US population—nutritional, meal pattern, and body weight correlates: National Health and Nutrition Examination Surveys 1999–2006. *The American journal of clinical nutrition* 2009;90(3):655-63.

25. Vivanti A. Origins for the estimations of water requirements in adults. *European journal of clinical nutrition* 2012;66(12):1282-89.

26. Grandjean AC, Grandjean NR. Dehydration and cognitive performance. *Journal of the American College of Nutrition* 2007;26(sup5):549S-54S.

27. Kyle UG, Bosaeus I, De Lorenzo AD, et al. Bioelectrical impedance analysis—part I: review of principles and methods. *Clinical Nutrition* 2004;23(5):1226-43.

28. Wells J, Fewtrell M, Davies P, et al. Prediction of total body water in infants and children. *Archives of disease in childhood* 2005;90(9):965-71.

29. Jones SL, Tanaka A, Eastwood GM, et al. Bioelectrical impedance vector analysis in critically ill patients: a prospective, clinician-blinded investigation. *Critical Care* 2015;19(1):1-11.

30. Ugras S. Evaluating of altered hydration status on effectiveness of body composition analysis using bioelectric impedance analysis. *Libyan Journal of Medicine* 2020;15(1).

31. Goldberg LR, Heiss CJ, Parsons SD, et al. Hydration in older adults: The contribution of bioelectrical impedance analysis. *International Journal of Speech-Language Pathology* 2014;16(3):273-81.

32. Häussinger D. The role of cellular hydration in the regulation of cell function. *Biochemical Journal* 1996;313(Pt 3):697.

33. Ritz P, Berrut G. The importance of good hydration for day-to-day health. *Nutrition reviews* 2005;63(suppl_1):S6-S13.

34. Montain SJ, Latzka WA, Sawka MN. Fluid replacement recommendations for training in hot weather. *Military medicine* 1999;164(7):502-08.

35. Wang Z, Deurenberg P, Wang W, et al. Hydration of fat-free body mass: review and critique of a classic body-composition constant. *The American journal of clinical nutrition* 1999;69(5):833-41.

36. Chumlea WC, Guo SS, Zeller CM, et al. Total body water data for white adults 18 to 64 years of age: the Fels Longitudinal Study. *Kidney international* 1999;56(1):244-52.

37. Rondon-Berrios H, Berl T. Physiology and pathophysiology of water homeostasis. *Disorders of Fluid and Electrolyte Metabolism* 2019;52:8-23.

38. Valtin H. "Drink at least eight glasses of water a day." Really? Is there scientific evidence for "8× 8"? *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 2002.

39. Hoenig MP, Zeidel ML. Homeostasis, the milieu interieur, and the wisdom of the nephron. *Clinical Journal of the American Society of Nephrology* 2014;9(7):1272-81.

40. Rohrscheib M, Argyropoulos C, Rondon-Berrios H, et al. Indices of serum tonicity in clinical practice. *The American Journal of the Medical Sciences* 2015;349(6):537-44.

41. Geirsdóttir ÓG, Bell JJ. *Interdisciplinary Nutritional Management and Care for Older Adults: An Evidence-Based Practical Guide for Nurses*: Springer Nature; 2021.

42. McHugh D, Gil J. Senescence and aging: Causes, consequences, and therapeutic avenues. *Journal of Cell Biology* 2018;217(1):65-77.

43. Phillips PA, Rolls BJ, Ledingham JG, et al. Reduced thirst after water deprivation in healthy elderly men. *New England Journal of Medicine* 1984;311(12):753-59.

44. Stachenfeld NS, DiPietro L, Nadel ER, et al. Mechanism of attenuated thirst in aging: role of central volume receptors. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 1997;272(1):R148-R57.

45. Brennan M, O'Keeffe ST, Mulkerrin EC. Dehydration and renal failure in older persons during heatwaves-predictable, hard to identify but preventable? *Age and ageing* 2019;48(5):615-18.

46. Volkert D, Beck AM, Cederholm T, et al. ESPEN guideline on clinical nutrition and hydration in geriatrics. *Clinical Nutrition* 2019;38(1):10-47.

47. Zizza CA, Ellison KJ, Wernette CM. Total water intakes of community-living middle-old and oldest-old adults. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences* 2009;64(4):481-86.

48. Picetti D, Foster S, Pangle AK, et al. Hydration health literacy in the elderly. *Nutrition and healthy aging* 2017;4(3):227-37.

49. Drewnowski A, Rehm CD, Constant F. Water and beverage consumption among adults in the United States: cross-sectional study using data from NHANES 2005–2010. *BMC public health* 2013;13(1):1-9.

50. Manz F, Wentz A, Sichert-Hellert W. The most essential nutrient: defining the adequate intake of water. *The Journal of pediatrics* 2002;141(4):587-92.

51. Stookey JD. Analysis of 2009–2012 nutrition health and examination survey (NHANES) data to estimate the median water intake associated with meeting hydration criteria for individuals aged 12–80 years in the US population. *Nutrients* 2019;11(3):657.

52. British Dietetic Association (BDA). *Hydration matters*. https://www.bda.uk.com/resource/hydration-matters.html (accessed 5th Oct 2022).

53. Chidester JC, Spangler AA. Fluid intake in the institutionalized elderly. *Journal of the American Dietetic Association* 1997;97(1):23-28.

54. Holben DH, Hassell JT, Williams JL, et al. Fluid intake compared with established standards and symptoms of dehydration among elderly residents of a long-term-care facility. *Journal of the Academy of Nutrition and Dietetics* 1999;99(11):1447.

55. Crecelius C. Dehydration: Myth and reality. *Journal of the American Medical Directors Association* 2008;9(5):287-88.

56. Van Regenmortel N, De Weerdt T, Van Craenenbroeck A, et al. Effect of isotonic versus hypotonic maintenance fluid therapy on urine output, fluid balance, and electrolyte homeostasis: a crossover study in fasting adult volunteers. *BJA: British Journal of Anaesthesia* 2017;118(6):892-900.

57. Mange K, Matsuura D, Cizman B, et al. Language guiding therapy: the case of dehydration versus volume depletion. *Annals of internal medicine* 1997;127(9):848-53.

58. Peeters G, Jones M, Byles J, et al. Long-term consequences of noninjurious and injurious falls on well-being in older women. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences* 2015;70(12):1519-25.

59. Bu F, Abell J, Zaninotto P, et al. A longitudinal analysis of loneliness, social isolation and falls amongst older people in England. *Scientific reports* 2020;10(1):1-8.

60. Tariq H, Kloseck M, Crilly RG, et al. An exploration of risk for recurrent falls in two geriatric care settings. *BMC geriatrics* 2013;13(1):1-7.

61. Fu WW, Fu TS, Jing R, et al. Predictors of falls and mortality among elderly adults with traumatic brain injury: a nationwide, population-based study. *PloS one* 2017;12(4):e0175868.

62. Hamrick I, Norton D, Birstler J, et al. Association between dehydration and falls. *Mayo Clinic Proceedings: Innovations, Quality & Outcomes* 2020;4(3):259-65.

63. Pak CY, Sakhaee K, Crowther C, et al. Evidence justifying a high fluid intake in treatment of nephrolithiasis. *Annals of internal medicine* 1980;93(1_Part_1):36-39.

64. Embon O, Rose G, Rosenbaum T. Chronic dehydration stone disease. *British journal of urology* 1990;66(4):357-62.

65. Soucie JM, Coates RJ, McClellan W, et al. Relation between geographic variability in kidney stones prevalence and risk factors for stones. *American journal of epidemiology* 1996;143(5):487-95.

66. Borghi L, Meschi T, Amato F, et al. Hot occupation and nephrolithiasis. *The Journal of urology* 1993;150(6):1757-60.

67. Siener R, Hesse A. Fluid intake and epidemiology of urolithiasis. *European journal of clinical nutrition* 2003;57(2):S47-S51.

68. Beetz R. Mild dehydration: a risk factor of urinary tract infection? *European journal of clinical nutrition* 2003;57(2):S52-S58.

69. Girard R, Gaujard S, Pergay V, et al. Risk factors for urinary tract infections in geriatric hospitals. *Journal of Hospital Infection* 2017;97(1):74-78.

70. Lean K, Nawaz RF, Jawad S, et al. Reducing urinary tract infections in care homes by improving hydration. *BMJ open quality* 2019;8(3):e000563.

71. Booth J, Agnew R. Evaluating a hydration intervention (DRInK Up) to prevent urinary tract infection in care home residents: A mixed methods exploratory study. *Journal of frailty, sarcopenia and falls* 2019;4(2):36.

72. Scott AM, Clark J, Del Mar C, et al. Increased fluid intake to prevent urinary tract infections: systematic review and meta-analysis. *British Journal of General Practice* 2020;70(692):e200-e07.

73. Roncal-Jimenez C, Lanaspa M, Jensen T, et al. Mechanisms by which dehydration may lead to chronic kidney disease. *Annals of Nutrition and Metabolism* 2015;66(Suppl. 3):10-13.

74. Correa-Rotter R, Wesseling C, Johnson RJ. CKD of unknown origin in Central America: the case for a Mesoamerican nephropathy. *American journal of kidney diseases* 2014;63(3):506-20.

75. Laws RL, Brooks DR, Amador JJ, et al. Changes in kidney function among Nicaraguan sugarcane workers. *International journal of occupational and environmental health* 2015;21(3):241-50.

76. Forootan M, Bagheri N, Darvishi M. Chronic constipation: A review of literature. *Medicine* 2018;97(20).

77. Tack J, Müller-Lissner S, Stanghellini V, et al. Diagnosis and treatment of chronic constipation–a European perspective. *Neurogastroenterology & Motility* 2011;23(8):697-710.

78. Arnaud M. Mild dehydration: a risk factor of constipation? *European journal of clinical nutrition* 2003;57(2):S88-S95.

79. Andrews CN, Storr M. The pathophysiology of chronic constipation. *Canadian Journal of Gastroenterology* 2011;25(Suppl B):16B-21B.

80. Sandle G. Salt and water absorption in the human colon: a modern appraisal. *Gut* 1998;43(2):294-99.

81. Dinning P, Smith T, Scott S. Pathophysiology of colonic causes of chronic constipation. *Neurogastroenterology & Motility* 2009;21:20-30.

82. George J, Rockwood K. Dehydration and delirium—Not a simple relationship. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 2004;59(8):M811-M12.

83. Wilson M, Morley J. Impaired cognitive function and mental performance in mild dehydration. *European journal of clinical nutrition* 2003;57(2):S24-S29.

84. Sfera A, Cummings M, Osorio C. Dehydration and cognition in geriatrics: a hydromolecular hypothesis. *Frontiers in molecular biosciences* 2016;3:18.

85. Yang M, Gao F, Liu H, et al. Hyperosmotic induction of aquaporin expression in rat astrocytes through a different MAPK pathway. *Journal of cellular biochemistry* 2013;114(1):111-19.

86. Thrane AS, Thrane VR, Nedergaard M. Drowning stars: reassessing the role of astrocytes in brain edema. *Trends in neurosciences* 2014;37(11):620-28.

87. Reyes-Haro D, Labrada-Moncada FE, Miledi R, et al. Dehydration-induced anorexia reduces astrocyte density in the rat corpus callosum. *Neural Plasticity* 2015;2015.

88. Riebl SK, Davy BM. The hydration equation: update on water balance and cognitive performance. *ACSM's health & fitness journal* 2013;17(6):21.

89. Nakamura K, Brown RA, Araujo D, et al. Correlation between brain volume change and T2 relaxation time induced by dehydration and rehydration: implications for monitoring atrophy in clinical studies. *NeuroImage: Clinical* 2014;6:166-70.

90. Streitbürger D-P, Möller HE, Tittgemeyer M, et al. Investigating structural brain changes of dehydration using voxel-based morphometry. 2012.

91. Zhao L, Li W, Tian P. Reconciling mediating and slaving roles of water in protein conformational dynamics. *PloS one* 2013;8(4):e60553.

92. Sen S, Voorheis HP. Protein folding: Understanding the role of water and the low Reynolds number environment as the peptide chain emerges from the ribosome and folds. *Journal of Theoretical Biology* 2014;363:169-87.

93. Stoppini M, Obici L, Lavatelli F, et al. Proteomics in protein misfolding diseases. *Clinical chemistry and laboratory medicine* 2009;47(6):627-35.

94. Guppy MP, Mickan SM, Del Mar CB, et al. Advising patients to increase fluid intake for treating acute respiratory infections. *Cochrane Database of Systematic Reviews* 2011(2).

95. Dreyfuss D, Leviel F, Paillard M, et al. Acute infectious pneumonia is accompanied by a latent vasopressin-dependent impairment of renal water excretion. *Am Rev Respir Dis* 1988;138(3):583-89.

96. Guppy MP, Mickan SM, Del Mar CB. "Drink plenty of fluids": a systematic review of evidence for this recommendation in acute respiratory infections. *BMJ* 2004;328(7438):499-500.

97. Zanin M, Baviskar P, Webster R, et al. The interaction between respiratory pathogens and mucus. *Cell host & microbe* 2016;19(2):159-68.

98. Russell MW, Moldoveanu Z, Ogra PL, et al. Mucosal immunity in COVID-19: a neglected but critical aspect of SARS-CoV-2 infection. *Frontiers in immunology* 2020:3221.

99. Noti JD, Blachere FM, McMillen CM, et al. High humidity leads to loss of infectious influenza virus from simulated coughs. *PloS one* 2013;8(2):e57485.

100. Stookey JD, Allu PK, Chabas D, et al. Hypotheses about sub-optimal hydration in the weeks before coronavirus disease (COVID-19) as a risk factor for dying from COVID-19. *Medical Hypotheses* 2020;144:110237.

101. Redant S, Vanderhulst J, Maillart E, et al. Significance of hypernatremia due to SARS-CoV-2 associated ARDS in critically ill patients. *Journal of Translational Internal Medicine* 2020;8(4):255-60.

102. Pirard P, Vandentorren S, Pascal M, et al. Summary of the mortality impact assessment of the 2003 heat wave in France. *Eurosurveillance* 2005;10(7):7-8.

103. Maughan RJ. Hydration, morbidity, and mortality in vulnerable populations. *Nutrition reviews* 2012;70(suppl_2):S152-S55.

104. Office for National Statistics. Deaths involving dehydration for 2011 to 2021 in England and Wales [Internet]. Available from: https://www.ons.gov.uk/aboutus/transparencyandgovernance/freedomofinformationfoi/deathsinvolvingdehydrationfor2011to2021inenglandandwales. Accessed 7th Oct 2022.

105. Mandal M. Ideal resuscitation fluid in hypovolemia: The quest is on and miles to go! *International Journal of Critical Illness and Injury Science* 2016;6(2):54.

106. El-Sharkawy AM, Sahota O, Lobo DN. Acute and chronic effects of hydration status on health. *Nutrition reviews* 2015;73(suppl_2):97-109.

107. Sakakibara R, Kishi M, Ogawa E, et al. Dehydration encephalopathy: A neurological emergency in the older adults. *Journal of the American Geriatrics Society* 2010;58(9):1819-21.

108. Beck AM, Seemer J, Knudsen AW, et al. Narrative review of low-intake dehydration in older adults. *Nutrients* 2021;13(9):3142.

109. Falszewska A, Szajewska H, Dziechciarz P. Diagnostic accuracy of three clinical dehydration scales: a systematic review. *Archives of disease in childhood* 2018;103(4):383-88.

110. Shirreffs SM. Markers of hydration status. *European journal of clinical nutrition* 2003;57(2):S6-S9.

111. Pinnington S, Ingleby S, Hanumapura P, Waring D. Assessing and documenting fluid balance. Nurs Stand. 2016 Dec 7;31(15):46-54. doi:10.7748/ns.2016.e10432.

112. Shepherd A. Measuring and managing fluid balance. *Nursing times* 2011;107(28):12-16.

113. Perrier E, Vergne S, Klein A, et al. Hydration biomarkers in free-living adults with different levels of habitual fluid consumption. *British Journal of Nutrition* 2013;109(9):1678-87.

114. Cheuvront SN, Kenefick RW, Charkoudian N, et al. Physiologic basis for understanding quantitative dehydration assessment. *The American journal of clinical nutrition* 2013;97(3):455-62.

115. Cheuvront SN, Ely BR, Kenefick RW, et al. Biological variation and diagnostic accuracy of dehydration assessment markers. *The American journal of clinical nutrition* 2010;92(3):565-73.

116. Bohnen N, Terwel D, Markerink M, et al. Pitfalls in the measurement of plasma osmolality pertinent to research in vasopressin and water metabolism. *Clinical chemistry* 1992;38(11):2278-80.

117. Masood Ashraf M, Rea R. Effect of dehydration on blood tests. *Practical Diabetes* 2017;34(5).

118. Hayuanta HH. Can hemoglobin-hematocrit relationship be used to assess hydration status? *Cermin Dunia Kedokteran* 2016;43(2):139-42.

119. Oates LL, Price CI. Clinical assessments and care interventions to promote oral hydration amongst older patients: a narrative systematic review. *BMC nursing* 2017;16(1):1-15.

120. Litchfield I, Magill L, Flint G. A qualitative study exploring staff attitudes to maintaining hydration in neurosurgery patients. *Nursing Open* 2018;5(3):422-30.

121. Vaughn VM, Szymczak JE, Newton DW, et al. Addressing the overuse of cultures to optimize patient care. *Annals of internal medicine* 2019;171(7_Supplement):S73-S74.

122. Lee K, Lee S, Lim J, et al. Providing essential clinical care for non-COVID-19 patients in a Seoul metropolitan acute care hospital amidst ongoing treatment of COVID-19 patients. *Journal of Hospital Infection* 2020;106(4):673-77.

123. Shells R, Morrell-Scott N. Prevention of dehydration in hospital patients. *British Journal of Nursing* 2018;27(10):565-69.

124. Wham C, Smithers A, Kruger R, et al. Factors associated with low-intake dehydration among older inpatients: A pilot study. *Australasian Journal on Ageing* 2021;40(2):e163-e72.

125. Bunn DK, Hooper L. Signs and symptoms of low-intake dehydration do not work in older care home residents—DRIE diagnostic accuracy study. *Journal of the American Medical Directors Association* 2019;20(8):963-70.

126. Wojszel ZB. Impending low intake dehydration at admission to a geriatric ward-prevalence and correlates in a cross-sectional study. *Nutrients* 2020;12(2):398.

127. Campbell N. Innovations to support hydration care across health and social care. *British Journal of Community Nursing* 2016;21(Sup7):S24-S29.

128. Clark VLP, Creswell JW, Green DON, et al. Mixing quantitative and qualitative approaches. *Handbook of emergent methods* 2008;363:363-87.

129. Clark VLP, Ivankova NV. *Mixed methods research: A guide to the field*: Sage publications; 2015.

130. Ivankova NV, Greer JL. Mixed methods research and analysis. *Research methods in applied linguistics: A practical resource* 2015:63-81.

131. Creswell JW, Clark VLP. *Designing and conducting mixed methods research*: Sage publications; 2017.

132. Tashakkori A, Teddlie C. *Sage handbook of mixed methods in social & behavioral research*: SAGE publications; 2021.

133. Ivankova NV, Creswell JW, Stick SL. Using mixed-methods sequential explanatory design: From theory to practice. *Field methods* 2006;18(1):3-20.

134. Langer G. Probability versus non-probability methods. *The Palgrave handbook of survey research* 2018:351-62.

135. Clarke V, Braun V. Thematic analysis: a practical guide. *Thematic Analysis* 2021:1-100.

136. Brinkmann S. Unstructured and semi-structured interviewing. *The Oxford handbook of qualitative research* 2014;2:277-99.

137. Kallio H, Pietilä AM, Johnson M, et al. Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of advanced nursing* 2016;72(12):2954-65.

138. Hilal AH, Alabri SS. Using NVivo for data analysis in qualitative research. *International interdisciplinary journal of education* 2013;2(2):181-86.

139. Mortelmans D. Analyzing qualitative data using NVivo. *The Palgrave handbook of methods for media policy research* 2019:435-50.

140. Braun V, Clarke V. Using thematic analysis in psychology. *Qualitative research in psychology* 2006;3(2):77-101.

141. Morris PL. The SAGE Encyclopedia of Communication Research Methods. Thousand Oaks, California: SAGE Publications, Inc; 2017. https://sk.sagepub.com/reference/the-sage-encyclopedia-of-communication-research-methods.

142. Creswell JW, Creswell JD. *Research design: Qualitative, quantitative, and mixed methods approaches*: Sage publications; 2017.

143. Noble H, Heale R. Triangulation in research, with examples: Royal College of Nursing, 2019:67-68.

144. Thurmond VA. The point of triangulation. *Journal of nursing scholarship* 2001;33(3):253-58.

145. O'brien C, Young A, Sawka M. Bioelectrical impedance to estimate changes in hydration status. *International journal of sports medicine* 2002;23(05):361-66.

146. Thomasset M. Bioelectric properties of tissue. Impedance measurement in clinical medicine. Significance of curves obtained. *Lyon medical* 1962;94:107-18.

147. Hoffer EC, Meador CK, Simpson DC. Correlation of whole-body impedance with total body water volume. *Journal of applied physiology* 1969;27(4):531-34.

148. Carlson-Newberry SJ, Costello RB. Bioelectrical impedance: A history, research issues, and recent consensus. *Emerging Technologies for Nutrition Research: Potential for Assessing Military Performance Capability* 1997.

149. Medical Research Council. *Bioelectric impedance analysis*. https://dapa-toolkit.mrc.ac.uk/anthropometry/objective-methods/bioelectric-impedence-analysis (accessed 10th July 2022).

150. Mulasi U, Kuchnia AJ, Cole AJ, et al. Bioimpedance at the bedside: current applications, limitations, and opportunities. *Nutrition in Clinical Practice* 2015;30(2):180-93.

151. Kyle UG, Soundar EP, Genton L, et al. Can phase angle determined by bioelectrical impedance analysis assess nutritional risk? A comparison between healthy and hospitalized subjects. *Clinical Nutrition* 2012;31(6):875-81.

152. Cannon T, Choi J. Development of a segmental bioelectrical impedance spectroscopy device for body composition measurement. *Sensors* 2019;19(22):4825.

153. Itobi E, Stroud M, Elia M. Impact of oedema on recovery after major abdominal surgery and potential value of multifrequency bioimpedance measurements. *Journal of British Surgery* 2006;93(3):354-61.

154. Valdespino-Trejo A, Orea-Tejeda A, Castillo-Martínez L, et al. Low albumin levels and high impedance ratio as risk factors for worsening kidney function during hospitalization of decompensated heart failure patients. *Experimental & Clinical Cardiology* 2013;18(2):113.

155. Powers JS, Choi L, Bitting R, et al. Rapid measurement of total body water to facilitate clinical decision making in hospitalized elderly patients. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences* 2009;64(6):664-69.

156. Hannan W, Cowen S, Plester C, et al. Comparison of bio-impedance spectroscopy and multi-frequency bio-impedance analysis for the assessment of extracellular and total body water in surgical patients. *Clinical science (London, England: 1979)* 1995;89(6):651-58.

157. Rikkert MGO, Deurenberg P, Jansen RW, et al. Validation of multi-frequency bioelectrical impedance analysis in detecting changes in fluid balance of geriatric patients. *Journal of the American Geriatrics Society* 1997;45(11):1345-51.

158. De Lorenzo A, Deurenberg P, Andreoli A, et al. Multifrequency impedance in the assessment of body water losses during dialysis. *Kidney and Blood Pressure Research* 1994;17(6):326-32.

159. Gudivaka R, Schoeller D, Kushner R, et al. Single-and multifrequency models for bioelectrical impedance analysis of body water compartments. *Journal of applied physiology* 1999;87(3):1087-96.

160. Scharfetter H, Wirnsberger G, Holzer H, et al. Influence of ionic shifts during dialysis on volume estimations with multifrequency impedance analysis. *Medical and Biological Engineering and Computing* 1997;35(2):96-102.

161. Martinoli R, Mohamed E, Maiolo C, et al. Total body water estimation using bioelectrical impedance: a meta-analysis of the data available in the literature. *Acta diabetologica* 2003;40(1):s203-s06.

162. Ellis KJ, Bell SJ, Chertow GM, et al. Bioelectrical impedance methods in clinical research: a follow-up to the NIH Technology Assessment Conference. *Nutrition* 1999;15(11-12):874-80.

163. Ward L, Heitmann B. Assessment of body composition by bioelectrical impedance analysis without the need for measurement of height. *Clinical Nutrition* 2001;20(1):21-26.

164. Ward LC. Bioelectrical impedance analysis for body composition assessment: reflections on accuracy, clinical utility, and standardisation. *European journal of clinical nutrition* 2019;73(2):194-99.

165. Trutschnigg B, Kilgour RD, Reinglas J, et al. Precision and reliability of strength (Jamar vs. Biodex handgrip) and body composition (dual-energy X-ray absorptiometry vs. bioimpedance analysis) measurements in advanced cancer patients. *Applied Physiology, Nutrition, and Metabolism* 2008;33(6):1232-39.

166. Barbosa-Silva MCG, Barros AJ. Bioelectrical impedance analysis in clinical practice: a new perspective on its use beyond body composition equations. *Current Opinion in Clinical Nutrition & Metabolic Care* 2005;8(3):311-17.

167. van Venrooij LM, de Vos R, Zijlstra E, et al. The impact of low preoperative fat-free body mass on infections and length of stay after cardiac surgery: a prospective cohort study. *The Journal of thoracic and cardiovascular surgery* 2011;142(5):1263-69.

168. Haverkort EB, Binnekade JM, de van der Schueren MA, et al. Estimation of body composition depends on applied device in patients undergoing major abdominal surgery. *Nutrition in Clinical Practice* 2015;30(2):249-56.

169. Czerniec SA, Ward LC, Lee M-J, et al. Segmental measurement of breast cancer-related arm lymphoedema using perometry and bioimpedance spectroscopy. *Supportive Care in Cancer* 2011;19(5):703-10.

170. Ward LC. Bioelectrical impedance analysis: proven utility in lymphedema risk assessment and therapeutic monitoring. *Lymphatic research and biology* 2006;4(1):51-56.

171. Jaeger JQ, Mehta RL. Assessment of dry weight in hemodialysis: an overview. *Journal of the American Society of Nephrology* 1999;10(2):392-403.

172. Schneditz D. The arrow of bioimpedance. *Kidney international* 2006;69(9):1492-93.

173. Pollock A, Berge E. How to do a systematic review. *International Journal of Stroke* 2018;13(2):138-56.

174. Cowell JM. Importance of peer review: Sage Publications Sage CA: Los Angeles, CA, 2014:394-95.

175. Šimundić A-M. Measures of diagnostic accuracy: basic definitions. *ejifcc* 2009;19(4):203.

176. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Journal of clinical epidemiology* 2009;62(10):e1-e34.

177. Page MJ, McKenzie JE, Bossuyt PM, et al. Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *Journal of clinical epidemiology* 2021;134:103-12.

178. The Cochrane Collaboration. *Data extraction forms*. https://dplp.cochrane.org/data-extraction-forms (accessed 4th May 2022).

179. Higgins JP, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 2011;343.

180. Hinneburg I. ROBINS-1: A tool for asssessing risk of bias in non-randomised studies of interventions. *Medizinische Monatsschrift fur Pharmazeuten* 2017;40(4):175-77.

181. Lisy K, Porritt K. Narrative synthesis: considerations and challenges. *JBI Evidence Implementation* 2016;14(4):201.

182. Allison RD, Lewis AR, Liedtke R, et al. Early identification of hypovolemia using total body resistance measurements in long-term care facility residents. *Gender medicine* 2005;2(1):19-34.

183. Buffa R, Mereu R, Putzu P, et al. Bioelectrical impedance vector analysis detects low body cell mass and dehydration in patients with Alzheimer's disease. *The journal of nutrition, health & aging* 2010;14:823-27.

184. Gaspar PM. Comparison of four stadards for determining adequate water intake of nursing home residents. *Research and theory for nursing practice* 2011;25(1):11-22.

185. Shimizu M, Kinoshita K, Maeno T, et al. Can Total Body Resistance Measured Using Bioelectrical Impedance Analysis Be the Index of Dehydration in Older Japanese Patients? *Journal of Clinical Medicine Research* 2017;9(11):926.

186. Stookey JD. High prevalence of plasma hypertonicity among community-dwelling older adults: results from NHANES III. *Journal of the American Dietetic Association* 2005;105(8):1231-39.

187. Culp KR, Wakefield B, Dyck MJ, et al. Bioelectrical impedance analysis and other hydration parameters as risk factors for delirium in rural nursing home residents. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 2004;59(8):M813-M17.

188. Dal Cin S, Braga M, Molinari M, et al. Role of bioelectrical impedance analysis in acutely dehydrated subjects. *Clinical Nutrition* 1992;11(3):128-33.

189. Patel RV, Matthie JR, Withers PO, et al. Estimation of total body and extracellular water using single-and multiple-frequency bioimpedance: SAGE Publications, 1994.

190. Ho LT, Kushner RF, Schoeller DA, et al. Bioimpedance analysis of total body water in hemodialysis patients. *Kidney international* 1994;46(5):1438-42.

191. Lindley E, Devine Y, Hall L, et al. A ward-based procedure for assessment of fluid status in peritoneal dialysis patients using bioimpedance spectroscopy. *Peritoneal dialysis international* 2005;25(3_suppl):46-48.

192. Kafri MW, Myint PK, Doherty D, et al. The diagnostic accuracy of multi-frequency bioelectrical impedance analysis in diagnosing dehydration after stroke. *Medical science monitor: international medical journal of experimental and clinical research* 2013;19:548.

193. Ritz P. Bioelectrical impedance analysis estimation of water compartments in elderly diseased patients: the source study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 2001;56(6):M344-M48.

194. Mallen C, Peat G, Croft P. Quality assessment of observational studies is not commonplace in systematic reviews. *Journal of clinical epidemiology* 2006;59(8):765-69.

195. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ* 2016;355.

196. O'Lone EL, Visser A, Finney H, et al. Clinical significance of multi-frequency bioimpedance spectroscopy in peritoneal dialysis patients: independent predictor of patient survival. *Nephrology Dialysis Transplantation* 2014;29(7):1430-37.

197. Park JH, Jo Y-I, Lee J-H. Clinical usefulness of bioimpedance analysis for assessing volume status in patients receiving maintenance dialysis. *The Korean journal of internal medicine* 2018;33(4):660.

198. Bunn D, Hooper L, Welch A. Dehydration and malnutrition in residential care: recommendations for strategies for improving practice derived from a scoping review of existing policies and guidelines. *Geriatrics* 2018;3(4):77.

199. Rushing J. Assessing for dehydration in adults. *Nursing2022* 2009;39(4):14.

200. Vivanti AP. *Screening and identification of dehydration in older people admitted to a geriatric and rehabilitation unit*. Queensland University of Technology, 2007.

201. Hooper R. Justifying sample size for a feasibility study: research design service. London: NIHR; 2019. Available from: https://www.rds-london.nihr.ac.uk/wpcms/wp-content/uploads/2019/02/Justifying-sample-size-for-feasibility-study-updated-22-Feb-2019.pdf. Accessed 3rd Aug 2022.

202. Bosy-Westphal A, Danielzik S, Dörhöfer R-P, et al. Patterns of bioelectrical impedance vector distribution by body mass index and age: implications for body-composition analysis–. *The American journal of clinical nutrition* 2005;82(1):60-68.

203. Bosy-Westphal A, Danielzik S, Dörhöfer RP, et al. Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. *Journal of Parenteral and Enteral Nutrition* 2006;30(4):309-16.

204. Skivington K, Matthews L, Simpson SA, et al. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *BMJ* 2021;374.

205. Treweek S, Mitchell E, Pitkethly M, et al. Strategies to improve recruitment to randomised controlled trials. *Cochrane Database of Systematic Reviews* 2010(4).

206. Arain M, Campbell MJ, Cooper CL, et al. What is a pilot or feasibility study? A review of current practice and editorial policy. *BMC medical research methodology* 2010;10(1):1-7.

207. Lancaster GA, Dodd S, Williamson PR. Design and analysis of pilot studies: recommendations for good practice. *Journal of evaluation in clinical practice* 2004;10(2):307-12.

208. Kraemer HC, Mintz J, Noda A, et al. Caution regarding the use of pilot studies to guide power calculations for study proposals. *Archives of general psychiatry* 2006;63(5):484-89.

209. Walter-Kroker A, Kroker A, Mattiucci-Guehlke M, et al. A practical guide to bioelectrical impedance analysis using the example of chronic obstructive pulmonary disease. *Nutrition Journal* 2011;10(1):1-8.

210. Hahnel E, Blume-Peytavi U, Trojahn C, et al. Prevalence and associated factors of skin diseases in aged nursing home residents: a multicentre prevalence study. *BMJ open* 2017;7(9):e018283.

211. Cihoric M, Kehlet H, Højlund J, et al. Bioimpedance spectroscopy fluid analysis in acute high-risk abdominal surgery, a prospective clinician-blinded observational feasibility study. *Journal of Clinical Monitoring and Computing* 2023;37(2):619-27.

212. Ikizler TA, Burrowes JD, Byham-Gray LD, et al. KDOQI clinical practice guideline for nutrition in CKD: 2020 update. *American journal of kidney diseases* 2020;76(3):S1-S107.

213. . *Healthcare*: MDPI.

214. Barnicot K, Allen K, Hood C, et al. Older adult experience of care and staffing on hospital and community wards: a cross-sectional study. *BMC Health Services Research* 2020;20:1-8.

215. McCrow J, Morton M, Travers C, et al. Associations between dehydration, cognitive impairment, and frailty in older hospitalized patients: an exploratory study. *Journal of gerontological nursing* 2016;42(5):19-27.

216. Chen CC-H, Dai Y-T, Yen C-J, et al. Shared risk factors for distinct geriatric syndromes in older Taiwanese inpatients. *Nursing research* 2010;59(5):340-47.

217. Abdelhamid A, Bunn D, Copley M, et al. Effectiveness of interventions to directly support food and drink intake in people with dementia: systematic review and meta-analysis. *BMC geriatrics* 2016;16(1):1-18.

218. Alsanie S, Lim S, Wootton SA. Examining the Utility of Bioelectrical Impedance Analysis for Detecting Low-Intake Dehydration in Older Adults in Clinical Care Settings: A Systematic Review. 2022.

219. Denneman N, Hessels L, Broens B, et al. Fluid balance and phase angle as assessed by bioelectrical impedance analysis in critically ill patients: a multicenter prospective cohort study. *European journal of clinical nutrition* 2020;74(10):1410-19.

220. Rösler A, Lehmann F, Krause T, et al. Nutritional and hydration status in elderly subjects: clinical rating versus bioimpedance analysis. *Archives of Gerontology and Geriatrics* 2010;50(3):e81-e85.

221. El-Sharkawy A, Virdee A, Wahab A, et al. Dehydration and clinical outcome in hospitalised older adults: a cohort study. *European Geriatric Medicine* 2017;8(1):22-29.

222. . *Gerontologist*: OXFORD UNIV PRESS INC JOURNALS DEPT, 2001 EVANS RD, CARY, NC 27513 USA.

223. Berwick DM. A primer on leading the improvement of systems. *BMJ* 1996;312(7031):619-22.

224. Taylor MJ, McNicholas C, Nicolay C, et al. Systematic review of the application of the plan–do–study–act method to improve quality in healthcare. *BMJ quality & safety* 2014;23(4):290-98.

225. Alsanie S, Lim S, Wootton SA. Detecting low-intake dehydration using bioelectrical impedance analysis in older adults in acute care settings: a systematic review. *BMC geriatrics* 2022;22(1):954.

226. . *Healthcare*: MDPI.

227. Davydov DM, Boev A, Gorbunov S. Making the choice between bioelectrical impedance measures for body hydration status assessment. *Scientific reports* 2021;11(1):7685.

228. Wirth R. Dehydration in geriatric patients and bioimpedance analysis. *Nutr Hosp* 2013;28(Suplemento 6).

229. Lukaski HC, Vega Diaz N, Talluri A, et al. Classification of hydration in clinical conditions: indirect and direct approaches using bioimpedance. *Nutrients* 2019;11(4):809.

230. Hoen L, Pfeffer D, Zapf R, et al. Association of drug application and hydration status in elderly patients. *Nutrients* 2021;13(6):1929.

231. Nwosu AC, Mayland CR, Mason S, et al. The association of hydration status with physical signs, symptoms and survival in advanced cancer—The use of bioelectrical impedance vector

analysis (BIVA) technology to evaluate fluid volume in palliative care: An observational study. *PloS one* 2016;11(9):e0163114.

232. Calcaterra V, Cena H, Manuelli M, et al. Body hydration assessment using bioelectrical impedance vector analysis in neurologically impaired children. *European journal of clinical nutrition* 2019;73(12):1649-52.

233. Pearson N, Naylor P-J, Ashe MC, et al. Guidance for conducting feasibility and pilot studies for implementation trials. *Pilot and feasibility studies* 2020;6:1-12.

234. Sekhon M, Cartwright M, Francis JJ. Acceptability of healthcare interventions: an overview of reviews and development of a theoretical framework. *BMC Health Services Research* 2017;17(1):1-13.

235. Borrelli B, Sepinwall D, Ernst D, et al. A new tool to assess treatment fidelity and evaluation of treatment fidelity across 10 years of health behavior research. *Journal of consulting and clinical psychology* 2005;73(5):852.

236. Frangeskou M, Lopez-Valcarcel B, Serra-Majem L. Dehydration in the elderly: a review focused on economic burden. *The journal of nutrition, health & aging* 2015;19:619-27.

237. Edmonds CJ, Foglia E, Booth P, et al. Dehydration in older people: A systematic review of the effects of dehydration on health outcomes, healthcare costs and cognitive performance. *Archives of Gerontology and Geriatrics* 2021;95:104380.

238. Jacobsen E, Cruickshank M, Cooper D, et al. Cost-effectiveness and value of information analysis of multiple frequency bioimpedance devices for fluid management in people with chronic kidney disease having dialysis. *Cost Effectiveness and Resource Allocation* 2021;19(1):1-10.

239. England NHS. Commissioning for Quality and Innovation (CQUIN): 2022/23, 2022.

240. Anantapong K, Sampson EL, Davies N. A shared decision-making model about care for people with severe dementia: a qualitative study based on nutrition and hydration decisions in acute hospitals. *International Journal of Geriatric Psychiatry* 2023;38(2):e5884.

241. Gitlin LN. Introducing a new intervention: An overview of research phases and common challenges. *The American Journal of Occupational Therapy* 2013;67(2):177-84.

242. Barbosa-Silva MCG, Barros AJ, Wang J, et al. Bioelectrical impedance analysis: population reference values for phase angle by age and sex–. *The American journal of clinical nutrition* 2005;82(1):49-52.

243. Lim C-K-M, Lim J-H, Ibrahim I, et al. Bioelectrical Impedance Analysis Derived-Phase Angle as a Pragmatic Tool to Detect Protein Energy Wasting among Multi-Ethnic Hemodialysis Patients. *Diagnostics* 2021;11(10):1745.

244. Silva AM, Campa F, Stagi S, et al. The bioelectrical impedance analysis (BIA) international database: aims, scope, and call for data. *European journal of clinical nutrition* 2023:1-8.

245. Dagne AH, Beshah MH. Implementation of evidence-based practice: the experience of nurses and midwives. *PloS one* 2021;16(8):e0256600.

246. Sarre S, Maben J, Aldus C, et al. The challenges of training, support and assessment of healthcare support workers: A qualitative study of experiences in three English acute hospitals. *International journal of nursing studies* 2018;79:145-53.

247. Sorenson C, Drummond M, Bhuiyan Khan B. Medical technology as a key driver of rising health expenditure: disentangling the relationship. *ClinicoEconomics and outcomes research* 2013:223-34.

248. Rodriguez Santana I, Aragón MJ, Rice N, et al. Trends in and drivers of healthcare expenditure in the English NHS: a retrospective analysis. *Health Economics Review* 2020;10(1):1-11.

Appendix A Service evaluation - MOP department approval

From: SafeguardSystemAdministrator@uhs.nhs.uk <SafeguardSystemAdministrator@uhs.nhs.uk>
Sent: 25 February 2022 16:14
To: Lim, Stephen <Stephen.Lim@uhs.nhs.uk>
Subject: Audit Notification - SEV/0439

Audit/SEV/Improvement Project Notification

Audit/SEV/Improvement Project Number:	**SEV/0439**
Audit/SEV Cycle Number (if aplicable):	**1**
Audit/SEV/Improvement Project Stage:	**03 SEV Ongoing Form**
Title:	**A service evaluation of hydration assessment tools used for older inpatients aged > 65 years admitted to University Hospital Southampton NHS FT**
Request Date:	**07/02/2022**
Target Date:	**30/06/2022**
Start Date:	/ /

1

Audit/SEV/Improvement Project Lead:	**Stephen Lim**
CE Lead (if applicable):	**Ibrahim Bodagh**
Comments:	**Dehydration is common medical problem in our patients and assessment of the tools we use to assess hydration will provide very useful data to assess our patients for this problem**

Please note that at Audit/SEV Stages 2 & 4, the audit/SEV will only be visible to CE leads whilst under review

Click on the link below to go to the Electronic Audit System(EAS)

Electronic Audit System (EAS)

Appendix B Service evaluation - Faculty ethical approval

Medicine

UNIVERSITY OF Southampton

18/5/22

Dear Saleh,

Re ERGO 71492 - A service evaluation of hydration assessment tools used for older inpatients aged ≥ 65 years admitted at University Hospital Southampton NHS Trust

Thank you for submitting your revisions relating to the above service evaluation. I am pleased to inform you that full approval has now been granted by the Faculty of Medicine Ethics Committee.

Approval is valid from today until 29/07/22, the end date specified in your application.

Please note the following points:

- the above ethics approval number must be quoted in all correspondence relating to your research, including emails;
- if you wish to make any substantive changes to your project you must inform the Faculty of Medicine Ethics Committee as soon as possible.

Please note that this email will now constitute evidence of ethical approval. Should you require a paper signed copy of this approval, please contact the FoMEC Administrative Team via email at: risethic@soton.ac.uk. We wish you success with your work.

Yours sincerely

Prof Edd James
Vice-Chair of the Faculty of Medicine Ethics Committee

Please reply to:
Faculty of Medicine Ethics Committee,
Southampton General Hospital, Mailpoint 801, South Academic Block, Tremona Road, Southampton SO16 6YD UK

University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 2819 Fax: +44 (0)23 8059 3131 www.southampton.ac.uk

Appendix C Service Evaluation - Data extraction sheet

UNIVERSITY OF Southampton

Service Evaluation Study
Medicine for Older People (MOP) wards
'Data Collection sheet'

DATE INFORMATION COLLECTED: ……

PARTICIPANT STUDY ID: ……

SECTION (1) DETAILS OF WARD AND PATIENT ASSESSED

- Ward's name: ……..

- Gender

☐ Male ☐ Female

- Age (years): ……

- Marital status (select one of followings):

☐ Single ☐ Married

☐ Divorced or separated ☐ Widowed

☐ Cohabiting

- Usual place of residence (select one of followings):

☐ Private home living alone ☐ Private home living with friends or relatives

☐ Sheltered/Supported Accommodation ☐ Residential/Nursing Care Home

☐ Other (please specify): ……

- Date of admission: ……

- Time of admission (12-hour clock): …… am / pm

- Day since admission: Day 1 ☐ Day 2 ☐ Day 3 ☐ Day 4 ☐ Day 5 ☐ Day ≥6 ☐

- Reason for admission: ……..

SECTION (2) PATIENT HYDRATION CARE ASSESSMENT AND MANAGEMENT

2.1 Has the local hydration assessment tool been carried out by the medical team within the first 24 hours of admission?

☐ Yes (go to 2.2)

☐ No (go to 2.1.1)

☐ No assessment conducted at all (end of visit here)

2.1.1 if no, please tick the day of first hydration care assessment conducted on admission:

Day 1	Day 2	Day 3	Day 4	Day 5	Day ≥6
☐	☐	☐	☐	☐	☐

2.2 Has a diagnosis of dehydration been reached?

☐ Yes (go to 2.2.1) ☐ No (end of visit here)

2.2.1 if yes, **which of the following category the patient was assigned to?**

☐ 'No action' (go to 2.5)

☐ 'Start Hydration chart' (go to 2.3)

☐ 'Start 24-hour fluid balance chart' (go to 2.4)

2.3 Was the hydration chart completed?

☐ Yes (go to 2.5) ☐ No (end of visit here)

2.4 Was the fluid balance chart completed?

☐ Yes (go to 2.5) ☐ No (end of visit here)

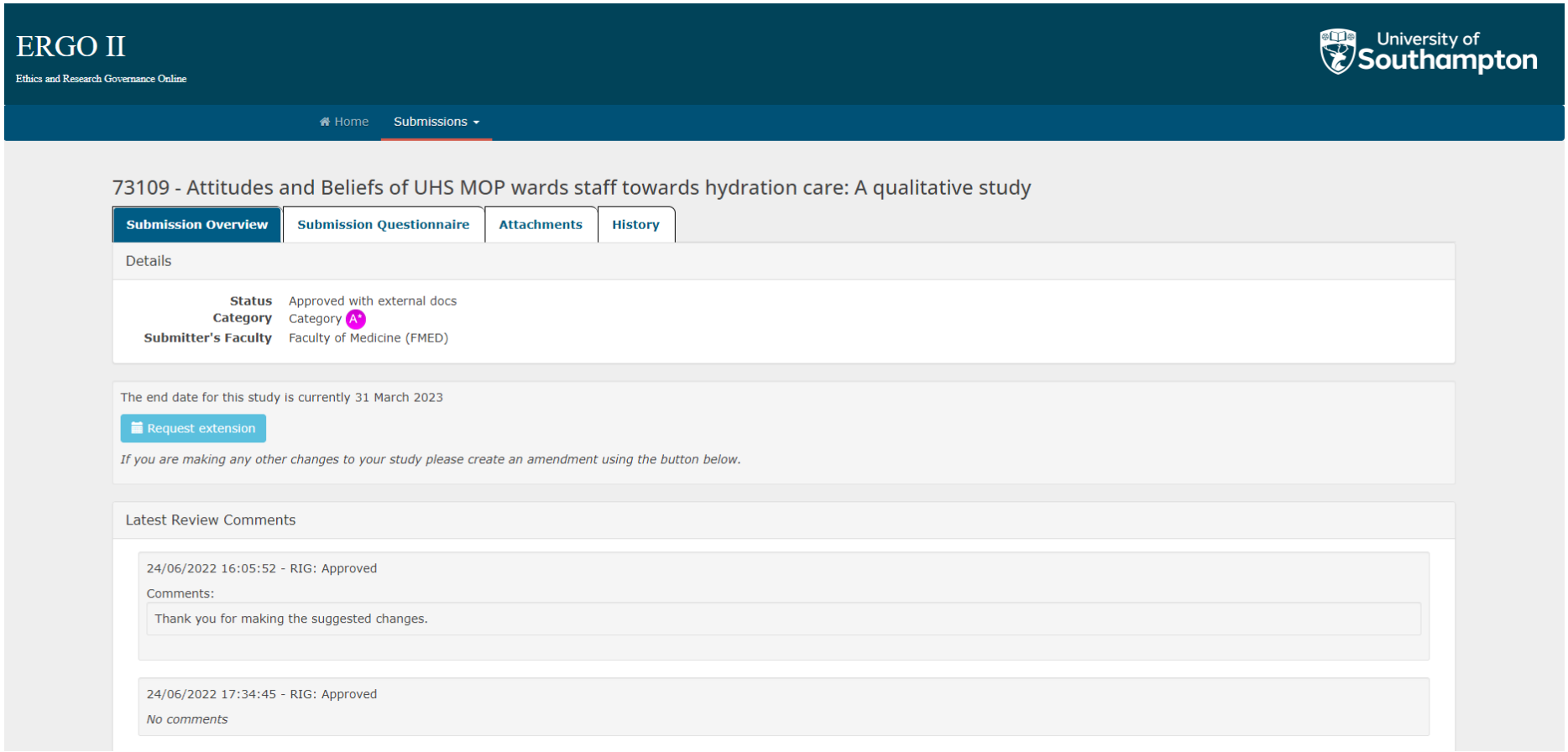
2.5 Has the hydration assessment tool been reviewed daily?

☐ Yes, for how many days since admission (……..day/s)? (go to 2.6) ☐ No (end of visit here)

2.6 Was the review time specified?

☐ Yes (Time (12-hour clock): …… am / pm) ☐ No (end of visit here)

Appendix D Qualitative interviews – Faculty ethical approval



Appendix E Qualitative interviews – University ethical approval

UNIVERSITY OF Southampton

24 June 2022

Project title: Attitudes and Beliefs of UHS MOP wards staff towards hydration care: A qualitative study

ERGO submission number: 73109

This letter is to confirm that the University of Southampton has agreed to act as Sponsor for the above research study under the terms of the UK Policy Framework for Health and Social Care Research (2017). We encourage you to become fully conversant with the terms of this Policy Framework (UKPF):

https://www.hra.nhs.uk/planning-and-improving-research/policies-standards-legislation/uk-policy-framework-health-social-care-research/

Sponsorship will remain in effect until the completion of the study and the ongoing responsibilities of the Chief Investigator have been met. Should the Chief Investigator fail to notify the Research Integrity and Governance Team of an amendment to the study, this may result in incorrect indemnity or sponsorship cover and may invalidate our agreement to sponsor.

If your study has been designated a Clinical Trial of an Investigational Medicinal Product, I would like to remind you of your responsibilities under the Medicines for Human Use Act regulations (2004/2006), The Human Medicines Regulations (2012) and EU Directive 2010/84/EU regarding pharmacovigilance. If your study has been designated a 'Clinical Investigation of a Medical Device' you also need to be aware of the regulations regarding conduct of this work.

Further guidance can be found:

http://www.mhra.gov.uk/

The University of Southampton fulfils the role of Sponsor in ensuring management, monitoring and reporting arrangements for research. As the Chief Investigator you are responsible for the daily management for this study, and you are required to provide regular reports on the progress of the study to the Research Integrity and Governance Team on this basis.

Please also familiarise yourself with the Terms and Conditions of Sponsorship attached, including reporting requirements of any Adverse Events to the Research Integrity and Governance Team and the hosting organisation.

If your project involves NHS patients or resources please send us a copy of your NHS REC and Trust approval letters when available. Please also be reminded that you may need a Research Passport to apply for an honorary research contract of employment from the hosting NHS Trust: https://intranet.soton.ac.uk/sites/researcherportal/Lists/Services1/testing.aspx?ID=607&RootFolder=%2A

Research & Innovation Services, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom Tel: +44 (0)23 8059 5058 www.southampton.ac.uk
Version 2. May 2019

Failure to comply with our Terms may invalidate your ethics approval and therefore the insurance agreement, affect funding and/or Sponsorship of your study; your study may need to be suspended and disciplinary proceedings may ensue.

Please do not hesitate to contact this office should you require any additional information or support. I would like to take this opportunity to wish you every success with your research.

Yours sincerely

Linda Hammond

Research Integrity and Governance Team

rgoinfo@soton.ac.uk

Tel No. 02380598677

Appendix F Qualitative interview - Health Research Authority (HRA) and Health and Care Research Wales (HCRW) ethical approval

Ymchwil Iechyd a Gofal Cymru
Health and Care Research Wales

NHS
Health Research Authority

Dr Kinda Ibrahim
Senior Research Fellow in Geriatric Medicine
University of Southampton
Academic Geriatric Medicine, Mailpoint 807
University Hospital Southampton
Southampton
SO16 6YD

Email: approvals@hra.nhs.uk
HCRW.approvals@wales.nhs.uk

13 July 2022

Dear Dr Ibrahim

HRA and Health and Care Research Wales (HCRW) Approval Letter

Study title:	**Beliefs and attitudes of UHS MOP wards staff towards the detection and management of low-intake dehydration in hospitalised older adults: A qualitative study**
IRAS project ID:	**312374**
Protocol number:	**73109**
REC reference:	**22/HRA/2759**
Sponsor	**The University of Southampton**

I am pleased to confirm that **HRA and Health and Care Research Wales (HCRW) Approval** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications received. You should not expect to receive anything further relating to this application.

Please now work with participating NHS organisations to confirm capacity and capability, in line with the instructions provided in the "Information to support study set up" section towards the end of this letter.

How should I work with participating NHS/HSC organisations in Northern Ireland and Scotland?
HRA and HCRW Approval does not apply to NHS/HSC organisations within Northern Ireland and Scotland.

If you indicated in your IRAS form that you do have participating organisations in either of these devolved administrations, the final document set and the study wide governance report

(including this letter) have been sent to the coordinating centre of each participating nation. The relevant national coordinating function/s will contact you as appropriate.

Please see IRAS Help for information on working with NHS/HSC organisations in Northern Ireland and Scotland.

How should I work with participating non-NHS organisations?
HRA and HCRW Approval does not apply to non-NHS organisations. You should work with your non-NHS organisations to obtain local agreement in accordance with their procedures.

What are my notification responsibilities during the study?

The *"After HRA Approval – guidance for sponsors and investigators"* document on the HRA website gives detailed guidance on reporting expectations for studies with HRA and HCRW Approval, including:

- Registration of Research
- Notifying amendments
- Notifying the end of the study

The HRA website also provides guidance on these topics and is updated in the light of changes in reporting expectations or procedures.

Who should I contact for further information?
Please do not hesitate to contact me for assistance with this application. My contact details are below.

Your IRAS project ID is **312374**. Please quote this on all correspondence.

Yours sincerely,
Libby Williamson
Approvals Specialist

Email: approvals@hra.nhs.uk

Copy to: *Mrs Linda Hammond*

List of Documents

The final document set assessed and approved by HRA and HCRW Approval is listed below.

Document	*Version*	*Date*
Copies of advertisement materials for research participants [Invitation Flyer]	0.02	11 July 2022
Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [Letter confirming insurance status]		24 June 2022
Interview schedules or topic guides for participants [Staff semi-structured interview guide]	0.01	19 June 2022
IRAS Application Form [IRAS_Form_28062022]		28 June 2022
Letter from sponsor [Letter confirming sponsorship]		24 June 2022
Letter from sponsor [Sponsor letter]		24 June 2022
Organisation Information Document [Confirmation of OID & SoE not needed]		20 September 2019
Organisation Information Document [Confirmation of OID & SoE not needed]		11 July 2022
Other [University ERGO approval]	1.0	24 June 2022
Participant information and informed consent form [Consent form]	0.03	11 July 2022
Participant information sheet (PIS) [Participant information sheet (PIS)]	0.03	11 July 2022
Proof of Insurance [Sponsor Insurance Certificate]		26 July 2021
Research protocol or project proposal [Project proposal]	1.1	19 June 2022
Response to Request for Further Information [Responses to HRA assessment queries]		
Schedule of Events or SoECAT [Confirmation of higher level agreement between sponsor & site]		11 July 2022
Summary CV for Chief Investigator (CI) [CI's CV (Dr Kinda Ibrahim)]		01 March 2022
Summary CV for student [Mr Saleh Alsanie's CV]		18 May 2022
Summary CV for supervisor (student research) [Dr Kinda Ibrahim CV]		01 March 2022

Appendix G Qualitative interviews – Information sheet

UNIVERSITY OF Southampton

Participant Information Sheet

Study Title: Beliefs and attitudes of staff towards the detection and management of low-intake dehydration in hospitalised older adults

Researcher name: Saleh Alsanie
IRAS number: 312374
ERGO number: 73109

You are being invited to take part in a study as we are interested to find out more about your views and experiences about current hydration care practice for hospitalised older adults.

Please read the following information carefully before deciding to take part in this research. If you have any questions, please do not hesitate to ask. If you decide to take part, you will be asked to sign a consent form.

What is the research about?
The research is part of a PhD research project at the University of Southampton. The purpose of the research is to explore the beliefs and attitudes of staff towards understanding issues that may help detect and manage low-intake dehydration better and exploring the barriers and facilitators of the current routine assessment, from the experiential perspective of those directly involved. Low-intake dehydration is a highly prevalent and burdensome problem that disproportionately affects older hospitalised patients due to their age- and comorbid-risk of excess fluid loss and insufficient fluid intake, which results in a net fluid deficit. It may lead to poor health outcomes and lengthening hospital stays if it is not adequately addressed during admission.

Why have I been asked to participate?
You are invited to take part in this study because you are a fully registered healthcare provider and currently involved in the clinical care of older inpatients (aged $\geqslant$ 65 years). Also, you have worked in MOP wards at UHS for at least 3 months. Your views and experiences are extremely valuable to help inform development of future NHS hydration care services for older inpatients.

What will happen to me if I take part?
An interview will be conducted by the PhD student (Saleh Alsanie (SA)) and will last 20-30mins. The first part of the interview will ask participants about their age, gender, clinical role, duration of tenure of current role. The second part will be open-ended questions. These questions will be used to enable participants to share their personal experiences and views on their attitudes and beliefs towards hydration and the factors that may affect the detection and management of low-intake dehydration in older inpatients admitted to the hospital.

The interview will be held either in-person or on MS Teams and will be digitally recorded and transcribed. You will also be asked to sign a written/online consent form before beginning the interview.

Are there any benefits in my taking part?
Whilst there are no specific and direct benefits for participants taking part in this study, they may be secondary benefits to participating in research generally. For example, participants will be significantly contributing to a field of research that aims to improve the quality of hydration care for older inpatients.

Are there any risks involved?
It is not anticipated that the study will expose any form of physical harm or pose any personal risk; however, there is a risk that the study may lead to questions that the participants may not be comfortable discussing as hospital staff are sharing their current practice. In such a case, the

interviewers are offered the opportunity to not answer any question and to stop the interview if they wish at any point. Other burden is that staff are very busy and taking 30 minutes out of their busy work schedules might be seen as a barrier.

Will my participation be confidential?
Your participation and the information we collect about you during the course of the research will be kept strictly confidential.

Only members of the research team and responsible members of the University of Southampton may be given access to data about you for monitoring purposes and/or to carry out an audit of the study to ensure that the research is complying with applicable regulations. Individuals from regulatory authorities (people who check that we are carrying out the study correctly) may require access to your data. All of these people have a duty to keep your information, as a research participant, strictly confidential.

Do I have to take part?
No, it is entirely up to you to decide whether or not to take part. If you decide you want to take part, your employment will not be affected in any way.

What happens if I change my mind?
You have the right to change your mind and withdraw at any time without giving a reason and without your participant rights or clinical role being affected.

How will my confidentiality be protected?
Anonymity and confidentiality of the study participants will be maintained. A non-identifying participant identity pseudonyms and codes will be allocated to each participant and will be used during transcription and analysis instead of real names. All data will be kept in SA's University of Southampton (UoS) OneDrive specified folder to the study. All data and information related to the study participants will be saved in a password-protected computer. In the research report, quotations from the original data will be mentioned without mentioning names.

The raw data will be archived for five years from the date of submission of the thesis. The data will be safely and securely kept by the lead supervisor in the University of Southampton. After this time, digitally recorded data will be destroyed by over writing, and data in hard copy will also be destroyed by shredding.

What will happen to the results of the research?
Your personal details will remain strictly confidential. Research findings made available in any reports or publications will not include information that can directly identify you without your specific consent.

Where can I get more information?
If you would like to get more information, please contact Saleh Alsanie, PhD student, School of Human Development and Health, Faculty of Medicine, University of Southampton, S.A.S.Alsanie@soton.ac.uk

What happens if there is a problem?
If there is any concerns about any aspect of the study or the way you have been approached or treated during the course of this study, please contact: Mr Saleh Alsanie (S.A.S.Alsanie@soton.ac.uk) or Dr Kinda Ibrahim (K.Ibrahim@soton.ac.uk) and we will do our best to answer your questions.

If you remain unhappy or have a complaint about any aspect of this study, please contact the University of Southampton Research Integrity and Governance Manager (023 8059 5058, rgoinfo@soton.ac.uk).

Who has reviewed the study?
This study has been reviewed and approved by University Hospital Southampton NHS Foundation Trust, the Health Research Authority and 'University of Southampton, Faculty of Medicine' Research Ethics Committee (reference – will be provided in due course).

Data Protection Privacy Notice
The University of Southampton conducts research to the highest standards of research integrity. As a publicly-funded organisation, the University has to ensure that it is in the public interest when we use personally-identifiable information about people who have agreed to take part in research. This means that when you agree to take part in a research study, we will use information about you in the ways needed, and for the purposes specified, to conduct and complete the research project. Under data protection law, 'Personal data' means any information that relates to and is capable of identifying a living individual. The University's data protection policy governing the use of personal data by the University can be found on its website (https://www.southampton.ac.uk/legalservices/what-we-do/data-protection-and-foi.page).

This Participant Information Sheet tells you what data will be collected for this project and whether this includes any personal data. Please ask the research team if you have any questions or are unclear what data is being collected about you.

Our privacy notice for research participants provides more information on how the University of Southampton collects and uses your personal data when you take part in one of our research projects and can be found at http://www.southampton.ac.uk/assets/sharepoint/intranet/ls/Public/Research%20and%20Integrity%20Privacy%20Notice/Privacy%20Notice%20for%20Research%20Participants.pdf

Any personal data we collect in this study will be used only for the purposes of carrying out our research and will be handled according to the University's policies in line with data protection law. If any personal data is used from which you can be identified directly, it will not be disclosed to anyone else without your consent unless the University of Southampton is required by law to disclose it.

Data protection law requires us to have a valid legal reason ('lawful basis') to process and use your Personal data. The lawful basis for processing personal information in this research study is for the performance of a task carried out in the public interest. Personal data collected for research will not be used for any other purpose.

For the purposes of data protection law, the University of Southampton is the 'Data Controller' for this study, which means that we are responsible for looking after your information and using it properly. The University of Southampton will keep identifiable information about you for 10 years after the study has finished after which time any link between you and your information will be removed. The raw data will not include identifiable recordings or any identifiable/personal information.

To safeguard your rights, we will use the minimum personal data necessary to achieve our research study objectives. Your data protection rights – such as to access, change, or transfer such information - may be limited, however, in order for the research output to be reliable and accurate. The University will not do anything with your personal data that you would not reasonably expect.

If you have any questions about how your personal data is used, or wish to exercise any of your rights, please consult the University's data protection webpage (https://www.southampton.ac.uk/legalservices/what-we-do/data-protection-and-foi.page) where

you can make a request using our online form. If you need further assistance, please contact the University's Data Protection Officer (data.protection@soton.ac.uk).

Thank you for taking the time to read this. Please ask any questions if you need to.

Appendix H Qualitative interviews – Consent form

UNIVERSITY OF Southampton

CONSENT FORM

Study title: Beliefs and attitudes of staff towards the detection and management of low-intake dehydration in hospitalised older adults

Researcher name: Saleh Alsanie
IRAS number: 312374
ERGO number: 73109

Please initial the box if you agree with the statement(s):

I have read and understood the information sheet dated (*11/07/2022, v0.3*) and have had the opportunity to ask questions about the study.	
I understand my participation in the study is voluntary and that I have the right to withdraw at any time without giving any reason and without any of my clinical role and my rights being affected.	
I understand that the data gained in the study will be treated confidentially.	
I agree to my interview being digitally recorded and I understand that transcripts of the interview will be anonymised, and any quotations will be non-attributable.	
I agree that you can use anonymous quotes from the interview in the findings. This may be in final reports, PhD thesis, conferences and in research journals.	
I agree to take part in this research project.	
I understand that information collected about me during my participation in this study will be stored on a University password-protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.	

'One copy of the signed consent form will be provided to participants and one copy will be retained for the study records'

.....	.....	.....
Name of participant (print name)	Date	Signature
.....	.....	.....
Name of researcher	Date	Signature

[11/07/2022] [v0.3]

Appendix I Semi-structured interviews – Topic guide

Hydration Care Study

Staff semi-structured interview guide

I would like to understand what you think of screening for dehydration among older inpatients

1. **Attitudes and beliefs towards dehydration**
   - How common is dehydration among older inpatients?
   - What are the main reasons for dehadration that you normally see in older inpatients?
   - What are the main symptoms of dehaydration in older inpatients?
   - How easy to recognise these symptoms? How confident are you in recognising signs and symptoms of dehydration?
   - What do you think the main consequences of dehydration in older people?
   - **In general, do you think the hydration status of admitted patients is appropriately assessed?** What makes you think the hydration status of admitted patients is (or isn't) adequately assessed?

2. **Current practice of hydration assessment**
   - What are your thoughts about routine screening for dehadration among older inpatients?
     - How is dehydration assessed in your wards?
     - How practical do you think it is to assess dehydration on a busy day in the ward?
     - Are there any challenges? What are they? (Time, resources, and staff training)?
   - Are there any potential advantages of assessing dehydration? What are they?

- How much is hydration assessment a priority compared to other tasks (e.g. less/more important)? How does it fit in your routine daily tasks?
- Are there any dedicated staff who are mainly focused on hydration assessment in patients? Who are they?
- Do you think assessing dehydration among older patients should be routinely implemented? Who do you think should be responsible for doing this assessment and maintaining patients are euhydrated (e.g nurses, dietitians)?

3. **Once dehydration is identified in patients**
   - How dehydration when identified is managed/treated?
   - What are the main interventions in place?
   - How effective they are?
   - What are the challenges of providing these interventions?
   - For doctors, in what ways can you support the ward staff to ensure patients drink enough?

4. **What do you think are other factors that could prevent older patients from drinking adequate water when admitted to the hospital?**
   - What can be done to encourage older patients to drink more water?
   - Do you use any other strategies to encourage your patients to drink? Can you give examples?

5. **Are there times when patients just don't want to drink?**
   - What sort of things can discourage them from drinking during admission?
   - Why is this?

6. **What sort of reasons would you give to patients about why they should drink well?**
   - What kind of problems may occur by not drinking enough?

7. **Considering everything we have talked about, what one thing do you suggest would help:**
   - Current practice to improve?
   - Patients to drink more?

8. **Would you like to add anything?**

Appendix J Qualitative study - Main themes and sub-themes

Findings From the Qualitative Study - Final Themes and Sub-Themes

1. **Staff Experiential Knowledge of Hydration**
    a. Dehydration Risk and Its Significance
        i. Risk of Dehydration Among Older Inpatients
        ii. Perceived Effects of Dehydration on Organ and Recovery
        iii. Perceived Benefits of Hydration Assessment
    b. Strategies to Keep Patients Hydrated
        i. Encourage Fluid Intake
        ii. Accessibility of Hydration Stations
        iii. Availability of Patient's Preferred Drinks
        iv. Hydration Education for Patients

2. **Difficulty in Dehydration Assessment and Diagnosis Due to Resources**
    a. Lack of Screening Tools and Difficulty in Diagnosis
        i. Lack of Availability of Screening Tools
        ii. Difficulty in Recognising Mild Dehydration Symptoms

3. **Patients Attributes Contributing to Difficulty in Dehydration Assessment**
        i. Patients Factors Contributing to Dehydration
        ii. Patient's Health Conditions

4. **Challenges Related to Staff Levels and Skills**
        i. Staff Skills and Training in Hydration Assessment
        ii. Staff Shortage Impact on Hydration Assessment
        iii. Workload and Time Constraints

Appendix K The search strategy for Ovid MEDLINE database

Ovid MEDLINE Search Strategy

ID	Search
1.	geriatrics.mp. or Geriatrics/ or Aged/
2.	aged subject.mp.
3.	frail elderly.mp. or Frail Elderly/
4.	old* adult*.mp.
5.	*Female/ or old* person*.mp. or *Male/
6.	old* m#n.mp.
7.	old* population*.mp.
8.	elderly people.mp.
9.	elderly population.mp.
10.	Aging/ or ageing.mp.
11.	senior citizen.mp.
12.	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11
13.	Electric Impedance/ or bioelectrical impedance analysis.mp.
14.	bioimpedance.mp.
15.	Electric Capacitance/ or capacitance.mp.
16.	BIA.mp.
17.	electrical resistance.mp. or Electric Impedance/
18.	bioimpedance analysis.mp.
19.	phase angle.mp.
20.	Electric Conductivity/ or ohmic.mp.
21.	reactance.mp.
22.	13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23.	12 and 22
24.	Fluid Therapy/ or hydration.mp. or Dehydration/ or Water/
25.	euhydration.mp.
26.	hypohydration.mp.
27.	fluid balance.mp. or Water-Electrolyte Balance/

28.	Water-Electrolyte Imbalance/ or fluid imbalance.mp.
29.	fluid measurement.mp.
30.	fluid management.mp.
31.	water volume.mp. or Body Water/
32.	fluid deficit.mp.
33.	liquid management.mp.
34.	liquid volume.mp.
35.	water intake.mp. or Drinking/
36.	liquid intake.mp.
37.	liquid balance.mp.
38.	liquid imbalance.mp.
39.	liquid monitor*.mp.
40.	24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39
41.	23 and 40
42.	hospital.mp. or Hospitals/
43.	acute care.mp.
44.	clinical care.mp.
45.	hospitalisation.mp. or Hospitalization/
46.	42 or 43 or 44 or 45
47.	41 and 46
48.	12 and 22 and 40 and 46
49.	limit 48 to (english language)

Appendix L Feasibility study - Health Research Authority (HRA) and East of England - Cambridge South Research Ethics Committee ethical approval

NHS
Health Research Authority

East of England - Cambridge South Research Ethics Committee
Equinox House
City Link
Nottingham
NG2 4LA

Please note: This is the favourable opinion of the REC only and does not allow you to start your study at NHS sites in England until you receive HRA Approval

28 February 2023

Dr Stephen Lim
Academic Geriatric Medicine, Mailpoint 807
University Hospital Southampton
Southampton
SO16 6YD

Dear Dr Lim

Study title:	**An evaluation of the feasibility and acceptability of using bioimpedance measurement in conjunction with existing methods to diagnose low-intake dehydration in hospitalised older people**
REC reference:	**23/EE/0067**
Protocol number:	**79301**
IRAS project ID:	**321556**

The Proportionate Review Sub-committee of the East of England - Cambridge South Research Ethics Committee reviewed the above application on 27 February 2023.

Ethical opinion

On behalf of the Research Ethics Committee (REC), the sub-committee gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Good practice principles and responsibilities

The UK Policy Framework for Health and Social Care Research sets out principles of good practice in the management and conduct of health and social care research. It also outlines the responsibilities of individuals and organisations, including those related to the four elements of research transparency:

1. registering research studies
2. reporting results
3. informing participants
4. sharing study data and tissue

Conditions of the favourable opinion

The REC favourable opinion is subject to the following conditions being met prior to the start of the study.

Number	Condition	Response from the applicant
1	Participant Information Sheet: Please replace 'adopting a supine position' with 'lying on your back' in the PIS to add clarity.	

You should notify the REC once all conditions have been met (except for site approvals from host organisations) and provide copies of any revised documentation with updated version numbers. Revised documents should be submitted to the REC electronically from IRAS. The REC will acknowledge receipt and provide a final list of the approved documentation for the study, which you can make available to host organisations to facilitate their permission for the study. Failure to provide the final versions to the REC may cause delay in obtaining permissions.

Confirmation of Capacity and Capability (in England, Northern Ireland and Wales) or NHS management permission (in Scotland) should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements. Each NHS organisation must confirm through the signing of agreements and/or other documents that it has given permission for the research to proceed (except where explicitly specified otherwise).

Guidance on applying for HRA and HCRW Approval (England and Wales)/ NHS permission for research is available in the Integrated Research Application System.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of management permissions from host organisations.

Registration of Clinical Trials

All research should be registered in a publicly accessible database and we expect all researchers, research sponsors and others to meet this fundamental best practice standard.

It is a condition of the REC favourable opinion that **all clinical trials are registered** on a publicly accessible database within six weeks of recruiting the first research participant. For this purpose, 'clinical trials' are defined as:

- clinical trial of an investigational medicinal product
- clinical investigation or other study of a medical device
- combined trial of an investigational medicinal product and an investigational medical device
- other clinical trial to study a novel intervention or randomised clinical trial to compare interventions in clinical practice.

Failure to register a clinical trial is a breach of these approval conditions, unless a deferral has been agreed by the HRA (for more information on registration and requesting a deferral see: Research registration and research project identifiers).

If you have not already included registration details in your IRAS application form you should notify the REC of the registration details as soon as possible.

Publication of Your Research Summary

We will publish your research summary for the above study on the research summaries section of our website, together with your contact details, no earlier than three months from the date of this favourable opinion letter.

Should you wish to provide a substitute contact point, make a request to defer, or require further information, please visit:
https://www.hra.nhs.uk/planning-and-improving-research/application-summaries/research-summaries/

N.B. If your study is related to COVID-19 we will aim to publish your research summary within 3 days rather than three months.

During this public health emergency, it is vital that everyone can promptly identify all relevant research related to COVID-19 that is taking place globally. If you haven't already done so, please register your study on a public registry as soon as possible and provide the REC with the registration detail, which will be posted alongside other information relating to your project. We are also asking sponsors not to request deferral of publication of research summary for any projects relating to COVID-19. In addition, to facilitate finding and extracting studies related to COVID-19 from public databases, please enter the WHO official acronym for the coronavirus disease (COVID-19) in the full title of your study. Approved COVID-19 studies can be found at:
https://www.hra.nhs.uk/covid-19-research/approved-covid-19-research/

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

After ethical review: Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study, including early termination of the study
- Final report
- Reporting results

The latest guidance on these topics can be found at https://www.hra.nhs.uk/approvals-amendments/managing-your-approval/.

Ethical review of research sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion").

Approved documents

The documents reviewed and approved were:

Document	*Version*	*Date*
IRAS Application Form [IRAS_Form_14022023]		14 February 2023
Letter from sponsor [79301_Insurance_Letter2023-02-10__14_57]	1.0	10 February 2023
Other [79301_Data+Management+Plans+for+Doctoral+Students+-+Certificate]	1.0	10 February 2023
Other [79301_Feasibility study - data collection sheet (A) (v0.01)]	0.01	10 February 2023
Other [79301_Feasibility study - data collection sheet (B) (v0.01)]	0.01	10 February 2023
Other [79301_Good+Clinical+Practice+certificate]	1.0	10 February 2023
Other [79301_Inpatient Hydration Assessment tool used at UHS]	1.0	10 February 2023
Other [79301_Insurance_Letter2023-02-10__14_57]	1.0	10 February 2023
Other [79301_Liability - evidence of cover letter 2022-2023 v2_2023-02-10__14_57]	1.0	10 February 2023
Other [79301_Research+Practice+in+Clinical+Settings+-+NIHR]	1.0	10 February 2023
Other [79301_Saleh's+CV+Jan+2023]	1.0	10 February 2023
Other [79301_Sponsor_Letter2023-02-10__14_11]	1.0	10 February 2023
Other [ERGO-University approval email]	1.0	10 February 2023
Participant consent form [79301_Patient consent form]	0.01	10 February 2023
Participant information sheet (PIS) [79301_20230124 PIS sheet - New]	0.01	10 February 2023
Research protocol or project proposal [79301_ERGO Research Protocol - Feasibility study]	1.0	10 February 2023
Summary CV for Chief Investigator (CI) [Curriculum Vitae S Lim	1.0	10 February 2023

January 2023 2 page]		
Summary CV for student [79301_Alsanie's+CV+-+IRAS+form]	1.0	10 February 2023

Membership of the Proportionate Review Sub-Committee

The members of the Sub-Committee who took part in the review are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website:
http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

HRA Learning

We are pleased to welcome researchers and research staff to our HRA Learning Events and online learning opportunities– see details at:
https://www.hra.nhs.uk/planning-and-improving-research/learning/

With the Committee's best wishes for the success of this project.

IRAS project ID: 321556	**Please quote this number on all correspondence**

Yours sincerely

PP
Dr Leslie Gelling
Chair

Email: cambridgesouth.rec@hra.nhs.uk

Enclosures: List of names and professions of members who took part in the review

"After ethical review – guidance for researchers"

East of England - Cambridge South Research Ethics Committee

Attendance at PRS Sub-Committee of the REC meeting held in correspondence.

Committee Members:

Name	*Profession*	*Present*	*Notes*
Dr Leslie Gelling (Chair)	Principal Academic in Adult Nursing	Yes	
Dr Stuart Owen	Director of Tombec Consulting Limited	Yes	
Dr Marijcke Veltman-Grisenthwaite	Assistant Director (Policy and Governance)	Yes	

Also in attendance:

Name	*Position (or reason for attending)*
Ms Tracy Hamrang	Approvals Administrator

Appendix M Feasibility study - Patient Information Sheet

University of Southampton

Participant Information Sheet

Study Title: An evaluation of the feasibility and acceptability of using bioimpedance measurement in conjunction with existing methods to diagnose low-intake dehydration in hospitalised older people

Researcher: Saleh Alsanie
IRAS number: 321556
ERGO number: 79301

You are being invited to take part in the above research study at the Southampton General Hospital and the University of Southampton, Faculty of Medicine. To help you decide whether you would like to take part or not, it is important that you understand why the research is being done and what it will involve. Please read the information below carefully and ask questions if anything is not clear or you would like more information before you decide to take part in this research. You may like to discuss it with others but it is up to you to decide whether or not to take part. If you are happy to participate you will be asked to sign a consent form.

What is the research about?
The research is part of a PhD research project at the University of Southampton. This research study aims to improve our understanding of how to evaluate the hydration status in older adults admitted to University Hospital Southampton (UHS) in the Medicine for older people (MOP) wards. This evaluation will be carried out once during your admission. Dehydration happens when we are not drinking enough to meet our needs/body demands. It is bad for all of us. Older people admitted to the hospital may be dehydrated or at risk of being dehydrated. We know that being dehydrated is more likely to contribute to poor health outcomes, including longer hospital stays and other health problems such as confusion and falls or even death. This research study aims to improve our understanding of how to evaluate the hydration status in older adults admitted to University Hospital Southampton (UHS) in the Medicine for older people (MOP) wards. This evaluation will be carried out once during your admission. We plan to capture the following data from your medical records: Gender, Height, Weight, Age, Marital Status, Usual Place of Residence, Time of Admission, Reason for Admission, Comorbidities, Current Medications, Diagnosis, Hydration Status, Clinical Frailty Scale (CFS), Mobility Status, Delirium Status, Malnutrition Universal Screening Tool (MUST) score and Acute Kidney Injury diagnosis via Creatinine blood test results. We will then be using a simple and safe machine called a 'Bioelectrical Impedance Analysis' to look at your hydration status. The entire session will only take up to 15mins of your time.

Why have I been asked to participate?
All patients who have been admitted to the MOP wards are eligible for the study. It would be an excellent opportunity for you and for us to learn more about your body's water content and how it is best assessed and diagnosed.

What will happen to me if I take part?

The following steps will be carried out once during your admission:
1. We will review your medical records and capture the following information from your record at the hospital: Gender, Height, Weight, Age, Marital Status, Usual Place of Residence, Time of Admission, Reason for Admission, Comorbidities, Current Medications, Diagnosis, Hydration Status, Clinical Frailty Scale (CFS), Mobility Status, Delirium Status, Malnutrition Universal Screening Tool (MUST) score and Acute Kidney Injury diagnosis via Creatinine blood test results.
2. Hydration assessment measurement - we will use a body analyser called 'Bioelectrical Impedance Analysis' to see how much water is in your body at one time. It involves lying down for 5-10mins connected to a portable meter. Some gel will attach small electrode pads to your right wrist and foot. The testing process is entirely safe and pain-free and we will ask you about the acceptability of it.

The entire process listed above should only take up to 15 minutes.

Are there any benefits in my taking part?
The study will not directly help you at present. However, you will be contributing to the current knowledge in this subject area. In the future, the research study's findings may allow clinicians to make better treatment decisions for older patients, improve their health outcomes, and enable the clinical team to detect and correct dehydration during admission.

Are there any risks involved?
There are no disadvantages or risks foreseen in taking part in the study, and the analyser does not have known adverse effects.

What data will be collected?
The researcher will first collect your general and clinical demographic information from your medical records (i.e. Gender, Height, Weight, Age, Marital Status, Usual Place of Residence, Time of Admission, Reason for Admission, Comorbidities, Current Medications, Diagnosis, Hydration Status, Clinical Frailty Scale (CFS), Mobility Status, Delirium Status, Malnutrition Universal Screening Tool (MUST) score and Acute Kidney Injury diagnosis via Creatinine blood test results).

Secondly, the researcher will collect your bioimpedance measurements using "ImpediMed SFB7 (Bioelectrical Impedance Spectroscopy (BIS))". The measurements will be taken 3 times on the same occasion. Bioimp Software PC Software will be used for displaying the impedance data. Measurements will be taken on their right wrist and foot, while lying on your back. You will be asked to remove watches and jewellery as they might affect the accuracy of the bioimpedance measurements. Electrode placements will be followed according to the device instructions, and your skin will be cleaned with an alcohol wipe at the placements of the device electrodes. The whole process will take up to 15 mins.

The bioimpedance procedure is a low-risk procedure, and it is a very straightforward analysis, similar to performing an electrocardiogram (ECG), which is routinely done in all patients admitted to the hospital. Whilst performing bioimpedance analysis, you will not be required to expose any part of your body beyond your right wrist and foot; hence your privacy will be protected at all times.

Access to medical records: Medical records will be looked at by Dr Lim, consultant geriatrician and academic supervisor. The researcher will conduct part of the data collection process by reviewing patients' medical, and nursing notes. Patients' medical and nursing notes and only be reviewed in the clinical area and will not be removed outside the area. Patient's notes will be returned to the notes trolley upon completion of data collection. All data collected and reported will be anonymised. This is made explicit in the PIS and consent form.

University computers: All are encrypted and password-protected using high levels of security in accordance with the University of Southampton policy. All data will be kept securely on the University secure network or on a secure cloud (e.g. University OneDrive) accessible through the University and which has similar security credentials to the University network.

All study data will be stored for 10 years in accordance with the University of Southampton Research Data Management Policy. All study data will be stored at the University of Southampton. Hard copies of study documents (i.e. data collection sheets) will be kept in a locked filing cabinet, with access restricted to the researcher and the research team. Electronic data files will be stored on password-protected computers only accessible by the University of Southampton staff involved in this study. All data storage will adhere to the University of Southampton principles for research data management, which include both institutional and researcher responsibilities.

Participants' names will not be included on the data collection forms, instead an identifying number will be used. In addition, the bioimpedance analyser will send the readings/results directly to the computer in an anonymised format, coded by identifier rather than by any patient identifiable information.

Patient's medical and nursing notes and only be reviewed in the clinical area and will not be removed outside the wards. The patient's notes will be returned to the notes trolley upon completion of data collection. The participant's ID sheet will be kept in a locked filing cabinet, with access restricted to the researcher and the research team.

In accordance with the RCUK Common Principles on Data Policy (2011), research data generated from this study and underpins findings in publications will be stored for 10 years. This storage will adhere to the University of Southampton Data Protection Act (2018). All personal information will be stored securely in accordance with the Data Protection Act 2018 for up to 12 months and then destroyed. The bioimpedance data will be deleted from the bioimpedance device immediately after transferring them to a University password-protected computer on the data collection day, but bioimpedance data will be stored in accordance with the University of Southampton data policy (outlined above). All study data will be stored at the University of Southampton. Hard copies of study documents (i.e. data collection sheets and consent forms) will be kept in a locked filing cabinet, with access restricted to appropriate University of Southampton staff. Electronic data files will be stored on password-protected computers only accessible by the University of Southampton staff involved in this study. All data storage will adhere to the University of Southampton principles for research data management, which include both institutional and researcher responsibilities.

Will my participation be confidential?
Your participation and the information we collect about you during the course of the research will be kept strictly confidential.

Only members of the research team and responsible members of the University of Southampton may be given access to data about you for monitoring purposes and/or to carry out an audit of the study to ensure that the research is complying with applicable regulations. Individuals from regulatory authorities (people who check that we are carrying out the study correctly) may require access to your data. All of these people have a duty to keep your information, as a research participant, strictly confidential.

We will keep your information safe and secure. People who do not need to know who you are will not be able to see your name and contact details. Your data will have a code number instead.All data will be kept in the researcher's University of Southampton (UoS) OneDrive specified folder to the study. All data and information related to the study participants will be saved in a University password-protected computer. In the research report, the original data will be mentioned without mentioning names. Hard copies of study documents (i.e. data collection sheets, consent forms) will be kept in a locked filing cabinet, with access restricted to appropriate University of Southampton staff.

Do I have to take part?
No, it is entirely up to you to decide whether or not to take part. If you decide you want to take part, you will need to sign a consent form to show you have agreed to take part.

What happens if I change my mind?
You have the right to change your mind and withdraw at any time without giving a reason and without your participant rights or your routine care being affected.

What will happen to the results of the research?
Your personal details will remain strictly confidential. Research findings made available in any reports or publications will not include information that can directly identify you without your specific consent. If you would like to receive a summary of the study findings, please provide your email address to the researcher. Once the study is published, the findings will be sent to your email address.

Where can I get more information?
If you would like to get more information, please contact Saleh Alsanie, PhD student, School of Human Development and Health, Faculty of Medicine, University of Southampton, S.A.S.Alsanie@soton.ac.uk

What happens if there is a problem?
If you have a concern about any aspect of this study, you should speak to the researchers who will do their best to answer your questions on the following contact details:

Mr Saleh Alsanie (S.A.S.Alsanie@soton.ac.uk)
Dr Stephen Lim (S.E.Lim@soton.ac.uk)

If you remain unhappy or have a complaint about any aspect of this study, please contact the University of Southampton Research Integrity and Governance Manager (023 8059 5058, rgoinfo@soton.ac.uk).

Data Protection Privacy Notice
The University of Southampton conducts research to the highest standards of research integrity. As a publicly-funded organisation, the University has to ensure that it is in the public interest when we use personally-identifiable information about people who have agreed to take part in research. This means that when you agree to take part in a research study, we will use information about you in the ways needed, and for the purposes specified, to conduct and complete the research project. Under data protection law, 'Personal data' means any information that relates to and is capable of identifying a living individual. The University's data protection policy governing the use of personal data by the University can be found on its website (https://www.southampton.ac.uk/legalservices/what-we-do/data-protection-and-foi.page).

This Participant Information Sheet tells you what data will be collected for this project and whether this includes any personal data. Please ask the research team if you have any questions or are unclear what data is being collected about you.

Our privacy notice for research participants provides more information on how the University of Southampton collects and uses your personal data when you take part in one of our research projects and can be found at http://www.southampton.ac.uk/assets/sharepoint/intranet/ls/Public/Research%20and%20Integrity%20Privacy%20Notice/Privacy%20Notice%20for%20Research%20Participants.pdf

Any personal data we collect in this study will be used only for the purposes of carrying out our research and will be handled according to the University's policies in line with data protection law. If any personal data is used from which you can be identified directly, it will not be disclosed to anyone else without your consent unless the University of Southampton is required by law to disclose it.

Data protection law requires us to have a valid legal reason ('lawful basis') to process and use your Personal data. The lawful basis for processing personal information in this research study is for the performance of a task carried out in the public interest. Personal data collected for research will not be used for any other purpose.

For the purposes of data protection law, the University of Southampton is the 'Data Controller' for this study, which means that we are responsible for looking after your information and using it properly. The University of Southampton will keep identifiable information about you for 10 years after the study has finished after which time any link between you and your information will be removed.

To safeguard your rights, we will use the minimum personal data necessary to achieve our research study objectives. Your data protection rights – such as to access, change, or transfer such information - may be limited, however, in order for the research output to be reliable and accurate. The University will not do anything with your personal data that you would not reasonably expect.

If you have any questions about how your personal data is used, or wish to exercise any of your rights, please consult the University's data protection webpage (https://www.southampton.ac.uk/legalservices/what-we-do/data-protection-and-foi.page) where you can make a request using our online form. If you need further assistance, please contact the University's Data Protection Officer (data.protection@soton.ac.uk).

Thank you for taking the time to read this. Please ask any questions if you need to.

Appendix N Feasibility study - Consent form

v0.02 (dated 28/02/2023)

UNIVERSITY OF Southampton

Participant Consent Form

Study title: An evaluation of the feasibility and acceptability of using bioimpedance measurement in conjunction with existing methods to diagnose low-intake dehydration in hospitalised older people

Researcher name: Saleh Alsanie
IRAS number: 321556
ERGO number: 79301

Please initial the box if you agree with the statement(s):

I have read and understood the information sheet (*v0.02 dated 28/02/2023*) for the above study and have had the opportunity to ask questions.	
I understand my participation in the study is voluntary and that I have the right to withdraw at any time without giving any reason and without any of my rights being affected. This will not affect my clinical management.	
I understand that the data gained in the study will be treated confidentially.	
I agree that the findings of the study may be used in PhD reports and thesis, conferences and in research journals.	
I understand that information collected about me during my participation in this study will be stored on a University password-protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.	
I agree to take part in this research project.	

'One copy of the signed consent form will be provided to participants and one copy will be retained for the study records'

..... Name of participant (print name)	..... Date	..... Signature
..... Name of researcher	..... Date	..... Signature

Appendix O Feasibility study - Data extraction form (A)

Observational Feasibility Study
Medicine for older people (MOP)
'Data Collection sheet (A)'

Researcher name: Saleh Alsanie
IRAS number: 321556
ERGO number: 79301

DATE: …… **WARD NUMBER: ……**

How many patients have been admitted to this ward? ……

Number of patients meet our study's EXCLUSION criteria: ……

Number of patients meet our study's INCLUSION criteria: ……

How many eligible patients can we recruit for the study today? ……

Reasons for not recruiting the other eligible patients:

- ……
- ……
- ……
- ……
- ……
- ……

Appendix P Feasibility study - Data extraction form (B)

Observational Feasibility Study
Medicine for older people (MOP)
'Data Collection sheet (B)'

Researcher name: Saleh Alsanie
IRAS number: 321556
ERGO number: 79301

DATE: ……

PARTICIPANT STUDY ID: ……

- Gender

☐ Male ☐ Female

- Age (years): …… **Height (cm):** …… **Weight (kg):** ……

- Marital status (select one of followings):

☐ Single ☐ Married ☐ Divorced or separated

☐ Widowed ☐ Cohabiting

- Usual place of residence (select one of followings):

☐ Private home living alone ☐ Private home living with friends or relatives

☐ Sheltered/Supported Accommodation ☐ Residential/Nursing Care Home

☐ Other (please specify): ……

- Date of admission: …… **Time of admission (12-hour clock):** …… am / pm

- Reason for admission: ……..

- Current Diagnosis: ……

- Comorbidities: ……

……

- Number of medications:……

……

- Malnutrition Universal Screening Tool (MUST) score: ……

- Creatinine (80-115 mmol/l): ……

2.1 Hydration Assessment:

No action category:

None of the yellow or red risk factors ☐	Medical fit patients awaiting discharge ☐	Daily weights deemed appropriate for monitoring hydration ☐
Monitoring not required after discussion with medical and/or nursing in charge ☐	Patient on an individualised end-of-life care plan ☐	

Start Hydration chart:

Dry mucous membranes, dry lip, skin turgor, sunken eyes ☐	Difficulty handling cups/cutlery, unable to pour their own drinks ☐	Age over 75 ☐	Respiratory rate more than 25 bpm ☐
Oral diuretics ☐	Febrile patients (Temp > 38 C) ☐	Delirium and/or dementia ☐	Constipation ☐
Diabetes ☐	Decreased appetite ☐	Thickened fluids ☐	Consuming clear or free fluids only ☐
Long term catheter ☐			

Start 24-hour fluid balance chart:

Acute Kidney injury and/or sudden decrease in urine output (<0.5mls/kg/hr) ☐	Sepsis ☐	IV fluids/NG/PEG feed or TPN ☐	IV diuretics ☐
Diarrhoea/High stoma output ☐	Post Op < 48hrs. (excluding day case) ☐	Nil by mouth > 6 hours ☐	Fluid restriction (exclude long term restrictions e.g. dialysis) ☐
IV chemotherapy ☐	High drainage wounds ☐	Increased vomiting/High NG output ☐	Short term catheter removed < 24 hours ☐
Requested by Clinical team ☐	NEWS2 ≥ 3 ☐		

2.2 Clinical Frailty Scale (CFS):

1. Very Fit ☐	2. Well ☐	3. Managing Well ☐	4. Vulnerable ☐
5. Mildly Frail ☐	6. Moderately Frail ☐	7. Severely Frail ☐	8. Very Severely Frail ☐
9. Terminally Ill ☐			

2.3 Presence of Delirium (through 4AT assessment or clinician diagnosis):

☐ Yes ☐ No

2.4 Mobility Status:

Walks independently ☐	Walks with assistance (e.g. stick, frame) ☐
Only able to transfer (can't walk, but can move from bed to chair) ☐	Hoist transfer ☐

2.5 Acceptability of bioimpedance use on patients:

1. Would you have this procedure again?

☐ Yes ☐ No

2. If no, is there any reason why you would not like to have it again in the future?

.....

.....

.....

Appendix Q NIHR Southampton - Procedure for using the Impedimed SFB7 Bioelectrical Impedance Machine

NIHR Southampton Biomedical Research Centre

Procedure for using the IMPEDIMED SFB7 BIOELECTRICAL IMPEDANCE MACHINE

BACKGROUND

This Standard Operating Procedure is to be used for measuring bioelectrical impedance (BI) using the ImpediMed SFB7 equipment. BI and Bioelectrical Impedance Spectroscopy (BIS) are methods designed for measuring body composition and are based on the observation that the body's lean compartment (which includes muscle, bone and water), conducts electricity far better than the body's fat compartment which is low in body water.

The ImpediMed SFB7 is a single channel – tetra polar device that scans 256 frequencies between 4 and 1000 kHz. Cole modelling with Hanai mixture theory are used to determine total body water (TBW), extracellular fluid (ECF) and intracellular fluid (ICF) from impedance data, and additional data can be generated both by the equipment directly and/or using the software supplied with the device.

PURPOSE

To ensure correct and uniform use of the ImpediMed SFB7 body composition monitoring unit for multi-frequency whole body electrical impedance.

SCOPE

This procedure applies to any study requiring measurements of bioelectrical impedance using the ImpediMed SFB7 body composition monitoring unit, within the BRC.

RESPONSIBILITIES

It is the responsibility of the measurer to use this procedure when measuring bioelectrical impedance using the ImpediMed SFB7 body composition monitoring unit. It is the responsibility of the principle investigator to ensure that staff members who are working on specific studies have adequate experience to do so.

PROCEDURE

Do not use this device on patients with active implanted medical devices, e.g cardiac pacemakers, defibrillators or patients connected to electronic life support devices. The ImpediMed SFB7 has yet to be clinically validated for use with pregnant patients; however, bioelectrical impedance technology has been shown to have no adverse affects.

Before testing

The operator should be mindful of the fact that certain situations are known to affect body water concentration:

- Just prior, during and just after menstruation.
- Use of diuretics.
- Renal or heart failure.
- Excessive exercise 2h prior to bioimpedance analysis.
- Consumption of excessive alcohol within 12h prior to analysis.

Preparing the volunteer

Prior to analysis the volunteer should:

1. Remove all jewellery (rings on fingers may be left on).
2. Remove stockings/tights/socks
3. Have an empty bladder
4. Be accurately measured for height (to the nearest 0.5 cm) and weight (to the nearest 0.1 kg).
5. Lie in the supine position for 5 minutes.
6. Ensure that their feet are not in contact with the bed frame (if present).
7. Extend their arms and legs making sure that they are not in contact with one another or touching/resting on any other part of the body.

Before using the ImpediMed SFB7:

8. Do not use the machine when it is plugged in to the mains. The measurements are meant to be made when the machine is operating on battery power.
9. Perform a calibration check on the machine (See "Calibration of the ImpediMed SFB7" section of this SOP). You will need to remove the alligator clips at the ends of the leads to do this.
10. Replace the alligator clips after performing the calibration test.

11. The manufacturers recommend the leads remain plugged in to the back of the device. Continual plugging and unplugging of the leads into the back of the machine is more likely to damage the leads over time.
12. Check the expiry date of the electrodes.
13. Remember to always use the stylus end (non-writing end) of the ImpediMed supplied pen to operate the touch screen. This pen is kept in the lid part of the ImpediMed carrying case.
14. Check the battery status in advance of seeing the patient. By selecting "setup" on the start screen you can check, by looking at the battery indicator, whether there is sufficient battery power to complete your series of measurements. To do this, select "setup" and look at the large battery symbol on the right side of the screen. To fully charge a depleted battery it will need to be plugged in for 6 hours (during which time the equipment may not be used). A fully charged battery supplies 4-8 hours worth of operating time before recharging is needed.
15. Wash your hands and explain the procedure to the volunteer.
16. Obtain accurate measurements of the volunteer's height (in cm, to the nearest 0.1 of a cm) and weight (in kg, to the nearest 0.1 of a kg) following appropriate SOPs.
17. Instruct the volunteer to remove their shoe and sock from their right foot, remove any watches or bracelets on the right wrist which may impede the correct placing of electrodes, and lie in the supine position for 5 minutes before taking the measurements.
18. Ensure that the legs and arms are spread out so they are not in contact with any other part of the body.
19. Thoroughly wipe (using sterettes) the area of the skin where the electrodes are to be attached (as products such as body moisturiser can affect the results).

Using the ImpediMed SFB7:

20. Turn on the SFB7 machine by pressing the on/off button on the front of the main unit (figure 1).

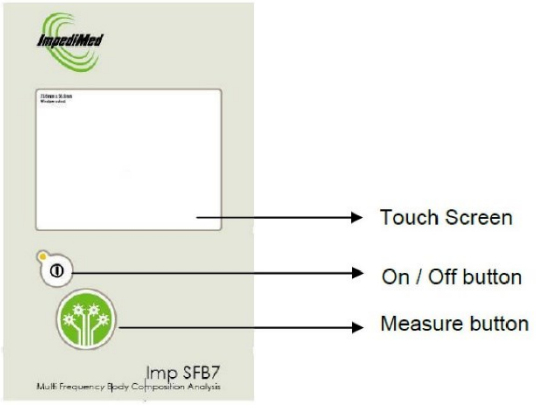


Figure 1. The front of the ImpediMed SFB7 unit.

21. To select whether you want the device to take measurements in BIS (bioimpedance spectroscopy) mode or in SFBI (selected frequencies) mode, tap "setup" (figure 2) on the start screen and then select "modules" (circled red, figure 3).

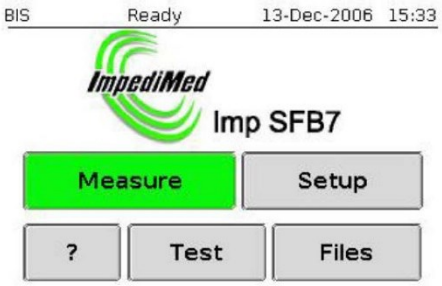


Figure 2. The start screen.

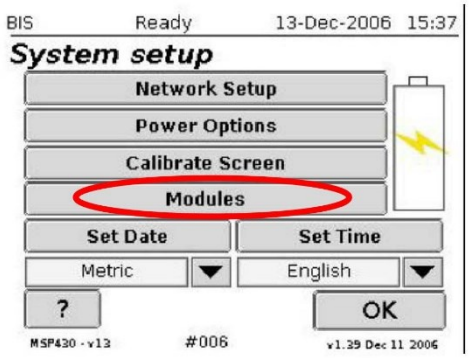


Figure 3. Setup screen

22. After tapping "modules", choose either BIS or SFBI by tapping the screen. The one you have selected to use, from the "modules" screen will be marked with a cross. BIS will then be displayed on the upper left of the ImpediMed machine screen (circled red, figure 4).

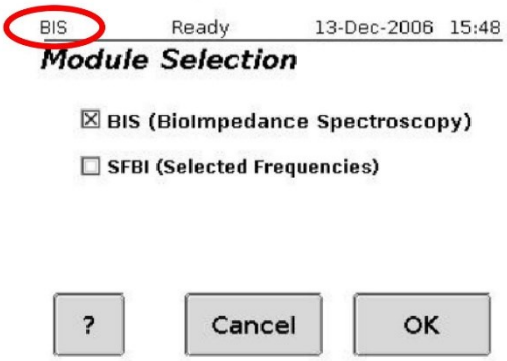


Figure 4. The module selection screen

23. Place two electrodes on both the right hand and the right foot with the tabs of the electrodes facing outwards (away from the volunteer) and connect the alligator clips on each lead to the appropriate electrode, following the instructions and diagrams below. There needs to be 5cm of free skin between the two electrodes. Use a ruler to measure this – there is one in the zip pocket of the ImpediMed machine case.
24. Note that the placement of the electrodes to which the red lead and the black lead are attached is further away from the knuckles and toes than that for the Bodystat QuadScan 4000 and the Bodystat 1500.

The yellow lead

The yellow lead end is attached to the electrode on the right hand, on the wrist next to the ulnar head (wrist joint, figure 5).

The red lead

The red lead is attached to the electrode on the dorsal surface of the right hand (figure 5).

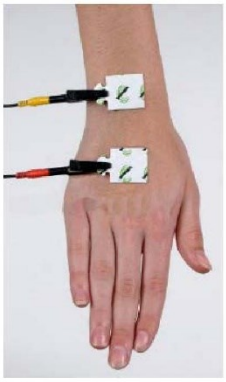


Figure 5. Placement of electrodes on hand

The blue lead

The blue lead end is attached to the electrode on the dorsal surface of the right foot, on the ankle at the level of the medial and lateral malleoli (large protruding bones on the side of the ankle, figure 6).

The black lead

The black lead end is attached to the electrode on the dorsal surface of the right foot (figure 6).

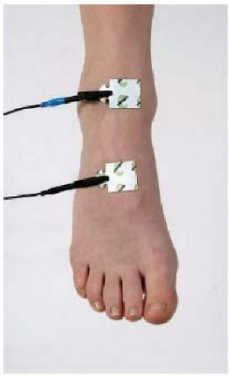


Figure 6. Placement of electrodes on foot

Making measurements in BIS mode

25. Select BIS mode by following the instructions above (no. 2, figure 3 and 4)
26. Tap "measure" on the starting screen to take you to the BIS "measurement setup" (figure 7) screen and tap on the "file name" box. This will bring up a key pad where you can type in the file name and/or number of your choice. After choosing a name for your file tap "ok" (If at this stage, the machine switches itself off, please follow the instructions on the laminated letter from ImpediMed [in a pocket of the ImpediMed machine carry case], which describes how to avoid this).

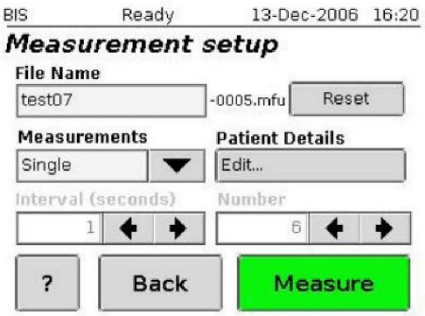


Figure 7. Measurement setup screen for BIS

27. Tap "patient details" and select the volunteer's gender, height, weight and age (figure 8) and then tap "ok". If you tap on the area circled red in figure 8 (instead of changing the value using the arrows), you can enter a more accurate height and weight value using the numerical key pad on the screen.

Figure 8. Patient details screen for BIS

28. Tap the down arrow to the right of the "measurements" box and select "continuous" and "3" (figure 7 – showing "single").
29. Check that all the alligator clips are correctly attached and that the volunteer is lying in the correct position and then press the measure button on the front of the device (large circular green button) or tap the "measure" box on the touch screen (figure 1 and 7).
30. Then tap "start" to begin.
31. Making measurements in SFBI mode – note: you do not need to enter details of weight, height, age and gender when using the SFBI mode only.
32. Select SFBI mode by following the instructions above (no. 2, figure 3 and 4)
33. Tap "measure" on the starting screen to take you to the SFBI "measurement setup" screen and tap on the "file name" box. This will bring up a key pad where you can type in the file name and/or number of your choice. After choosing a name for your file tap "ok" (If at this stage, the machine switches itself off, please follow the instructions on the laminated letter from ImpediMed [in a pocket of the ImpediMed machine carry case], which describes how to avoid this).
34. Tap the down arrow to the left of the "measurements" box and select "single" (figure 9).
35. Now the machine is set to SFBI, the box that said patient details in the BIS mode now says "Selected frequencies" and SFBI is displayed in the upper left of the screen (circled red, figure 9).

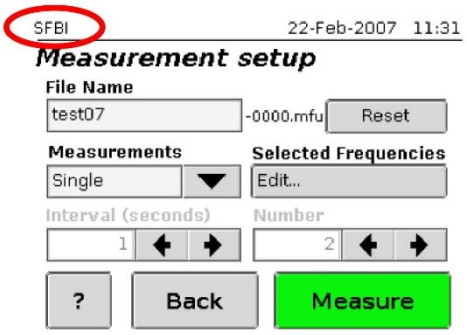


Figure 9. Measurement setup screen for SFBI

36. Tapping on the "selected frequencies" box will take you to the "frequency selection" screen where you may then select which frequencies you would like the machine to use for the measurements (figure 10). Tap on the boxes to put a cross in the frequencies you want to use. This section also gives you the opportunity to select frequencies of your own choice.

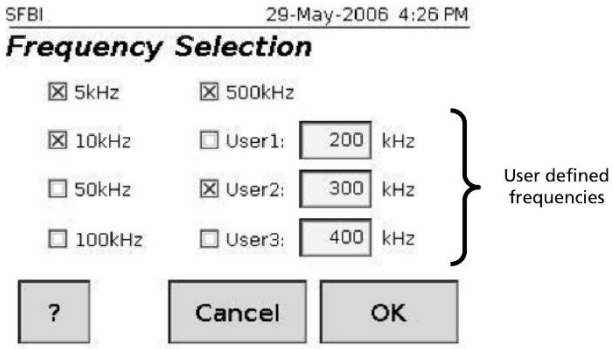


Figure 10. Frequency selection screen for SFBI

37. To make measurements at user-defined frequencies, tap on the box containing the numerical values, adjacent to the User1, User2 and User3 boxes. By doing so, you will be taken to the number keypad where you can enter the kHz value of your choice. Ensure that the boxes next to User1, User2 and User3 are marked with crosses or the machine will not make the measurements at your chosen frequencies.
38. Check that all the alligator clips are correctly attached and that the volunteer is lying in the correct position and then press the measure button on the front of the device (large circular green button) or tap the "measure" box on the touch screen (figure 1 and 7).

Calibration of the ImpediMed SFB7

ImpediMed recommends that calibration checks be performed at the start of each day of use. This is done using the RRC Test Cell, supplied with the machine.

39. Switch on the machine and set it to BIS mode, by following the instructions above (no. 2, figure 3 and 4).
40. Remove the alligator clips from the ends of the leads.
41. Plug the leads into the appropriate sockets of the test cell (figure 11).

Figure 11. The leads connected to the calibration Test Cell

42. From the starting screen, tap "test"
43. Then tap "start".
44. The screen will display "Calculating".
45. Followed by "passed" in green text or "failed" in red text.
46. If the test fails, an error code will be shown. In thtis instance, contact ImpediMed, your distributor or an authorised service centre, quoting the error code to arrange for service or repair.
47. By tapping "more" you can view graphs.

The *Rzero* value should be 604 ohms (± 5) and the *Rinf* value should be 403 (± 5)

Appendix R Quality improvement protocol

Quality improvement protocol – Hydration care project

Title

Enhancing Accuracy and Completeness of Fluid Chart Documentation in 'Medicine for Older People' (MOP) Wards

Background

In MOP wards, a significant challenge identified is the incomplete documentation of 24-hour fluid balance sheets, particularly for patients in critical dehydration categories. This gap highlights systemic issues in record-keeping and monitoring practices within these wards, impacting patient hydration care.

Objective

To enhance the accuracy and completeness of record-keeping in MOP wards, specifically focusing on the thorough documentation of 24-hour fluid balance sheets for patients in critical dehydration categories.

Methods

1. **Training and Education:**
    a. Targeted training sessions will be conducted for staff on the importance of complete and accurate record-keeping.
    b. Easy-to-follow guidelines and checklists will be developed for completing fluid balance sheets.
2. **Monitoring and Supervision:**
    a. Regular audits of fluid balance sheets will be implemented to ensure compliance with documentation standards.
    b. A supervisory system will be established where senior staff periodically review records for completeness and accuracy.
3. **Feedback and Improvement:**
    a. Regular feedback will be provided to staff based on audit results.
    b. An open culture will be encouraged where staff can suggest improvements to the record-keeping process and Plan-Do-Study-Act (PDSA) model will be used.

Timeline

The timeframe to measure the improvement will 12 months and 'Plan, Do, Study, Act' (PDSA) cycles will be carried out throughout the project.

- Phase 1 (Months 1-3): Staff training and implementation of new guidelines.
- Phase 2 (Months 4-6): Initial audits and feedback sessions.
- Phase 3 (Months 7-12): Ongoing monitoring, supervision and continuous improvement efforts.

Expected Outcome

- Enhanced accuracy and completeness in the documentation of fluid balance sheets.
- Improved patient care through better monitoring of hydration status.
- Development of a culture that values precise and thorough record-keeping.

Responsibilities

- Nursing/Dietitian Project Supervisor: To oversee the training and implementation of new guidelines and conduct audits.
- Nursing Staff: To follow the updated record-keeping procedures.
- Local QI team: To meet once a month, either face to face or virtually to provide feedback and guidance to the QI processes as part of quality assurance.

Conclusion

This protocol aims to address the record-keeping inefficiencies in MOP wards, with a specific focus on the documentation of 24-hour fluid balance sheets. By enhancing training, establishing rigorous monitoring and feedback mechanisms and fostering a culture of continuous improvement, the protocol seeks to improve the quality of patient hydration care in MOP wards.

Appendix S Work Published in a Peer-Reviewed Journal

Alsanie *et al. BMC Geriatrics* (2022) 22:954
https://doi.org/10.1186/s12877-022-03589-0

BMC Geriatrics

RESEARCH Open Access

Detecting low-intake dehydration using bioelectrical impedance analysis in older adults in acute care settings: a systematic review

Saleh Alsanie[1,2†], Stephen Lim[3,4,5†] and Stephen A. Wootton[1,3*]

Abstract

Background: Dehydration is a frequent cause of excess morbidity and poor health outcomes, particularly in older adults who have an increased risk of fluid loss due to renal senescence, comorbidities, and polypharmacy. Detecting dehydration is key to instigating treatment to resolve the problem and prevent further adverse consequences; however, current approaches to diagnosis are unreliable and, as a result, under-detection remains a widespread problem. This systematic review sought to explore the value of bioelectrical impedance in detecting low-intake dehydration among older adults admitted to acute care settings.

Methods: A literature search using MEDLINE, EMBASE, CINAHL, Web of Science, and the Cochrane Library was undertaken from inception till May 2022 and led to the eventual evaluation of four studies. Risk of bias was assessed using the Cochrane tool for observational studies; three studies had a high risk of bias, and one had a low risk. Data were extracted using systematic proofs. Due to insufficient reporting, the data were analysed using narrative synthesis.

Results: One study showed that the sensitivity and specificity of bioelectrical impedance in detecting low-intake dehydration varied considerably depending on the total body water percentage threshold used to ascertain dehydration status. Other included studies supported the technique's utility when compared to conventional measures of hydration status.

Conclusions: Given the scarcity of literature and inconsistency between findings, it is not possible to ascertain the value of bioelectrical impedance for detecting low-intake dehydration in older inpatients.

Keywords: Acute care, Bioelectrical impedance analysis, Dehydration, Older adults, Systematic review

Background

Dehydration is a highly prevalent and burdensome problem that disproportionately affects older hospitalised patients due to their age and comorbidity risk of excess fluid loss and insufficient fluid intake, which results in a net fluid deficit [1]. In physiological terms, dehydration can be defined as a relative reduction in total body water (TBW) volume to less than an individual's usual volume, leading to impaired renal and haemodynamic functions involved in the regulation of blood pressure and systemic organ perfusion [2]. The prevalence of dehydration among the older population varies by geographic region and patient setting and has been reported to be as high as 39% among nursing home residents and approximately 25% among hospitalised patients [3]. The increased risk of dehydration among older adults has been attributed to the age-related decline in renal function, also known as renal senescence, with glomerular

†Saleh Alsanie and Stephen Lim contributed equally are joint first authors.
*Correspondence: saw@soton.ac.uk
[1] School of Human Development and Health, Faculty of Medicine, University of Southampton, Southampton, UK
Full list of author information is available at the end of the article

filtration rate decreasing by more than 50% over the ages of 30–80 years [4, 5].

In most cases, dehydration can be avoided through adequate fluid intake, although chronic comorbidities, such as diabetes, renal disease, cognitive impairment, mental health problems, and polypharmacy, increase the risk and are commonly observed among those with recurrent hydration problems [6]. Common causes of excess morbidity and mortality include hypovolaemia, hypotension, electrolyte disturbances, cardiac arrhythmias, delirium, seizures, renal failure, and hypovolaemic shock [7]. In a landmark study based on 10 million hospital records of patients admitted to hospitals in the United States, older adults with diagnosed dehydration observed 30-day mortality of 17% and one-year mortality of 48%, highlighting that dehydration is a significant issue affecting the vulnerable older population [8].

The recent European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines for hydration in the field of geriatrics state that dehydration in older adults is due to either low fluid intake (due to a lack of drinking), excess fluid loss, or a combination of both; practice guidance remains the mainstay for hydration care in this population group worldwide [9, 10]. The ESPEN guidelines specifically define low-intake dehydration as a shortage of body water that leads to reductions in intracellular and extracellular fluid and, subsequently, increased osmolality across both cellular compartments.

Accurate detection of impending dehydration is key to preventing complications, excess morbidity and mortality among predominantly older adults who represent an already at-risk group for poor outcomes during and following hospitalisation. There is no reliable objective method to assess dehydration in clinical practice to both diagnose and confirm the resolution of dehydration. The diagnosis of dehydration has traditionally depended on clinical symptoms and signs such as moisture of mucous membranes and physiological responses to hypovolaemia, including tachycardia and reductions in blood pressure from baseline values in those who are severely dehydrated [11]. In patients with early or minor dehydration, clinical assessment methods are markedly insensitive, and are associated with delays in initiating hydration therapy and increased risk of complications [12]. More objective measures such as urea, creatinine, and plasma osmolality, and the assessment of urine colour, output, and osmolality, as well as body weight are available not not used routinely in practice due to insufficient sensitivity and reliability, inhibiting early diagnosis and treatment [13, 14].

Bioelectrical Impedance Analysis (BIA) is a portable, easy-to-use, inexpensive and non-invasive method, that is accessible at the point of care and can be repeated frequently with minimal consumable costs [15, 16]. It measures whole-body impedance (Z), the opposition of the body to alternating current consisting of two components: resistance (R) and reactance (Xc). Resistance is the decrease in voltage reflecting conductivity through ionic solutions. Reactance is the delay in the flow of current measured as a phase-shift, reflecting dielectric properties, i.e., capacitance, of cell membranes and tissue interfaces. Both measures will alter with changes in hydration status. BIA is not a direct method for the assessment of body composition and its utility relies on the relationship between impedance measures and the fluid and electrolyte status of the body. In the euhydrated state, impedance measures can be used to predict estimates of total body water (as well as intracellular and extracellular fluid water), and in turn, the proportions of fat and lean by applying suitable (i.e. age-, sex- and population- and device-specific) equations for the calculation of body compartments. However, these conditions are frequently violated in sick and hospitalized patients since disturbed hydration or altered distribution of extra- and intracellular water are often present. In contrast, the measured values of resistance and reactance, and the derived parameter of Phase Angle, are not affected by the factors that affect the assumptions used in the estimation of body composition, have both excellent accuracy and precision, and may offer an objective measure that can be used to mark differences in hydration status in older people at risk of low-intake dehydration in the clinical setting [16–18].

In summary, low-intake dehydration is a common problem that predominantly affects older patients with intermittent illness and can lead to excess morbidity when undetected and untreated. There are various approaches to the diagnosis of low-intake dehydration, including clinical examination and objective quantitative measures of hydration status such as plasma and urine osmolality and specific gravity, although neither of these, whether used in isolation or combination, are sufficiently accurate to diagnose dehydration. More recently, BIA has emerged as a novel approach to diagnosing low-intake dehydration, although this requires further evaluation.

This systematic review specifically sought to explore the use of BIA for low-intake dehydration among older adults admitted to acute hospital care facilities.

Methods

A search for literature pertinent to the research question was undertaken using the electronic databases Ovid MEDLINE and EMBASE, CINAHL (EBSCO), Web of Science Core Collection (indexes SCI Expanded, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI), and Cochrane Central and CDSR. The search terms,

syntaxes, and Boolean operators used for database searching are detailed in Table 1 in accordance with the accepted population, exposure/interest, outcomes, and setting (PE/IOS) framework [19]. Details of the search strategy for each database are included in appendices.

A literature search was performed for randomised controlled trials and observational cross-sectional, cohort, and case–control designs. Search results were limited for publications in peer-reviewed journals in English Language, with time limit from inception till May 2022, and publications which reported on each of the PE/IOS components. The inclusion criteria was both male and female older adults (defined as age $\geq$ 65 years), as this is the usual age threshold to define the population group of older persons who are most affected by dehydration. Such persons had to have low-intake dehydration measured using BIA during the receipt of care within a hospital setting. Studies were not limited by publication date or geographic setting, as it was pertinent to include all relevant evidence. Peer-review was considered necessary to identify and evaluate evidence of sufficient scientific and ethical rigour [20]; details regarding peer-review were either determined from the journal website or from databases indexing the journal. The criteria for publications in English language was necessary to comprehend and collectively analyse the reported outcomes without the need for translation. Studies among children and younger adults were excluded from the review because of the low rate of low-intake dehydration among these population groups. Finally, outcomes regarding the value of BIA for detecting low-intake dehydration had to comprise indices of diagnostic accuracy, such as sensitivity and specificity, as these are widely used among diagnostic accuracy reviews and are amenable to pooled statistical analyses [21]. The inclusion and exclusion criteria are presented in Table 2.

Studies were selected using the usual filtering process of title/abstract and full-text screening, with citations managed using Clarivate Analytics® EndNote X9 referencing software [22]. The results of the study selection are presented in the Results section and in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram in Fig. 1 [23, 24].

The data required for critical appraisal and results synthesis were systematically extracted using pre-developed electronic proformas taken from the Cochrane Handbook for Systematic Reviews and adapted to suit the construct of interest [26]. Data extraction was conducted by two reviewers (SA and SL). Any discrepancies were discussed with a third reviewer (SAW) to reach a consensus. Quality assessment of eligible studies was performed using the Cochrane Risk-of-Bias Tool for Randomised Controlled Trials and a modified version of the Cochrane tool for non-randomised studies [27, 28]. The risk of bias for each study was rated in accordance with Cochrane guidelines as either low, high, or unclear; judgements regarding external validity are noted in the discussion section of this report. Data regarding the diagnostic utility of BIA included consideration of pooled meta-analyses, which would have been conducted using the Cochrane Collaborations RevMan® v5.3 software®. However, the outcome data were not amenable to meta-analyses due to the lack of reporting of true positives, true negatives, false positives, and false negatives. As only one study in the review reported diagnostic accuracy indices, a consistent analytical approach in the form of narrative synthesis was undertaken to describe the value of BIA for detecting low-intake dehydration [29].

Results

Study selection

Following the search for literature using the defined strategy, a total of 2,743 studies were retrieved. Before

Table 1 Search strategy informed by the PE/IOS framework

PE/IOS	Search Terms and Boolean Combinations
Population	'Geriatrics' OR 'aged' OR 'aged subject' OR 'frail elderly' OR 'old* adult*' OR 'old* person*' OR 'old* people' OR 'old* patient*' OR 'old* m#n' OR 'old* wom#n' OR 'old* age' OR 'elder*' OR 'old* male*' OR 'old* female*' OR 'old* population*' OR 'geriatric*' OR 'elderly people' OR 'elderly person' OR 'ageing' OR 'aging' OR 'senior citizen*'
Exposure/interest	'Bioelectrical impedance analysis' OR 'bioelectrical' OR 'electric impedance' OR 'impedance' OR 'BIA' OR 'reactance' OR 'resistance' OR 'bioimpedance' OR 'bioimpedance analysis' OR 'electrical' OR 'phase angle' OR 'ohmic' OR 'capacitance'
Outcomes	'Hydrat*' OR 'dehydrat*' OR 'euhydrat*' OR 'rehydrat*' OR 'body water' OR 'body fluid*' OR 'hypohydrat*' OR 'fluid* balance*' OR 'fluid* imbalance*' OR 'fluid* measur*' OR 'fluid* monitor*' OR 'water* volum*' OR 'water* intake' OR 'water* balance*' OR 'water* imbalance*' OR 'water* measur*' OR 'water* monitor*' OR 'fluid* deficit*' OR 'fluid* manag*' OR 'liquid* manag*' OR 'liquid* volum*' OR 'liquid* intake' OR 'liquid* balance*' OR 'liquid* imbalance*' OR 'liquid* measur*' OR 'liquid* monitor*'
Setting	'Hospital*' OR 'clinical care' OR 'acute care' OR 'hospitalisation'

PE/IOS population, exposure/interest, outcomes, and setting

key: *truncation syntax

Table 2 The inclusion and exclusion criteria used in the review

Study Characteristics (PE/IOS)	Inclusion Criteria	Exclusion Criteria
Research design	Randomised controlled trials and observational studies, including cross-sectional, cohort, and case–control studies	Secondary review research, animal, laboratory-based, and qualitative studies, editorials, letters, case series, and case reports
Publication date	No restriction	-
Language	English	Other languages
Peer-reviewed research	Journals	Articles not subject to peer review
Geographical region	No restriction	-
Study quality	No restriction	-
Population	Older adults aged ≥ 65 years with low-intake dehydration (plasma osmolality ≥ 295 mOsm/kg)	Younger adults aged 18–64 years or children aged < 18 years Older adults with euhydration or plasma osmolality < 295 mOsm/kg
Exposure/interest	Hydration status measured using BIA	-
Outcomes	Diagnostic value, including measures of sensitivity, specificity, total accuracy, and/or positive or negative predictive values	Outcomes irrelevant to the research question
Setting/context	Hospital or other acute healthcare facilities	Community care facilities

BIA bioelectrical impedance analysis, *PE/IOS* population, exposure/interest, outcomes, and setting

screening for titles/abstracts, 758 duplicates were discarded. The remainder 1,985 studies were screened for titles/abstracts, and 1,968 studies which did not fit inclusion criteria or were irrelevant were excluded, leaving 17 articles for full-text review. This final process led to the further exclusion of 13 studies for the following reasons: 1) evaluation of BIA used among older adults in non-hospital or non-acute setting; 2) unclear outcomes regarding the diagnostic value of BIA for low-intake dehydration in older adults; 3) evaluation of BIA used among younger adults and/or children. The remaining four studies met each of the inclusion criteria and were therefore deemed eligible for review.

Study characteristics

The research designs of the four studies (Table 3) identified for collective review [28,29,30,] comprised two single-centre prospective observational cohort studies [30, 31], a multi-centre prospective cohort study [22] and a randomised non-controlled study [32].

A summary of the findings of the four studies is presented in Table 4. The populations and sample sizes were as follows: older adults ($n=61$) admitted to the intensive care unit who received mechanical ventilation and had an expected length of stay of ≥ 48 h [30], older adults (n = 27) admitted to hospital with acute stroke [31], older adults ($n=32$) admitted to medical and surgical wards [22], and older adults ($n=169$) admitted to geriatric wards for acute medical problems across six hospitals [32].

The mean age of subjects across the studies ranged between 63 and 80.1 years; the study of subjects with a mean age of 63 years reported by Jones et al. [30] was included due to the predominance of older adults in the cohort. Patient hydration status was ascertained using the following techniques: bioelectrical impedance vector analysis [30], multi-frequency BIA [22, 31], and single-frequency BIA [32].

BIA outcome measures used to determine hydration status differed between studies and included TBW percentage, intracellular water percentage, extracellular water percentage, and extracellular water:intracellular water ratio. Only one study [31] reported diagnostic accuracy indices, as noted in the meta-analysis and narrative synthesis subsections.

Quality assessment

As no studies included in the review were randomised controlled trials, the Risk of Bias for Non-Randomised Studies tool was used to inform the risk of bias among the observational studies [33]. A summary of the assessments is provided in Table 5. Overall, three studies were rated as having a low risk of bias [22, 30, 32], whilst the remaining study observed an unclear risk of bias due to uncertainty regarding selection bias and bias related to missing data [31]. Specific insight into the factors leading to such judgements of quality is provided below, in accordance with the recommendations of Mallen, et al. [33].

Two of the studies [22, 30] recruited subjects using consecutive sampling techniques, which is a credible approach to avoiding selection bias in non-randomised observational studies, given that there is no risk of selectivity in including or excluding participants with

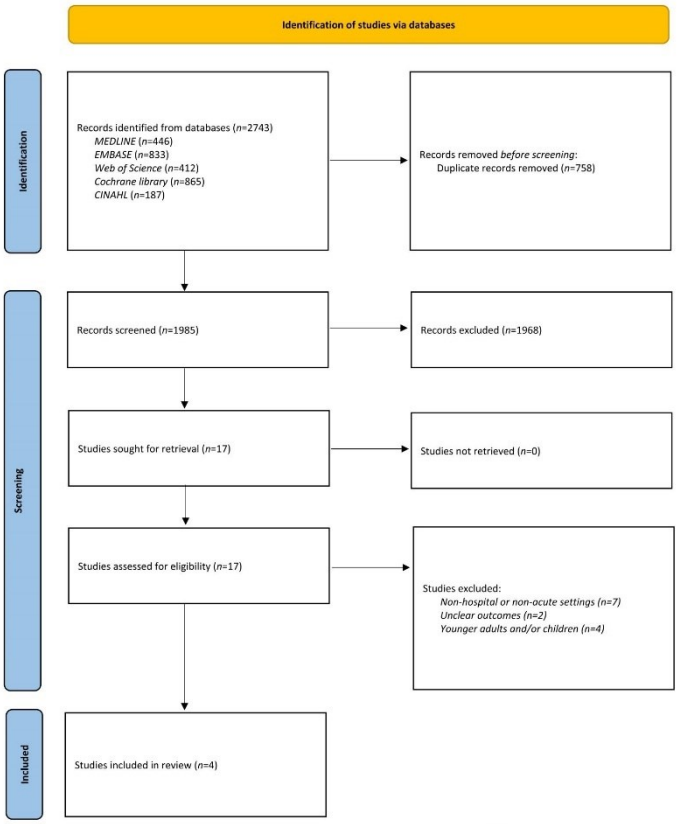


Fig. 1 The process by which the studies were selected, depicted using the PRISMA flow diagram [25]. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

characteristics that may skew measured outcomes. Of the two other studies, Powers, et al. [32] utilised random sampling, while the sampling technique was not sufficiently described by Kafri, et al. [31], leading to low and unclear selection bias risk judgements, respectively. As each studied different specific populations the external validity (generalisability of the findings to all older patients) is poor. Jones, et al. [30] restricted subjects to those admitted to the intensive care unit and who were expected to be ventilated for longer than 48 h, while Kafri, et al. [31] included subjects with incident stroke, which co-existed with extensive exclusion criteria, thus impairing external validity to the general older population. Ritz, et al. [22] and Powers, et al. [32] and included older adults admitted to medical and surgical wards for various clinical reasons and with minimal exclusion criteria offering broader generalisability to other older adult populations. Sample size also affected the external validity of most studies [30–32] in this review, with only one study [22] attaining a reasonably sized representative sample (i.e. 169 subjects).

The studies included in this review were judged to have a low risk of confounding bias, as the authors accounted for multiple demographic and clinical factors in the statistical analyses, which were considered important or potential influencers of hydration status. There was also a minimal risk of misclassification bias across all studies

Table 3 The selected studies included in the current review

Author and Year	Design	Setting	Participants (sample size)	Bioelectrical Impedance Analysis	Comparators
Jones, et al. [30] (2015)	Prospective, observational cohort (single centre)	Australia	Subjects ($n = 61$) admitted to the ICU who received mechanical ventilation and with an expected hospital stay of ≥ 48 h Patients with dehydration had a mean age of 66 years Sex: Female (38%) and male patients (62%)	Bioelectrical impedance vector analysis (Renal EFG BIVA™ Technology; EFG Diagnostic, Belfast, UK) Impedance of 50 kHz Pairs of electrodes were placed on the dorsum of the wrist and the ipsilateral ankle	A comparator was not used
Kafri, et al. [31] (2013)	Prospective, observational cohort (single centre)	United Kingdom	Older adults ($n = 27$) admitted to hospital with acute stroke Patients with dehydration had a mean age of 73.5 years Sex: Not reported	Multi-frequency BIA (Maltron BioScan® 920–2; Maltron International, Essex, UK) Impedance of 5 kHz, 50 kHz, and 100 kHz Pairs of electrodes were placed on the talus and the third and fifth digits of the foot and the third and fifth knuckles of the hand and the wrist	Serum osmolality was analysed using freezing point depression (295–300 mOsm/kg) (i.e. impending dehydration), with current dehydration being ≥ 301 mOsm/kg Serum osmolarity (mOsm/L) was calculated from combined concentrations of serum sodium, potassium, glucose, and urea ([2 × Na +] + [2 × K +] + urea + glucose) (i.e. 295–300 mOsm/L [impending dehydration], with dehydration at the time of the study of ≥ 301 mOsm/L)
Powers, et al. [22] (2009)	Randomised non-controlled study	United States	Older adults ($n = 32$) admitted to medical and surgical wards Patients with dehydration had a mean age of 77.1 years Sex: Female (63%) and male patients (37%)	Single-frequency BIA (RJL Systems® Analyser, Clinton Township, Michigan, USA) Impedance of 50 kHz Pairs of electrodes were placed on the dorsal surfaces of the right hand and foot proximal to the metacarpal, phalangeal, and metatarsal phalangeal joints One additional pair of electrodes were applied at the pisiform bone of the right wrist and between the medial and lateral malleoli of the right ankle	TBW was determined by ^2H_2O dilution, and ECW was measured by using sodium bromide (NaBr) dilution The participants provided baseline blood samples To measure TBW, the participants were asked to drink water containing ^2H_2O at an amount of 30 mg/kg of body weight. To measure ECW, the participants were asked to drink water containing NaBr at an amount of 70 mg/kg of body weight A second blood sample was obtained 3–4 h after the oral dose. Plasma was separated from the blood samples Isotope ratio mass spectroscopy was used to determine ^2H_2O in the plasma. TBW was calculated using the following equation: TBW = [^2H_2Odose/(^2H_2O 3 h − ^2H_2O 0 h)]/1.04 To measure ECW, NaBr dilution was assayed by using a high-performance liquid chromatography anion-exchange method after serum ultrafiltration. The equation used for the ECW calculation was: ECW = [Br Dose/(Br dose 3 h − Br dose 0 h)] × 0.90 × 0.95 ICW was calculated as TBW − ECW

Table 3 (continued)

Author and Year	Design	Setting	Participants (sample size)	Bioelectrical Impedance Analysis	Comparators
Ritz [32] (2001)	Prospective observational cohort (multi-centre)	France	Older adults ($n = 169$) admitted to geriatric wards for acute medical problems across six hospitals Patients with dehydration had a mean age of 81.4 years Sex: Female (64%) and male (36%) patients	Multi-frequency BIA (Analycor-3®; Spengler, Cachan, France) Impedance of 5 kHz, 50 kHz, and 100 kHz, with current of 400 μA Pairs of electrodes were placed on the distal end of the third metacarpal bone and the distal end of the second metatarsal bone. One additional pair of electrodes was applied between the styloid processes of the radius and ulna and between the two malleoli of the ankle	Dilution measurements of deuterated water ($H_2^{18}O$) for TBW and Br dilution for ECW The patients were considered dehydrated if they had plasma sodium levels of ≥ 142 mmol/L, and they were considered euhydrated if their plasma sodium concentrations were ≤ 135 mmol/L At baseline, overnight fasting (approximately 12 h) was required, and the participants provided plasma and urine samples to determine the natural abundance of $H_2{}^{18}O$ enrichment and Br concentration An amount of 2% of $H_2{}^{18}O$-enriched water (approximately 50 g) was orally administered to the subjects, and 20 g of potassium Br syrup (containing approximately 1 g of Br) was given to half the participants. After an interval of 4–5 h, the plasma and urine samples were collected The following equation was used to calculate ECW after considering the mean Br plasma concentration 4 and 5 h after the dose: ECW = 0.90 × 0.95 × (Br dose) / [delta(Br plasma)] Br dose = the dose given and delta (Br plasma) = the difference in mean plasma concentration between the administration of the dose and the baseline concentration

[2] H_2O deuterium oxide, *Br* bromide, *EBW* extracellular water, *ICU* intensive care unit, *NaBr* sodium bromide, *TBW* total body water, $H_2{}^{18}O$ water enriched with oxygen-18

Table 4 A summary of the findings of the four included studies

Author and Year	BIA Equipment/Protocol	BIA data (R [Ohm/m]; Xc [Ohm/m] and Pa [degrees])	Measure of Hydration Status	Descriptive Findings
Jones, et al. [30] (2015)	Bioelectrical impedance vector analysis (Renal EFG BIVA™ Technology; EFG Diagnostic, Belfast, UK) Impedance of 50 kHz Pairs of electrodes were placed on the dorsum of the wrist and the ipsilateral ankle The measurements were taken twice daily (in the morning and afternoon) for the first five days of each patient's stay in the ICU or until ICU discharge, where the patients were positioned horizontally and placed in the supine position for ≥ 2 min	Dehydration ($n = 14$): R = 321.0 Xc = 43.6 Pa = 9.1 Euhydration ($n = 22$): R = 314.0 Xc = 29.6 Pa = 95.5 Overhydration ($n = 25$): R = 224.0 Xc = 16.5 Pa = 3.8	A quantitative estimation was made of TBW volume as a percentage of fat-free body mass Dehydration (TBW of ≤ 72% of fat-free body mass) Euhydration (TBW of 73–74% of fat-free body mass) Overhydration (TBW of ≥ 75% of fat-free body mass)	BIA was used to categorise the patients according to hydration status using TBW volume thresholds of ≤ 72% (signifying dehydration), 73–74% (reflecting normal hydration), and ≥ 75% (indicating overhydration). While no direct measures of diagnostic accuracy were reported given the lack of a comparator group, the results showed that BIA reliably identified dehydration based on positive physiological responses to fluid challenges and maintenance fluid therapy. Dehydration, identified using BIA, was associated with a non-significant increase in the requirement for renal replacement therapy ($p = 0.800$), length of ICU stay ($p = 0.870$), length of hospital stay ($p = 0.220$), admission to intensive care ($p = 0.890$), and the rate of hospital mortality ($p = 0.550$) compared to normally hydrated subjects (all $p > 0.05$)
Kafri, et al. [31] (2013)	Multi-frequency BIA (Maltron BioScan® 920–2; Maltron International, Essex, UK) Impedance of 5 kHz, 50 kHz, and 100 kHz Pairs of electrodes were placed on the talus and the third and fifth digits of the foot and on the third and fifth knuckles of the hand and the wrist The participants fasted for at least two hours and were asked to remove any jewellery and to micturate if they wished before the BIA measurements were taken Two consecutive measurements were taken over a couple of seconds within 20 min of the blood samples being taken while the subjects were in the supine position. The recordings were repeated a few minutes later. An average of the two consecutive measurements was calculated. The first data set was used in the event of variation of ≥ 3% Height, weight, gender, age, and ethnicity were entered into the MF-BIA device BIA outputs (the mean of the two readings) were used to calculate TBW (L) and ECW (L) using published equations for older people TBW, ECW, and ICW were calculated as body weight percentages using equations specifically developed for older adults (rather than those already programmed in the device) TBW was estimated using the Vaché equation: TBW = (2.896) + (0.366*height^2/R100) + (0.137*weight) + (2.485*G) R100 = impedance at 100 Hz, and G = gender, with a value of 1 for men and 0 for women ECW was estimated using the Visser equation: ECW (Women) = (1.7) + (0.2*height^2)/(R5) + (0.057*weight) ECW (men) = (4.8) + (0.225* height^2)/(R5)	Not reported	A quantitative estimation was made of (1) TBW volume as a percentage of body weight, (2) ICW as a percentage of TBW, and (3) ECW as a percentage of TBW using MF-BIA (using published equations for older adults)	The accuracy of BIA varied with the threshold of TBW volume congruent with dehydration. The highest sensitivity (100%) was observed for TBW volume of 55% with low corresponding specificity (i.e. of only 14%). The highest specificity (91%) was observed for a TBW volume of 45%; however, the corresponding sensitivity was only 17%. The positive and negative predictive values were 25–33% and 79–100%, respectively. Optimal accuracy with a modest sensitivity and specificity (62–67%) was observed for a TBW volume threshold of 52%

Table 4 (continued)

Author and Year	BIA Equipment/Protocol	BIA data (R [Ohm/m]; Xc [Ohm/m] and Pa [degrees])	Measure of Hydration Status	Descriptive Findings
Powers, et al. [22] (2009)	Single-frequency BIA (Real-Time RJL Systems® Analyser, Clinton Township, Michigan, USA) Impedance of 50 kHz Pairs of electrodes were placed on the dorsal surfaces of the right hand and foot proximal to the metacarpal, phalangeal, and metatarsal phalangeal joints One additional pair of electrodes was applied at the pisiform bone of the right wrist and between the medial and lateral malleoli of the right ankle The participants were placed in the supine position, with their arms and legs abducted at an angle of 30–45°. Overnight fasting was required	Not reported	R, Xc, Ht_2, wt, gender, age, and amount of exercise were entered into a software programme called Cyrus TBW and ECW were estimated using the BIA device	The use of BIA was associated with small inter-individual variability in relation to the accurate measurement of TBW volume percentage (4.1%), compared to the reference tests, which suggests that the method feasibly identified dehydration and changes in hydration status. ECW volume, measured using BIA, was not significantly different to that measured using NaBr ($p = 0.430$)
Ritz [32] (2001)	Multi-frequency BIA (Analycor-3®; Spengler, Cachan, France) Impedance of 5 kHz, 50 kHz, and 100 kHz, with current of 400 μA Pairs of electrodes were placed on the distal end of the third metacarpal bone and the distal end of the second metatarsal bone. One additional pair of electrodes was applied between the styloid processes of the radius and ulna and between the two malleoli of the ankle The measurements were taken on both sides of the body. Overnight fasting (approximately 12 h) was required. The measurements were taken after resting for at least 30 min and up to five hours post the administration of the $H_2^{18}O$ and Br doses	Not reported	A quantitative estimation was made of TBW and ECW as a percentage of body weight TBW was estimated at 50 kHz and 100 kHz using the following equations: TBW (l) 2.896 0.366 Ht^2 = +/-/100 + 0.137 wt + 2.485G TBW (l) 3.026 0.358 Ht^2 = +/-/50 + 0.149 wt + 2.924G ECW was estimated at 5 kHz using the following equations: ECW (Segal, l) = -6.1 + 0.284 Ht^2/5 + 0.112 wt ECW (Visser, men, l) = 4.8 + 0.225 Ht^2/5 ECW (Visser, women, l) = 1.7 + 0.2 Ht^2/5 + 0.057 wt In all the equations, Ht was measured in centimetres, and wt in kilogrammes. I signifies 'impedance', and G 'gender' (with values of 0 and 1 for women and men, respectively)	Sufficient comparability was observed between BIA and the reference tests in measuring TBW volume; notably, the method was able to discriminate between dehydration and normal hydration based on a TBW volume of 0.25–0.39 L. In this regard, average TBW volume in normally hydrated subjects was 0.69–0.83 L, considerably higher than that in dehydrated subjects

BIA bioelectrical impedance analysis, *Br* bromide, *ECW* extracellular water, *Ht* height, *ICU* intensive care unit, *ITW* intracellular water, *MF-BIA* multi-frequency bioelectrical impedance analysis, *NaBr* sodium bromide, *Pa* phase angle, *R* resistance, *TBW* total body water, *wt* weight, *Xc* reactance, *I* impedance

Table 5 Critical appraisal of the quality of the included studies using the Cochrane ROBINS-I tool [34]

Included Studies	Selection Bias	Confounding Bias	Classification of Exposure Bias	Missing Data Bias	Outcome Measurement Bias	Reporting Bias	Overall Risk of Bias
Jones, et al. [50]	L	L	L	L	L	L	L
Kafri, et al. [51]	U	L	L	L	H	H	H
Powers, et al. [53]	L	L	L	L	H	H	H
Ritz [52]	L	L	L	L	H	H	H

[*] *U* unclear; *H* high, *L* low

in this review, given that evidence-based thresholds were used to categorise subjects into hydration status categories (euhydrated, dehydrated, and over-hydrated). There was a low risk of outcome measurement bias due to the homogenous derivation of hydration status based on calculations of TBW through BIA. The study by Jones, et al. [30] was the only one to denote/report on the raw data measures for BIA, including resistance, reactance, and phase angle, and thus was considered to have a low risk of reporting bias. While the other three studies in this review did not report the raw data measures but used these to derive the predicted values of TBW, the risk of reporting and measurement biases were high. This might have affected the overall accuracy in diagnosing the hydration status of the participants as the raw data measures are independent of regression equations or weight and can be carried out in situations where BIA assumptions are not valid for estimating body fluid compartments.

Narrative synthesis

In the study conducted by Kafri, et al. [31], the authors determined the diagnostic accuracy of BIA for dehydration by comparing BIA-derived estimates of TBW with measurements of plasma osmolality. The diagnostic accuracy was found to vary markedly depending on which threshold of TBW was used to define dehydration. The highest sensitivity (100%) was observed for a TBW percentage threshold of 55%, although the corresponding specificity was only 14%. The positive and negative predictive values were 25% and 100%, respectively. In contrast, the highest specificity (91%) was observed for the TBW percentage threshold of 45%, although the corresponding sensitivity was only 17%. The positive and negative predictive values were 33% and 79%, respectively. Similar observations were found when diagnostic accuracy was based on derived estimates of intracellular and extracellular water percentages and extracellular to intracellular water ratios, with progressive increases in sensitivity and progressive decreases in specificity when the threshold values increase. The most desirable balance of accuracy was observed at a TBW percentage threshold of 52%, which yielded a modest sensitivity (67%) and specificity (62%).

Powers, et al. [32] found that when compared to estimates of TBW by deuterium dilution. BIA-derived estimates of TBW were comparable with only a small mean difference in TBW percentage (4.1%) with modest inter-individual differences suggesting that the two approaches to estimating TBW were comparable in detecting differences in hydration status; both were far superior to estimates of TBW derived using conventional predictive approaches using anthropometry.

Ritz, et al. [52] also compared BIA-dervied estimates of TBW against estimates of TBW by deuterium dilution in a large multicentre trial in patients with differing degrees of hydration from dehydrated, euhydrated and overhydrated. They found that TBW could be estimated accurately by BIA and whilst there was a small difference in the estimated TBW, this difference was not affected by hydration status and concluded that BIA could be used to moniter changes in fluid balance across a range of hydration disorders.

Finally, in the study reported by Jones, et al. [30], the authors used bioelectrical impedance vector analysis to classify patients into three categories of hydration status using TBW percentage thresholds of $\leq 72\%$ (signifying dehydration), 73–74% (indicating normal hydration), and $\geq 75\%$(denoting overhydration). They found higher resistance, with lower reactance, and phase angle values in dehydrated than in euhydrated and overhydrated patients; values that differed progressively from states of overhydration to dehydration and reflected the changes in hydration status with therapeutic intervention. The authors also found that dehydration ascertained using bioelectrical impedance vector analysis was associated with non-significant increases in the need for renal replacement therapy and admission to the intensive care unit, intensive care unit and hospital lengths of stay, and the rate of hospital mortality when compared to normally hydrated subjects (all $p > 0.05$).

Discussion

This systematic review sought to explore the diagnostic utility of BIA for the detection of low-intake dehydration among older adults admitted to acute care facilities. Of the four studies that met the inclusion criteria were identified, only Kafri, et al. [31] reported the diagnostic accuracy of a BIA-derived estimate of TBW against a clinical measure of dehydration (osmolality). The studies by Ritz, et al. [22] and Powers, et al. [32] compared the BIA-dervied estimates of TBW against those derived by deuterium-dilution. Whilst they found some degree of concordance between the different approaches to estimating TBW they did not compare them against other clinical measures. Jones, et al. [30] reported differences in impedance values in those they categorised as dehydrated compared to those who were eu/overhydrated. They adopted a qualitative approach using vector analysis fidning demonstrating changes in the vector with fluid replacement but once again made no comparision against clinical measures. Taken together, the scarcity and quality of published studies and heterogeneity of observations does not permit any firm conclusion as to the diagnostic utility of BIA in the detection of low-intake dehydration in older people in the acute clinical setting.

Some support in using BIA to detect dehydration may be provided by studies in younger adults and children or in the non-acute clinical setings or in the community. Several such studies were revealed by the search strategy but were not included in the final evaluation as they did not meet the inclusion criteria. Of particular interest, Shimizu, et al. [25] showed that resistance measures using BIA could derive thresholds to discriminate dehydration from normal hydration in a cohort of adults from an outpatient department. The authors found that those adults identified as dehydrated using clinical assessment had a higher resistance than those normally hydrated and that resistance correlated well with plasma osmolality and other laboratory biomarker measurements. Similarly, Dal Cin, et al. [35] found that BIA could detect dehydration induced by furosemide therapy in a small series of young adults with normal health. In adults with renal disease, O'Lone et al. [36] demonstrated that multifrequency bioimpedance spectroscopy in peritoneal dialysis patients was an independent predictor of patient survival whilst Park et al. [37] have demonstrated the cinical usefulness of bioimpedance analysis for assessing volume status in patients receiving maintenance dialysis.

In contrast, Rikkert, et al. [38] showed that the sensitivity of BIA for detecting dehydration among community-dwelling older adults was only 14% when compared to a reference comparator comprising a composite of clinical examination, laboratory tests, and changes in weight. Finally, a recent Cochrane review reported by Hooper, et al. [39] evaluated various measures to detect dehydration in older adults, including BIA, but was primarily based on studies excluded from this review conducted among populations attending non-hospital or non-acute settings. The review concluded that clinical assessment measures of hydration status had greater feasibility, cost-effectiveness, and speed than that derived using BIA.

Based on the limited evidence included in this review, measured impedance values appear to change with altered hydration status but the diagnostic utility of detecting low-intake dehydration in older people in the acute care setting remains unclear. This review has several limitations. Firstly, the literature search comprised an informed series of sources and an extensive series of terms; however, there is a residual risk that one or more studies were precluded from the review. Second, this issue could have been exacerbated by the restriction criteria defined for eligible studies. Third, there were only four studies that met the inclusion criteria which together with marked methodological heterogeneity precluded inter-study comparisons and meta-analysis. Finally, variances in outcomes across the studies could have resulted from a difference in BIA equipment and/or a lack of quality control or calibration of the instruments.

Whilst severe dehydration may be readily identified in the acute setting using conventional clinical assessments, those with less overt or early dehydration may be overlooked, undiagnosed and untreated. Future primary research should explore the usefulness of BIA as an adjunct to aid diagnostic accuracy, especially when there is clinical uncertainty, in older adults in high risk settings such as acute care. Future publications would have greater value if they reported the measured values of resistance, reactance and phase angle in addition to the derived estimates of body water and report how they relate to clinical measures of hydration used in routine care.

Abbreviations

BIA: bioelectricalimpedance analysis; ESPEN: EuropeanSociety for Clinical Nutrition and Metabolism; PRISMA: PreferredReporting Items for Systematic Reviews and Meta-Analyses; TBW: totalbody water.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-022-03589-0.

Additional file 1.

Additional file 2.

Additional file 3.

Additional file 4.

Additional file 5.

Acknowledgements
Not applicable

Authors' contributions
SA and SL are the joint first authors who conceived and designed the study and search strategy, screened the title/abstract and full-text, assessed quality of the included studies, extracted and analysed data and wrote the manuscript. SAW conceived and designed the study and search strategy, assessed quality of the included studies and analysed data. All authors reviewed and provided comment on the manuscript. All authors read and approved the final manuscript.

Funding
There was no direct funding to the review. SA is supported by the College of Applied Health Sciences in Arrass, Qassim University, Saudi Arabia.

Availability of data and materials
The dataset used and analysed during this review are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
SAW leads an investigator-led Collaborative Research Agreement between the University of Southampton, University Hospitals Southampton NHS Trust and seca GmbH. The design, conduct and reporting of the review were done without any financial support from any company, and no company was informed of the design, conduct and preparation of the manuscript. SA and SL declare that they have no competing interests.

Author details
[1]School of Human Development and Health, Faculty of Medicine, University of Southampton, Southampton, UK. [2]Department of Clinical Nutrition, College of Applied Health Sciences in Arrass, Qassim University, Buraydah, Saudi Arabia. [3]NIHR Southampton Biomedical Research Centre, University of Southampton and University Hospital Southampton NHS Trust, Southampton, UK. [4]Academic Geriatric Medicine, University of Southampton, Southampton, UK. [5]NIHR ARC Wessex, University of Southampton, Southampton, UK.

Received: 15 December 2021 Accepted: 4 November 2022
Published online: 12 December 2022

References

1. Bunn D, Hooper L, Welch A. Dehydration and malnutrition in residential care: recommendations for strategies for improving practice derived from a scoping review of existing policies and guidelines. Geriatrics. 2018;3:77.
2. Cheuvront SN, Kenefick RW, Charkoudian N, Sawka MN. Physiologic basis for understanding quantitative dehydration assessment. Am J Clin Nutr. 2013;97:455–62.
3. Paulis SJ, Everink IH, Halfens RJ, Lohrmann C, Schols JM. Prevalence and risk factors of dehydration among nursing home residents: a systematic review. J Am Med Dir Assoc. 2018;19:646–57.
4. Lindeman RD, Tobin J, Shock NW. Longitudinal studies on the rate of decline in renal function with age. J Am Geriatr Soc. 1985;33:278–85.
5. López-Otín C, Blasco MA, Partridge L, Serrano M, Kroemer G. The hallmarks of aging. Cell. 2013;153:1194–217.
6. El-Sharkawy AM, Sahota O, Maughan RJ, Lobo DN. The pathophysiology of fluid and electrolyte balance in the older adult surgical patient. Clin Nutr. 2014;33:6–13.
7. El-Sharkawy AM, Sahota O, Lobo DN. Acute and chronic effects of hydration status on health. Nutr Rev. 2015;73(Suppl 2):97–109.
8. Warren JL, Bacon WE, Harris T, McBean AM, Foley DJ, Phillips C. The burden and outcomes associated with dehydration among US elderly, 1991. Am J Public Health. 1994;84:1265–9.
9. Volkert D, Beck AM, Cederholm T, Cruz-Jentoft A, Goisser S, Hooper L, et al. ESPEN guideline on clinical nutrition and hydration in geriatrics. Clin Nutr. 2019;38:10–47.
10. Masot O, Miranda J, Santamaría AL, Pueyo EP, Pascual A, Botigué T. Fluid intake recommendation considering the physiological adaptations of adults over 65 years: a critical review. Nutrients. 2020;12:3383.
11. Rushing J. Assessing for dehydration in adults. Nursing. 2009;39:14.
12. Vivanti AP. Screening and identification of dehydration in older people admitted to a geriatric and rehabilitation unit. https://eprints.qut.edu.au/16635/ (2007). Accessed 22 Feb 2021.
13. Vivanti A, Harvey K, Ash S, Battistutta D. Clinical assessment of dehydration in older people admitted to hospital: what are the strongest indicators? Arch Gerontol Geriatr. 2008;47:340–55.
14. Grandjean AC, Grandjean NR. Dehydration and cognitive performance. J Am Coll Nutr. 2007;26(Suppl 5):549S-5554.
15. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis—part I: review of principles and methods. Clin Nutr. 2004;23:1226–43.
16. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis—part II: utilization in clinical practice. Clin Nutr. 2004;23:1430–53.
17. Ugras S. Evaluating of altered hydration status on effectiveness of body composition analysis using bioelectric impedance analysis. Libyan J Med. 2020;15:1741904.
18. Goldberg LR, Heiss CJ, Parsons SD, Foley AS, Mefferd AS, Hollinger D, et al. Hydration in older adults: the contribution of bioelectrical impedance analysis. Int J Speech Lang Pathol. 2014;16:273–81.
19. Pollock A, Berge E. How to do a systematic review. Int J Stroke. 2018;13:138–56.
20. Cowell JM. Importance of peer review. J Sch Nurs. 2014;30:394–5.
21. Šimundić AM. Measures of diagnostic accuracy: basic definitions. EJIFCC. 2009;19:203–11.
22. Ritz P. Bioelectrical impedance analysis estimation of water compartments in elderly diseased patients: The Source Study. J Gerontol A Biol Sci Med Sci. 2001;56:M344–8.
23. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol. 2009;62:e1-34.
24. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. J Clin Epidemiol. 2021;134:103–12.
25. Shimizu M, Kinoshita K, Maeno T, Kobayashi H, Maeno T. Can total body resistance measured using bioelectrical impedance analysis be the index of dehydration in older Japanese patients? J Clin Med Res. 2017;9:926–8.
26. The Cochrane Collaboration. Data extraction forms. https://dplp.cochrane.org/data-extraction-forms (2021) Accessed 02 Dec 2020.
27. Higgins JP, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011;343: d5928.
28. Hinneburg I. ROBINS-1: a tool for assessing risk of bias in non-randomised studies of interventions. Med Monatsschr Pharm. 2017;40:175–7.
29. Lisy K, Porritt K. Narrative synthesis: considerations and challenges. Int J Evid Based Healthc. 2016;14:201.
30. Jones SL, Tanaka A, Eastwood GM, Young H, Peck L, Bellomo R, et al. Bioelectrical impedance vector analysis in critically ill patients: a prospective, clinician-blinded investigation. Crit Care. 2015;19:290.
31. Kafri MW, Myint PK, Doherty D, Wilson AH, Potter JF, Hooper L. The diagnostic accuracy of multi-frequency bioelectrical impedance analysis in diagnosing dehydration after stroke. Med Sci Monit. 2013;19:548–70.
32. Powers JS, Choi L, Bitting R, Gupta N, Buchowski M. Rapid measurement of total body water to facilitate clinical decision making in hospitalized elderly patients. J Gerontol A Biol Sci Med Sci. 2009;64:664–9.
33. Mallen C, Peat G, Croft P. Quality assessment of observational studies is not commonplace in systematic reviews. J Clin Epidemiol. 2006;59:765–9.
34. Sterne JA, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ. 2016;355: i4919.

35. Dal Cin S, Braga M, Molinari M, Cristallo M, Di Carlo V. Role of bioelectrical impedance analysis in acutely dehydrated subjects. Clin Nutr. 1992;11:128–33.
36. O'Lone EL, Visser A, Finney H, Fan SL. Clinical significance of multi-frequency bioimpedance spectroscopy in peritoneal dialysis patients: independent predictor of patient survival. Nephrol Dial Transplant. 2014;29:1430–7.
37. Park JH, Jo YI, Lee JH. Clinical usefulness of bioimpedance analysis for assessing volume status in patients receiving maintenance dialysis. Korean J Intern Med. 2018;33:660–9.
38. Olde Rikkert MG, Deurenberg P, Jansen RW, van't Hof MA, Hoefnagels WH. Validation of multi-frequency bioelectrical impedance analysis in detecting changes in fluid balance of geriatric patients. J Am Geriatr Soc. 1997;45:1345–51.
39. Hooper L, Abdelhamid A, Attreed NJ, Campbell WW, Channell AM, Chassagne P, et al. Clinical symptoms, signs and tests for identification of impending and current water-loss dehydration in older people. Cochrane Database Syst Rev. 2015. https://doi.org/10.1002/14651858.

Publisher's Note

Appendix T Poster Presented in a Conference

Understanding the Scale of Low-Intake Dehydration on 'Medicine for Older People' Wards: A Mixed-Methods Study

Saleh Alsanie[1,2], Kinda Ibrahim[3,4,5], Stephen Lim[3,4,6], Stephen Wootton[1,6]

[1]School of Human Development and Health, Faculty of Medicine, University of Southampton, Southampton, UK, [2]Department of Clinical Nutrition, College of Applied Health Sciences in Arrass, Qassim University, Buraydah, Saudi Arabia, [3]Academic Geriatric Medicine, University of Southampton, Southampton, UK, [4]NIHR ARC Wessex, University of Southampton, Southampton, UK, [5]School of Primary Care, Population Sciences and Medical Education, Faculty of Medicine, University of Southampton, Aldermoor Health Centre, Aldermoor Close, Southampton, UK, [6]NIHR Southampton Biomedical Research Centre, University of Southampton and University Hospital Southampton NHS Trust, Southampton, UK.

Introduction 1

- Dehydration is a serious concern for patients during their hospital stay, particularly for older adults[1]. The ageing process, combined with certain illnesses such as dementia, makes older adults particularly vulnerable to chronic and acute dehydration[1,2].
- Recent studies have shown that traditional signs and symptoms of low-intake dehydration (i.e. a deficiency of water due to insufficient drinking) may not always indicate its presence in older inpatients, which can lead to incorrect or missed assessments. This can cause significant morbidity including falls, constipation, delirium, respiratory and urinary tract disorders, and even death[2,3].
- Diagnosing low-intake dehydration early on is difficult, and treatment delays can compound the negative consequences of dehydration[1,3].
- We sought to determine the scope and practice of detecting and managing low-intake dehydration in 'Medicine for Older People' (MOP) wards at University Hospital Southampton (UHS).

Study Aim, Objectives and Research Questions 2

Aim

To comprehensively assess hydration care for older inpatients admitted to 'Medicine for Older People' (MOP) wards at the University Hospital Southampton (UHS).

Objectives

This study was structured into two distinct phases employing both quantitative and qualitative methods:

1. **Quantitative Phase (Phase 1):** a service evaluation focused on reviewing patients' documentation and assessing the completion of a local hydration assessment tool and hydration/fluid balance charts for patients at risk of dehydration.
2. **Qualitative Phase (Phase 2):** qualitative interviews aimed at understanding the beliefs and perspectives of the medical staff regarding hydration care.

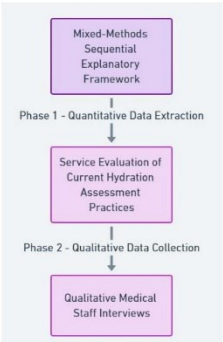
Research Questions

1. **Quantitative Research Question:** "Is low-intake dehydration routinely identified and managed accordingly in Medicine for Older People (MOP) settings?" This question evaluates the current practice in identifying and addressing low-intake dehydration in older inpatients.
2. **Qualitative Research Question:** "What are the experiences of geriatric staff towards dehydration assessment and the current practice?" This question seeks to explore the perceptions and experiences of medical and nursing staff in MOP wards concerning the assessment and management of dehydration.

Methods 3

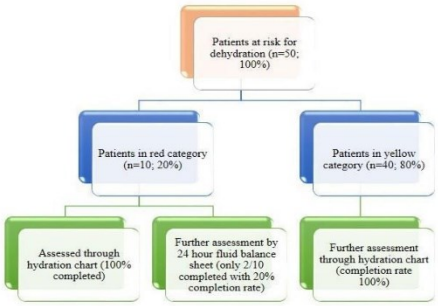
A sequential explanatory mixed-methods design was employed.

- **Phase 1 (Quantitative):** A service evaluation was conducted via a prospective chart review in May 2022. Fifty patients aged 65 and above who were deemed 'Medically Optimised for Discharge' were included. The evaluation focused on completion of hydration risk assessment tools, fluid balance charts and medical and nursing notes review.
- **Phase 2 (Qualitative):** Semi-structured interviews with MOP ward staff explored their beliefs and experiences concerning hydration care.



Quantitative Results 4

- All 50 patients in the cohort were at risk for dehydration; 80% had hydration assessment within the first 24 hours of admission, while the remaining 20% were not assessed within this critical initial period.
- Challenges were noted in the consistency of performing hydration assessments and fluid balance charts.

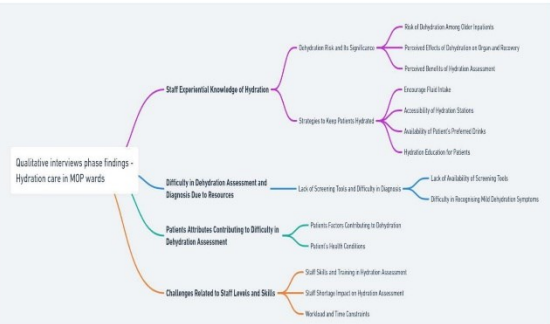


Qualitative Results 5

- Four key themes were identified: staff experiential knowledge of hydration, challenges in dehydration assessment due to resource limitations, patient attributes contributing to assessment difficulty, and challenges related to staff levels and skills.

- *"Increased length of hospital stay definitely because if a patient is not drinking and eating, it is a really difficult one."* (P2_N, Nurse)

- *"So sometimes we might miss out some of the patients... because of the busyness."* (P9_N, Nurse)



Conclusions

- The study emphasises the critical importance of hydration assessment in older inpatients, identifying significant challenges in current practices.
- Comprehensively examining the practice, challenges, and perspectives regarding hydration care for older inpatients in MOP wards revealed areas for improvement and future research directions.
- This study highlights the need for improved hydration education, the development of objective assessment tools, and solutions for staff-related constraints.

References

1. El-Sharkawy, A.M., Watson, P., Neal, K.R. et al. (2015). Hydration and outcome in older patients admitted to hospital (The HOOP prospective cohort study). Age and ageing, 44(6), pp.943-947.
2. Hooper, L., Abdelhamid, A., Attreed, N.J. et al. (2015). Clinical symptoms, signs and tests for identification of impending and current water-loss dehydration in older people. Cochrane Database of Systematic Reviews.
3. Lacey, J., Corbett, J., Forni, L. et al. (2019). A multidisciplinary consensus on dehydration: definitions, diagnostic methods and clinical implications. Annals of medicine, 51(3-4), pp.232-251.