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The Epidemiology of Grip Strength of Older People in a Range of Healthcare Settings

by

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ABSTRACT

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Studies assessing the grip strength of older people have typically recruited community dwelling participants, or those in acute hospital settings. There are few studies of grip strength of older people in rehabilitation or long term care. The aim of this thesis was therefore to investigate the epidemiology of grip strength in these healthcare settings.

The specific objectives were to study in each setting a) the feasibility and acceptability of grip measurement; b) the grip strength values recorded in comparison with published reference ranges; c) the clinical correlates of grip strength; and d) the association of grip strength with discharge outcomes for the rehabilitation inpatients.

Participants were recruited prospectively between 2007 and 2010 from four healthcare settings within the same geographical area. Data on age, anthropometry, current co-morbidities and medication, physical, cognitive and nutritional status, and subsequent -discharge were recorded, and grip strength was measured. The feasibility of grip strength measurement was evaluated and its acceptability was assessed by questionnaire and by semi-structured interviews with a purposive sample of participants from each setting.

305 participants were recruited. Almost all could complete the grip strength assessment and would repeat the test. Qualitative data confirmed the high level of acceptability of grip strength measurement. There were significant differences in grip strength of both men and women between settings, and the grip strength of the in-patients and the nursing home residents was far below published reference values. Age, gender, body size and Barthel Score were the characteristics most consistently associated with grip strength in these settings. Among the 101 rehabilitation in-patients higher grip strength was associated with a reduced length of stay but this was only statistically significant among the men.

This thesis has demonstrated that grip strength measurement of older people in these healthcare settings is both feasible and acceptable, and has described its values as well as its clinical correlates. It has shown the need for reference ranges specific to each healthcare setting since grip strength appears to be associated with length of stay even amongst those with low grip strength.

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DECLARATION OF AUTHORSHIP

I, **Helen Clare Roberts**

declare that the thesis entitled

<u>The epidemiology of grip strength of older people in a range of healthcare settings</u>

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- 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;
- where I have consulted the published work of others, this is always clearly attributed;
- 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;
- I have acknowledged all main sources of help;
- 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;
- parts of this work have been published as:

1. Helen C Roberts, Holly Syddall, Cyrus Cooper, Avan Aihie Sayer. Is grip strength associated with length of stay in hospitalised older patients admitted for rehabilitation? Findings from the Southampton Grip Strength Study. Age and Ageing 2012: in press.

2. H.C. Roberts, J. Sparkes, H. Syddall, J. Butchart, J. Ritchie, C. Cooper, A.A. Sayer. Is measuring grip strength acceptable to older people? The Southampton Grip Strength Study. Journal of Aging Research & Clinical Practice 2012; 1 (2): 135-140.

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6. J Sparkes, J Ritchie, J Butchart, SE Salomone, K Jameson , AA Sayer, HC Roberts. The acceptability of grip strength assessment in four health and social care settings. Age Ageing 2010; 39 supplement 2ii2

Signed: …Helen Roberts ………………………..

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Abbreviations

ADL	Activity of Daily Living
ANOVA	Analysis of Variance
ASHT	American Society of Hand Therapists
BMI	Body Mass Index
CI	Confidence Interval
Co-morbidity	Concurrent illness
CONSORT statement	Consolidated standards of reporting trials statement
COPD	Chronic Obstructive Pulmonary Disease
EWGSOP	European Working Group on Sarcopenia in Older People
HR	Hazard Ratio
IADL	Independent Activity of Daily Living
IHD	Ischaemic Heart Disease
IQR	Inter Quartile Range
MMSE	Mini Mental State Examination
MUST	Malnutrition Universal Screening Tool
N	Newton
OT	Occupational Therapist
PD	Parkinson’s disease
RA	Rheumatoid Arthritis
SD	Standard Deviation
SUHT	Southampton University Hospitals NHS Trust
wte	Whole time equivalent

Chapter 1 Background

1.1 Aim and objectives

The aim of this thesis is to investigate the epidemiology of grip strength in four healthcare settings where to date it has been little explored. This will be achieved by studying:

a) the feasibility and acceptability of grip measurement among older people in these healthcare settings

b) the grip strength values recorded in each healthcare setting in comparison with published reference ranges

c) the clinical correlates of grip strength in the different healthcare settings

d) the association of grip strength with discharge outcomes for the rehabilitation inpatients.

1.2 **What is grip strength?**

The term grip strength refers to the force of hand grasp and is usually measured isometrically using a dynamometer held in the subject's hand which is squeezed as hard as possible. Grip strength force is measured in kilograms, pounds or newtons. In this thesis grip strength will refer to squeezing the dynamometer to obtain the most powerful grip possible and then relaxing.

1.3 Why is grip strength important?

Measuring the grip strength of older people is important because low grip strength is associated with geriatric syndromes such as sarcopenia and frailty, and with poor current and future health.

1.3.1 Association of grip strength with sarcopenia

1.3.1.1 Definition of sarcopenia

Sarcopenia is generally defined as the loss of skeletal muscle mass and function that occur with increasing age (1). The term was first used by Irwin Rosenberg in 1989 and derives from the Greek ‘sarx’ (flesh) and ‘penia’ (loss) (2). The European Working Group on Sarcopenia in Older people (EWGSOP) established in 2009 defined age-related sarcopenia as a syndrome characterised by progressive and generalized loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life and death (3). Recognised risk factors for age-related sarcopenia include increasing age, low levels of physical activity, poor nutrition, inflammation and co-morbidities e.g. diabetes, as well as low birth weight, pre-pubertal and pubertal growth (4)

1.3.1.2 Significance of sarcopenia

Sarcopenia is common in men and women with a prevalence estimated between 5-13% in people aged 60-70 years and between 11-50% in people aged over 80 years (5). The prevalence of sarcopenia reported depends on the definition used, highlighting the need for a consensus. Since the number of people aged 60 years and over was estimated at 600 million in the year 2000, and is predicted to rise to 2 billion by 2050, sarcopenia affects more than 50 million people today and may affect more than 200 million over the next 40 years.

Sarcopenia is costly both to the individual and to the population. Sarcopenia is associated with reduced mobility, difficulty with activities of daily living, increased risk of falls and fractures, reduced independence and increased mortality rates. It is estimated that $18.5 bn representing 1.5% of the total healthcare expenditure in the United States for the year 2000 was attributable to sarcopenia (6).

1.3.1.3 Grip strength and the diagnosis of sarcopenia

The diagnosis of sarcopenia relies on the accurate measurement of muscle mass, muscle strength and physical performance, and then consensus on the cut-off points of these measures required for the diagnosis.

Grip strength is the only measure recommended by the EWGSOP for measurement of muscle strength, as a ‘good simple measure’. It has been shown to correlate highly with leg strength and calf cross-sectional area, and to have a stronger association with poor mobility and future clinical outcomes than low muscle mass (7). However this recommendation comes with the caveat that grip strength should be measured in standard conditions with a well-studied model of dynamometer and with known reference populations.

1.3.2 Association of grip strength with frailty

1.3.2.1. Definition of frailty

Frailty is common in older people. It has been described as ‘a physiologic state of increased vulnerability to stressors that results from decreased physiologic reserves, and even dysregulation, of multiple physiologic systems’ (8). Frailty may be considered to be a precursor of disability, such that disability is a consequence rather than a cause of frailty, and frail people need not be disabled (9).

Frailty is often defined as a physical / biological phenotype using physical measures such as grip strength e.g. Fried’s model (10), or as a syndrome including functional decline, nutrition and cognitive decline e.g. the Strawbridge frailty score (11). More recent models of frailty include summation of the number of impairments e.g. the Frailty Index developed by Rockwood (12).

There is considerable overlap between frailty and sarcopenia, and the assessment of both often involves the measurement of grip strength. Most frail older people have sarcopenia, while some people with sarcopenia are also frail. Grip strength has been proposed as a single marker of physical frailty (13).

1.3.2.2 Significance of frailty

Despite the lack of consensus on a definition for frailty or how to assess it, frailty is common. Studies using the Fried model of frailty report a prevalence of frailty between 4% and 25% (14). The prevalence increases with age, and is usually estimated to be higher in women (10) and ethnic minorities such as African-Americans (15). Frailty is associated with current disability and co-morbidity, and with future increased risk for adverse health outcomes such as disability, falls, admission to hospital, admission to care homes, and death (10) (16).

1.3.2.3 Grip strength and the diagnosis of frailty

The most widely used method of assessing frailty currently is that of Fried (10). This model defines frailty as a clinical syndrome in which three or more of the following criteria are present:

1) unintentional weight loss (>10lbs or 5kg over the last year)
2) self-reported exhaustion
3) weakness as shown by low grip strength (lowest 20%)
4) slow walking speed (lowest 20%)
5) low physical activity (lowest 20%)

1.4 How is grip strength currently measured

Grip strength can be measured quantitatively using a hand dynamometer. However the methods used to characterise grip strength vary considerably, for example with regard to the choice of dynamometer or the measurement protocol used. This has the potential to introduce measurement error. The EWGSOP report recognised the challenge of determining how best to measure variables such as grip strength, and the importance of using a standardised method using a well-validated dynamometer.

1.4.1 Choice of dynamometer

Table 1.1 indicates the main features of the different types of dynamometer. The Jamar hand dynamometer (Lafayette Instrument Company, USA) is the most widely cited in the literature and accepted as the gold standard by which other dynamometers are evaluated (17;18). It has the most extensive normative data (19) although data are available for other instruments such as the BTE Work Simulator (20) and the Martin Vigorimeter (21). Excellent concurrent validity of the Jamar with known weights (weights suspended from the handle to assess accuracy of measurement) is reported ($r = 0.9998$ (22) ; $r>0.96$ (23)), and for these reasons the Jamar dynamometer was selected for use in this study.

Other dynamometers are available and a review (22) of the reliability and validity of the Jamar in comparison with other grip strength measurement devices concluded that excellent inter-instrument reliability exists between the Jamar, Dexter and Baseline dynamometers, which all measure grip strength in pounds and kilograms and could be used interchangeably. There was also similar evidence between the Jamar and Rolyan hydraulic dynamometers. Moderate to excellent reliability was found between the Jamar, the Baltimore Therapeutic Equipment (BTE) work simulator and the BTE Primus and the Martin Vigorimeter, but they use different units of measurement and the BTE is not a portable machine. Similar reliability was found between the Jamar and the MicroFET 4 (24) and DynEX (25) dynamometers. Low inter-instrument reliability scores were reported between the Jamar, the sphygmomanometer and the Vigorimeter. It is unclear whether the electronic Grippit dynamometer and the Jamar can be used interchangeably (26).

Instrument type	Hydraulic	Pneumatic	Mechanical	Strain
Measures	Grip strength	Grip pressure	Grip strength	Grip strength
Based on	A sealed hydraulic system that enables grip strength to be read off a gauge dial	The compression of an air filled compartment, eg. a bag or bulb	The amount of tension produced in a spring	The variation in electrical resistance of a length of wire due to the strain applied to it
Example of instrument	Jamar	Martin Vigorimeter	Harpenden dynamometer	Isometric Strength Testing Unit
Units	Kilograms (kg) or pounds of force (lbf)	Milimeters of mercury (mmHg) or pounds per square inch (psi) (lb/in2)	Kilograms (kg) or pounds of force (lbf)	Newtons of force (N)
Advantages	Portable, economical, large amount of normative data available.	Gentler on weak or painful joints	No evidence for superiority presented in the literature	Are not subject to leaks (of oil/water/air), which can compromise accuracy
Limitations	Can cause stress on weak joints. Can develop slow leaks and hysteresis	These instruments measure grip pressure, which is dependent on the surface area over which the force is applied. Hand size can therefore influence the measurement	Reproducibility of the grip force measurements is limited due to difficulties in exactly replicating the grip position and in calibrating the device	Can be expensive and heavy

Table 1.1 Key features of hand dynamometers

1.4.2 Jamar dynamometer

The Jamar is small and portable but relatively heavy at approximately 0.75 kg. The dial reads force in both kilograms and pounds, with markings at intervals of 2kg or 5lb, allowing assessment to the nearest 1kg or 2.5 lb. It requires 3-4 pounds of force to make the indicator needle move which may be inappropriate when measuring grip strength in very weak patients (27) and the reading error is reported to be greater at lower loadings. The calibration accuracy should be checked on new machines (28) and the manufacturers recommend annual or more frequent calibration if used on a daily basis.

Figure 1.1 Jamar dynamometer

1.4.3 Feasibility of grip strength measurement

The measurement of grip strength has been little studied in older people from different healthcare settings. A Japanese prospective cohort study of 3,340 ambulatory people aged 65 years or more recruited from 213 day care centres evaluated physical and cognitive tests to screen for falls (29). Grip strength was reported as one of the most practicable tests with more than 90% participants able to complete it. A UK study of grip strength in people aged 75 years and over recruited from a day hospital and continuing care wards found that all of the 40 patients at the day hospital and 26/30 (87%) of the continuing care patients were able to complete the grip assessment (30). A Portuguese study of people aged 65 – 99 years from a retirement home (n=25) and from a day care centre (n=30) compared the performance of four dynamometers (23). All participants were able to have their grip strength measured using the Jamar and three other dynamometers.

1.4.4 Accuracy of grip strength measurement

1.4.4.1 Impact of the measurement protocol

The lack of a standardized method of measuring grip strength has been highlighted as an issue by the European Working Group on Sarcopenia in Older People. Variation in the method of assessment has the potential to introduce measurement bias to the grip strength values reported and make comparisons between studies inaccurate. Table 1.2 outlines examples of the differences in the measurement protocols of published studies.

The Jamar is a variable hand span dynamometer with five handle positions. As shown in Table 1.2, most studies have used the second position for all participants. This has been assumed to be the most reliable and consistent position (18) and is the position advocated for routine use. However hand size is important and only 60% of 214 volunteers demonstrated maximal grip strength at position two (31) and 56 healthy volunteers self-selected position two or three for maximal grip strength (32). Handle positions one (33) and five (34) have been found to be significantly less reliable than the other positions, but for people with very small hands position one may be required (35). Hand dominance may also influence the final value reported where only one hand is assessed, which is variably chosen to be the dominant or non-dominant hand. A review of 10 studies found that right dominant subjects were stronger with their right hand whereas among left dominant subjects the results were similar in both hands (36).

The position of the wrist and forearm (37), elbow (38) (18) (39) (40) and shoulder (41) have been shown to determine the maximum mean grip strength. Posture is also important although studies variably report no significant difference in grip strength with subjects in either sitting or standing positions (42) or higher grip strength with college students standing rather than sitting (43). Hillman (44) found that readings with subjects' elbows unsupported were significantly higher than when they were supported.

The American Society of Hand Therapists (ASHT) recommends standardized positioning: subject seated, shoulders adducted and neutrally rotated, elbow flexed at 90 degrees, forearm in neutral and wrist between 0 and 30 degrees of dorsiflexion (45). The need for a standard protocol to improve the validity of assessment is illustrated by Spijkerman 1991 (46) who found that allowing subjects to assume a comfortable position produced significantly different readings from the ASHT protocol.

Most studies either do not report how much encouragement they give or report differing amounts (Table 1.2). Different methods of instruction and/or verbal encouragement can affect performance (47) and so introduce measurement error, as may the volume of instruction (48). Mathiowetz (49) has a set of standardized instructions: "I want you to hold the handle like this and squeeze as hard as you can." The examiner demonstrates and then gives the dynamometer to the subject. After the subject is positioned appropriately, the examiner says, "Are you ready? Squeeze as hard as you can." As the subject begins to squeeze, the examiner says, "Harder!… Harder!… Relax."

There is little literature on training individuals to measure grip strength, but there is evidence that assessment of grip strength by different hand therapists can be considered interchangeable, if they follow the same protocol (50). Currently research staff are trained prior to measuring grip strength (51) but this is typically poorly documented and not standardised across studies.

Author and year of publication	Population (n)	Handle setting	Body position	Encouragement/ instructions	Hands tested	Measure used
Bohannon 2005 (52)	Community dwelling elders, USA (21)	2nd	ASHT recommendations	Not stated	Both	Single trial
Desrosiers 1995 (21)	Community dwelling elders, Canada (360)	2nd	ASHT recommendations	Standardized instructions according to Mathiowetz et al. 1984	Both	Highest of three
Fried 2001 (10)	Community dwelling elders from the Cardiovascular Health Study (5317)	Not stated	Not stated	Not stated	Dominant	Mean of three
Massy-Westropp 2004 (53)	Healthy adults, Australia (419)	2nd	ASHT recommendations	Not stated	Both	Single trial
Mathiowetz 1985 (54)	Healthy adults, USA (628)	2nd	ASHT recommendations	Standardized instructions according to Mathiowetz et al. 1984	Both	Mean of three
Sayer 2007 (55)	Community dwelling elders from the Hertfordshire Cohort Study, UK (2677)	Most comfortable	Subjects seated, forearms rested on the arms of the chair, wrist just over the end of the arm of the chair in a neutral position, thumb facing upwards, feet flat on the floor	Standardized encouragement given	Both	Highest of three
Werle 2009 (56)	Community dwelling adults, Switzerland (1023)	2nd	ASHT recommendations	Standard instructions at a constant volume	Both	Mean of three

Table 1.2 Examples of variation in grip strength measurement protocol in published studies

1.4.4.2 Number of attempts and summary measure reported

There is great variation in this between studies, despite the impact of reporting mean or maximum values. The American Society of Hand Therapists (ASHT) protocol (Table 1.3) uses the mean of three trials of grip strength in each hand (45), which was found to have higher test-retest reliability among female students than either one trial alone or the maximum of three trials (49). However Hamilton et al. (33) found similar test-retest reliability with one trial alone, the mean of two or three trials, and the maximum of three trials. A recent UK study found that one trial was as reliable and less tiring than three trials (57). Standardised protocols typically incorporate a one minute interval between repeat testing of the same hand as grip strength has been shown to decrease gradually during repeated measurement without rest but not during interval measurement (58). It is unclear if grip strength is subject to a diurnal variation (59) (60).

1.4.4.3 Reliability and reproducibility

Measurements of grip strength taken with the Jamar dynamometer have evidence for good to excellent ($r>0.80$) test-retest reproducibility (49) and excellent ($r=0.98$) inter-rater reliability (50). High test-retest reproducibility has been shown among older American community dwelling volunteers (mean age 75 years) tested repeatedly over a 12 week period (52)**.** However concerns have been raised about the reliability of grip strength assessment at low grip strength values (27).

1.4.4.4 Responsiveness to change

Nitschke et al. (61) evaluated test-retest reliability in the maximum grip strength of 32 healthy women and pain free grip in 10 disabled women. The measurement variation between tests was +/- 5.7 kg and +/- 5.9 kg for the healthy and disabled women respectively. They proposed a minimal clinically significant change of 6 kg. Similarly, studies identifying recovery after stroke estimate the difference in repeat measures of hand grip strength to be between 4.7 kg (62) and 6.2 kg (63).

However significant clinical change may be obscured by measurement variation. The clinical meaning of change in grip strength over time has been evaluated using the standardised mean response, calculated as the mean change / standard deviation of the change (64). Other authors have similarly used the effect size, calculated as the difference between the mean (median) value of grip strength 'after' and 'before', divided by the standard deviation (inter quartile range) of the 'before' measurement (65). For both measures a value of 0.2 – 0.5 is considered a low responsiveness, 0.51 – 0.8 is moderate and >0.8 shows a high level of responsiveness.

1.4.5 The Southampton Protocol

The Southampton group has further developed the ASHT protocol to include clearer instructions for positioning of the arms and feet, and also standardised encouragement, number of trials and method of scoring (maximum grip strength from six trials, three with either hand) (Table 1.3). This protocol has been extensively used by different researchers in the Hertfordshire Cohort Study and Hertfordshire Ageing Study with community dwelling people aged 65 years and over (66) and was adopted for this study.

Figure 1.2 Recommended position for grip strength assessment

Domain	ASHT	Southampton Protocol
Posture	Subject seated	Subject seated, same chair for every measurement
Arm position	Shoulders adducted and neutrally rotated, elbow flexed at 90 degrees, forearm in neutral	Forearms rested on the arms of the chair
Wrist position	Wrist between 0 and 30 degrees of dorsiflexion	Wrist just over the end of the arm of the chair, in a neutral position, thumb facing upwards
Lower extremity position		Feet flat on the floor
Encouragement		"I want you to squeeze as hard as you can for as long as you can until I say stop. squeeze, squeeze, squeeze, stop" (when the needle stops rising)
Number of trials		3 trials on each side, alternating sides
Score to use		Maximal grip score from all 6 trials used

Table 1.3 Comparison of ASHT and Southampton protocols for grip strength measurement

1.4.6 Acceptability of grip strength measurement

Few authors have evaluated the acceptability of grip strength assessment. Helliwell et al in 1987 (67) assessed the acceptability of three dynamometers (not the Jamar) by asking 26 patients with arthritis which one they preferred. The question asked was 'if you had to squeeze these devices each day as part of your assessment, which one would you prefer?' There is no information on why they expressed a preference, nor on their views of grip strength measurement as part of routine clinical care.

Harding et al in 1994 aimed to develop a battery of measures to assess the physical performance of chronic pain patients, and grip strength was included (68). Acceptability was evaluated in terms of subjects' refusal rates for completion of each measure, and all of the 431 subjects were able to complete the grip strength measurement.

There is no evidence on the acceptability of grip strength measurement among people in different healthcare settings.

1.5 Grip strength values of older people

As discussed in the previous section the interpretation of grip strength values requires the use of a standardized method of measurement and a calibrated and validated dynamometer. It also requires a reference range appropriate to the population being assessed (3). The use of grip strength values to predict outcomes of care for individuals additionally requires cut-off values appropriate to that population.

1.5.1 Reference ranges derived from community dwelling older people

There are a number of published reference ranges for the grip strength of adult men and women, and almost all are derived from community dwelling people living in their own homes. For younger and middle-aged adults this probably does represent the majority of the population of a similar age. However older people are likely to be more heterogenous because of the age-related increase in morbidity, disability and use of healthcare. Thus there are concerns that the reference ranges derived from community dwelling older adults may not be representative of the majority of the population in this age group, and in particular those in different healthcare settings.

Grip strength is associated with age and gender, and so reference ranges are typically presented by age bands for men and women separately. Stratification by age also avoids the difficulty of interpreting the results of studies with under or over-representation of older adults, which could potentially lead to higher or lower overall mean grip strength values. However grip strength is also influenced by body size and some studies, although not reference ranges, present cut-off values adjusted for BMI.

Reference ranges should be derived from large random samples which are representative of the population studied, and have sufficient numbers of older participants to be reliable (56). A meta- analysis of 12 studies from USA, Canada, UK, Australia and Sweden representing a largely Caucasian population, has described 'consolidated norms' (69) for use as global reference ranges as shown in Table 1.4. Reference ranges and grip strength values have also been published based on studies from a number of individual countries around the world. Some of the studies are of large population based random samples, while others are of smaller convenience samples, and this may account for some of the difference in grip strength values reported. The variable use of maximum or mean values as previously discussed is another reason for variation in the values reported (70).

1.5.1.1 European grip strength values

A Swiss population–based study of community dwelling people aimed to establish normative data for grip strength, and the results for older people are shown in Table 1.4 (56). Interestingly the standard deviation (SD) of the mean grip strength remained similar for each age group at around 6-9 kg for men and 4-6 kg for women, which represented 15-16% of mean grip strength in those aged under 70 years, but increased to 21-29% of mean grip strength in people age 70 years and older. This may simply reflect the lower grip strength values in the older age groups. However it may also reflect the increased heterogeneity of older people since the grip strength of those not needing daily help was 59% higher than those who were dependent on such help (mean grip strength 33.8 kg compared to 21.3 kg).

The results of two Spanish studies aiming to establish normal reference values in healthy adults are shown in Table 1.4 (70) (71). The population-based study of 313 people aged 70 years and over from northern Spain can be seen to have reported lower grip strength values than the study of healthy volunteers, underlining the importance of selection bias in the reference population sample.

A Danish study of cross-sectional and longitudinal data on grip strength has unusually published reference ranges for grip strength not only by age (up to 95 years in 5 year age bands), gender but also by height (5 cm sub-groups) (72). This may facilitate the comparison of grip strength between populations of different body size e.g. different ethnicities.

The prevalence of low grip strength assessed in accordance with Fried's original criteria has been shown to vary across the 10 European countries participating in the Survey of Health Aging and Retirement in Europe (SHARE) study (73). A north – south gradient was found with countries such as Sweden, Denmark, the Netherlands, Germany, Austria and Switzerland having a lower prevalence of weakness than southern countries (Italy, Spain and Greece). This may have partly reflected the lower rates of institutionalization in southern countries such that more people with low grip strength were included, but a higher prevalence of weakness was also found among older non-disabled people as well as middle-aged people in the southern countries. Difference in body size may be a confounding factor but a similar north-south gradient for grip strength has been reported among nonagenarians and centenarians in Denmark, France and southern Italy, which was not attenuated by adjustment for height, physical and cognitive function and number of co-morbidities (74).

1.5.1.2 North American grip strength reference values

Mathiowetz in 1985 (54) was one of the earliest authors to use a Jamar dynamometer with a standard protocol to establish reference ranges up to age 75 years and over for a community dwelling healthy North American population. A study of healthy female volunteers, including older age groups up to 89 years, found generally higher values than those published (75). Desrosiers et al established normative data for healthy older community dwelling volunteers living in Canada (21), and these studies are included in Bohannon's meta-analysis and subsequent consolidated norms (Table 1.4).

1.5.1.3 South American grip strength reference values

A Brazilian study, conducted as part of a survey of people living in privately owned houses, produced reference ranges for grip strength for adults but grouped those aged 70 years and over all together (76). The mean (SE) grip strength for 76 men aged 70 years and over was 31.8 (0.79) kg and the corresponding value for 172 older women was 17.2 (0.41) kg. A second study of community dwelling older people in Brazil recruited participants up to the age of 90 years and aimed to produce reference ranges but the results for people aged 60 years and over were again presented as one group (77). The mean (SD) maximum grip strength was 31.3 (8.0) kg for the men and 19.1 (5.2) kg for the women.

1.5.1.4 Australian grip strength reference values

A study of community dwelling older Australians reported grip strength reference ranges of 17-49 kg for 17 men aged 75 years and over, and 5-34 kg for 29 women of the same age (53), but mean values were not presented. A more recent study aimed to compare normative data derived from community dwelling Australians with international norms (78). Older participants' results were presented for those aged 70 years and over: the mean (SD) maximum grip strength for older men was 33 (7.8) kg and for older women it was 20 (5.8) kg.

1.5.1.6 Asian grip strength reference values

Wu et al were concerned about the use of Bohannon's consolidated norms (derived largely from Caucasian people) in their Chinese population in Taiwan, and so conducted a survey using a Jamar dynamometer and the ASHT protocol (79). As can be seen from Table 1.4 the mean grip value for 18 Taiwanese men aged 70-74 years was only 65% of that of Bohannon's consolidated norms, and for 17 women the value was similar at 68%. After gender and age, palm length was found to be the variable most strongly associated with grip strength. Longer palm length was associated with higher grip strength, possibly due to a greater bulk of thenar musculature and/or acting as a proxy for height, which was not measured in this study. Other studies have similarly found lower grip strength values among younger Hong Kong and mainland Chinese populations (80), and the use of local reference ranges specific to regions and/or populations has been recommended by these authors.

A study of 412 healthy adult community dwelling Malaysians aged up to 65 years found no statistically significant difference in grip strength between participants of Malay (53%), Chinese (17%) or Indian (30%) origin, but all had significantly lower values (approximately 65-68%) than those reported in North American and European reference ranges (81). However the values for grip strength in these comparisons were not adjusted for body size, and the authors recommend that reference ranges account for height, weight, hand dominance and occupation as well as age and gender. More recently a study of 80 patients admitted to an acute geriatric ward in Kuala Lumpur (mean age 79 years) reported a mean (SD) maximum grip strength of 18.4 (6.9) kg for men and 12.6 (5.7) for women (82).

1.5.1.7 African grip strength values

There are relatively few studies of grip strength from African countries. Pieterse and colleagues studied older male and female Rwandan refugees (83) most of whom were farmers. The mean (SD) maximum grip strength of 71 men aged 70 years and over was 26.2 (6.0) kg and for the 64 women aged 70 years and over it was 19.0 (4.3) kg. Participants' ages ranged from 50- 92 years but the values for those older than 70 were grouped together. In keeping with other populations significant determinants of low grip strength for this study group were low BMI, as well as higher age, female gender and shorter height. There may have been a survivor bias in the population within the refugee camp, with frailer older people less likely to survive the journey, resulting in higher grip strength values. However the values are similar to those reported from studies of another rural population in Malawi (84). The Malawi study reports mean (SD) maximum grip of 25.9 (5.1) kg among 42 men aged 70 years and over, and 19.7 (4.5) kg for 28 women of the same age.

		Mean grip strength (kg) by age band				
Author and year of publication	**Population (n)**	**70 - 74 years**	**75 - 79 years**	**80 - 84 years**	**85 - 89 years**	**90 - 99 years**
Bohannon 2006 (69)	Meta-analysis of 12 studies (3317 subjects) North America & Australia	M: 38.2 F: 24.2	M: 33.0 F: 21.6	M: 30.1 F: 17.3	M: 25.8 F: 17.1	M: 18.9 F: 15.2
Frederiksen 2006 (72)	Danish elders from 3 existing cohorts	M:32.2–42.0 F:18.6-24.2	M:30.3-37.0 F:18.1-27.4	M: 24.0-38.1 F:16.9-22.9	M:19.2-28.8 F:14.5-20.7	**90-95 years** M:19.0-22.3 F:12.6-14.9
Werle 2009 (56)	Switzerland (1023)	M: 41.7 F: 26.4	M: 36.8 F: 25.0	M: 30.7 F: 19.7	M: 23.2 F: 16.9	
Luna-Heredia 2005 (70)	Healthy volunteers Spain	**70-79 years** M: 29.5 F: 17.0		**80-84 years** M:24.2) F:16.6	**85 + years** M:21.8 F:13.8	
Puig Domingo 2008 (71)	Population based study Spain	**70-80 years** M: 20.5 F: 10.1		**>80 years** M: 15.5 F: 6.9		
Wu 2009 (79)	Healthy volunteers Taiwan	**70-74 years** M: 24.7 F:16.5	**75 + years** M: 22.5 F: 13.4			

Table 1.4 Examples of reference ranges for grip strength for community dwelling men and women

1.5.2 Grip strength values from studies in healthcare settings

No reference ranges have been published for grip strength in healthcare settings and few studies have reported on grip strength in healthcare settings other than acute hospitals.

A retrospective study of 188 patients (mean age 58 years, range 18 – 87) under-going acute rehabilitation found that only 6.9% had grip strength values that were equal to or greater than the normative values published by Mathiowetz in 1985, and 76% had grip strength lower than the normative values in both hands (85) . Overall the group's mean grip strength was 37% lower in the left hand and 43% lower in the right hand. Bohannon conducted a similar retrospective notes review of 41 consecutive patients (mean age 74 years) receiving domiciliary rehabilitation for stroke disease, cancer, osteoarthritis and fractures (86). He also reported a reduction in grip strength with mean values 25% lower than age-adjusted normative values for both left and right hands.

Giuliani et al studied 1,791 residents (mean age 84 years) of 189 residential care homes in North America (87). Mean (SD) grip strength for the 90% of participants who were able to complete the assessment was 14 (6.9) kg for both men and women, which was again lower than reported values for community dwelling older adults (Table 1.4). Two other studies have reported values for grip strength in care homes. A Portuguese study assessed the grip strength of 25 residents in a care home and 30 older people (mean age 79 years) attending a day centre of whom 85% were independently mobile (23). The mean grip strength for men was 24.8 (10.7) kg and for women 15.5 (5.7) kg. A study of 84 older Guyanese residents of 3 care homes found a mean grip strength of 26 kg for men and 17.7 kg for women (88) .

1.5.3 Cut-off values and definition of low grip strength

The lack of agreement about cut-off values to define normality has been raised as a limitation in the use of grip strength (81). However this is in part because the cut-off value is specific to the identification of a certain characteristic or outcome in a particular group of people.

Epidemiological studies have often taken body size into account when using cut-off values. Fried stratified grip strength in the Cardiovascular Health Study by BMI as well as gender, such that the cut-off value for the lowest 20% grip strength varied between 29 and 32kg according to BMI for men and 17 and 21kg for women (10). The Hispanic Established Populations for Epidemiologic Studies of the Elderly (HEPESE) (89) used slightly different BMI values from those of Fried, because of documented differences in BMI between Mexican and non-hispanic white Americans. This study of community dwelling people aged 65 years and over had cut-off values for the lowest 20% grip strength of between 21 and 25.5 kg for men and 13.5 and 15 kg for women. Sallinen evaluated the association of cut off values and BMI and concluded that cut-off values for mobility limitation varied according to BMI particularly among men (90). In the Hertfordshire Cohort Study of community dwelling older people in the UK aged 59-77 years the lowest 20% grip strength values are 38 kg for men and 22 kg for women (66).

Studies have also developed numerical cut-off points. However the cut-off value depends on the reason for discriminating between groups within a given population, and a high sensitivity may be required for early detection of those at risk of adverse outcomes, whereas greater diagnostic accuracy may be appropriate for identifying those with weak grasp e.g. after hand surgery. For example a grip strength of 9 kg has been considered to be the limit of functionality required to perform most daily activities (91). By comparison a Taiwanese study of healthy community dwelling volunteers identified optimum cut off values of 28.5 kg for men and 18.5 kg for women to identify those who were unable to perform a heavy task (lift an 11kg weight) with a sensitivity of 53% for men and 46% for women with a specificity of 84% for both (92). Cut-off values of 34 kg and 22 kg were associated with higher sensitivity (75%) but lower specificity. A Japanese study evaluating screening for falls among participants aged 65 years and over attending day care centres used ROC curve analysis to determine a cut point of 17 kg or less (29). While this had a relative risk of 1.41 for future falls, with both a sensitivity and specificity of 55% it was not useful for prediction of falls in individual participants. Lauretani et al (7) recommended cut off values of 30 kg for men and 20kg for women for use in clinical practice to identify those with poor mobility based on the community based InCHIANTI study. Other authors have advocated the use of the 5th percentile value for grip strength in the dominant and non-dominant hands of a reference sample as the cut off values for a healthy participant (93) .

Cut-off values are less frequently stated for people in healthcare settings. A cut-off value of 10 kg or less was found to be predictive of adverse outcomes of admission with pneumonia in one study (94). A study of older people in continuing care wards, attending a day hospital for rehabilitation and age-matched community dwelling older people found that the lowest 20% of grip strength corresponded to a grip strength of 16 kg or less (30). Several studies have adopted the use of a value equal to 85% of the mean values observed in a healthy population, which was initially proposed to identify patients at risk of adverse outcomes such as post-surgical complications (95) (96) (97). This technique has been reported as having 64 - 87% sensitivity and 48 -86% specificity, with 26 - 65.5% positive predictive values and 82 - 94.8% negative predictive values in the detection of surgical complications in patients (complication incidence of 14 - 30%) (70).

1.6 Known influences on grip strength values

There are a number of individual and clinical characteristics which have clearly described associations with grip strength including age, gender, body size, co-morbidities, medication, physical function, cognitive function, nutritional status and falls.

1.6.1 Individual characteristics: age, gender, body size

Age and gender are strongly associated with grip strength among healthy people (4). Grip strength is higher in men than women for any given age and has been shown in both cross-sectional and longitudinal studies to increase throughout childhood, peak in early adulthood and then start to gradually decline after the age of 35-40 years (98) .

Differences in the rate of decline with increasing age are reported and may be partly attributed to cross sectional versus longitudinal study design. A Danish study combining cross-sectional and longitudinal data collection on 8,342 participants found that between the ages of 50 and 85 years the decline in grip strength was almost linear with a mean annual loss of 0.65 kg for men and 0.34 kg for women, but that the decline then tended to level off for the oldest women (72). By comparison a longitudinal study of older community dwelling American women followed up for 10 years reports that the average reduction in grip strength rises among women after the age of 80 years (99). However there may have been a survivor effect as only around half of the original participants completed the 10 year follow-up, whereas the Danish study employed statistical techniques to account for participants who dropped out of the study or died. A study of American women found higher grip strength values among peri-menopausal African American women compared to white caucasian American women, but both groups had a similar longitudinal decline in grip strength over time (100).

Authors have also variably reported either a greater annual loss in women compared to men (101) or a similar decline in both men and women (102). Finally a mean decline in grip strength is not universal: a lack of decline in grip strength among 15% participants older than 60 years followed up for 9 years has been reported (103).

Men have stronger grip strength than women, such that grip strength among Danish men aged 80 years has been reported as equal to that of women aged 45 years (72). Similarly Canadian women have been reported as having between 54% and 68% of the grip strength of men (21). However body size is associated with grip strength, and increasing height, weight and BMI are associated with stronger grip strength (104) although obesity is associated with a weaker grip (105). Greater palmar length (79) and adductor pollicis muscle thickness (77) have also been associated with increased grip strength, thus male gender may be in part acting as a marker for increased body size in the association with grip strength.

1.6.2 Co-morbidities

Grip strength is associated with the total number of co-morbidities (106) as well as specific diseases.

Grip strength has been found to be lower in older people with type 2 diabetes mellitus (107) (108) with a graded association between grip strength and impaired glucose tolerance compared to normal glucose levels. Lower grip strength has also been associated with the metabolic syndrome, including specifically higher fasting triglycerides, higher blood pressure and increased waist circumference (55). Lower grip strength was found to be associated with greater insulin resistance in women but not men in an Italian population-based study of 968 older people (109). However although grip strength is lower in diabetics, longitudinal studies have shown a similar decline in grip strength over 3 years among older adults with and without type 2 diabetes (110). The reduction in grip strength in type 2 diabetes may be mediated through a link between the mechanical and metabolic functions of ageing muscle (55), and there may also be a link through autonomic dysfunction (111). Grip strength has been advocated as a test of sympathetic function which could be incorporated into routine autonomic testing (112).

Grip strength is associated with blood pressure. A Dutch study of 550 participants aged 85 years found that higher systolic blood pressure, mean arterial pressure and pulse pressure were associated with higher grip strength after adjustment for the total numbers of co-morbidities and medications (113). During a 4 year follow-up period a decline in systolic blood pressure, mean arterial pressure and pulse pressure were associated with a decline in grip strength. A population-based cross sectional study of community dwelling men found no association between vascular status (as measured by ankle arm index, pulse wave velocity and intima-media thickness) and grip strength (114).

Grip strength is reduced in patients with arthritis. A study of American adult women with rheumatoid arthritis (RA), osteoporosis and age-matched controls found that grip strength was significantly lower in the RA patients than the osteoporotic patients or the controls (115). Grip strength correlated with the duration of disease and also with total bone mineral density in the RA patients.

1.6.3.Medication

Grip strength is associated with the total number of medications used, and has been shown to decrease progressively with increasing number of medications (116). Among the HCS community dwelling sample of 2,987 men and women (mean age 66 years) after adjustment for age and height each additional medication was associated with an average reduction in grip strength of 0.36 kg (95% CI 0.21, 0.52, $p<0.01$) for men and 0.42 kg (95% CI 0.31, 0.53 $p<0.01$) for women.

Grip strength may also be associated with specific medications. In the HCS study the use of furosemide, nitrates and calcium channel blockers among men and women, and fibrates among women was associated with reduction in grip strength. The association with nitrates among men and women and fibrates among women persisted after adjustment for age, height and co-morbidity. The use of sedatives and psychotropic medication has also been associated with low grip strength. A cross-sectional study of 700 community dwelling people aged 75 years and over found that any sedative use was associated with a reduction in grip strength, and that an increase in the number of sedatives was associated with a further reduction in grip strength (117).

The Drug Burden Index is a measure of exposure to anti-cholinergic and sedative medications which has been reported to be associated with poorer physical performance (chair stands and 6m walk) in a cross-sectional analysis of community dwelling participants of the Health, Aging and Body Composition study (118). The association was further studied over 5 years in a longitudinal study which additionally included grip strength as an outcome measure, and an increase in the drug burden index was associated with a reduction in grip strength (119).

1.6.4 Physical function

Physical activity is associated with grip strength in older people. A study of 75 year old men and women in Finland found that higher grip strength was associated with greater current independent mobility (120). A study of the customary physical activity among the men and women of the Hertfordshire Cohort Study found that higher levels of usual activity such as gardening, were associated with higher grip strength among women but not men (121). A Canadian study of 904 people aged 67-84 years found that low grip was associated with low mobility scores (122).

A study of 377 community dwelling people aged 65 years and over in Chile found that low grip strength was the only variable significantly associated with self reported and observed functional limitations in men and women (123). In the UK grip strength was associated with disability in the 'Healthy old people in Edinburgh' cohort of 603 community dwelling people aged 70 years and over (124). The Leiden 85+ study found that lower grip strength was associated with higher levels of ADL and IADL disability (125).

Shectman measured grip strength among 832 American community dwelling elders aged 60 years and over, who were known to have activity limitations (126). Grip strength was shown to be similar among people with minimal or visual impairment, and these groups had higher grip strength values than those with motor or cognitive impairments. Furthermore grip strength for comparative age bands was lower than those of a study of healthy community dwelling elders, even among the group with minimal impairments.

There is evidence that grip strength can be improved by increasing the level of physical activity of older people, and exercise, particularly resistance training, has been suggested as an intervention to improve muscle strength. A 24 week aquatic training programme improved the grip strength of healthy female volunteers aged over 60 years compared to a control group (127). Chair based resistance training three times weekly for 4 weeks improved the grip strength of African –American older women recruited from a day centre by 5% (128). There is also evidence for the role of exercise among care home residents. A controlled trial of seated exercise by residents of care homes reported a significant improvement in grip strength in the exercise group (129). A study of tai chi among residents of care homes in Taiwan similarly found an improvement in grip strength (130).

1.6.5 Cognitive function

Low grip strength has been shown to be associated with lower Mini Mental State Examination (MMSE) scores in the Dutch Leiden 85-plus study (125). 555 subjects aged 85 years were assessed for grip strength, and those in the lower third had a mean MMSE of 22.3 points, significantly lower than the higher third's score of 26.3 points ($p<0.001$). In America Shechtman similarly found that in a group of 832 people aged over 60 years cognitive impairment was associated with lower grip strength (126). A Japanese study of 207 community-dwelling people aged 85 years also reports an association between lower grip strength and lower MMSE scores (131). Declining grip strength has also been reported to be associated with an increased risk of developing Alzheimer's disease in the Rush Memory and Aging Project which studied 877 older people without dementia at baseline (132).

1.6.6 Nutritional status

Lower grip strength has been found to be associated with worse nutritional status, as measured by the MUST score, in a study of older people admitted to acute care of the elderly wards in the UK (133). In a Spanish study of community dwelling people aged 70 years and over, grip strength was correlated with the mini nutritional assessment score, with lower grip among those at risk of malnutrition ($r=0.29$ men $p=0.001$; $r=0.20$ women $p=0.017$) (71). A study in Portugal of medical and surgical patients found that poor nutritional status was associated with low grip strength (70). Grip strength has been recommended as a screening tool to identify patients who are malnourished or at risk of malnutrition (134) and has been shown to increase among acute stroke patients with increased energy and protein dietary intake (135). Grip strength has been shown to differentiate between undernourished and underweight people with the same BMI (136).

Grip strength is associated with specific dietary components as well as overall protein and energy intake. Grip strength has been shown to be positively associated with a prudent diet, characterized by high consumption of fruit, vegetables, whole-grain cereals and fatty fish (137). Consumption of fatty fish was the most important dietary item and was independently associated with grip strength for both men and women. Fatty fish is an important source of dietary vitamin D, but in this study the association between fatty fish consumption and grip strength was much stronger than that between vitamin D and grip strength, indicating that possibly other constituents of fatty fish were influencing muscle function.

Vitamin D receptors have been found located on skeletal muscle but epidemiological studies have failed to establish a clear association between vitamin D level and grip strength. Earlier studies reported that lower vitamin D levels were associated with lower grip strength (138) and a positive association is reported among the women of the HCS (138) and older Americans (139). However recent studies of older Australians (140), French women (141) and New Zealand women (142) have not found a similar association.

Grip strength has been reported to be positively associated with B-carotene (143), selenium (144), vitamin C (138) and vitamin E intake (145), suggesting that anti-oxidant status may impact on muscle function

1.6.7 Falls

Sayer et al found a significant association between low grip strength and falls among 2,148 community dwelling older people who had a one year falls prevalence of 14.3% (men) and 22.5% (women) (146). Higher grip strength was found to be associated with a reduced risk of falls among the 5,995 men aged 65 years and over participating in the Osteoporotic Fractures in Men Study (147). Lower grip strength was found to be associated with increased likelihood of poor balance and dizziness among 2,925 participants aged 65 years and over in the English Longitudinal Study of Ageing (148). A recent study of stroke patients undergoing rehabilitation reported that grip strength on the unaffected side was associated with risk of falling over a 6 month period (149).

1.7 The association of grip strength with future health

Low grip strength has also been found to be associated with the subsequent development of specific co-morbidities, reduced physical function and disability, cognitive decline, and falls and fractures, as well as an increased risk of admission to hospital and care homes, adverse outcomes of admission to hospital, and mortality.

1.7.1 Co-morbidities

The predictive value of grip strength and its association with subsequent coronary artery disease and cerebro-vascular disease was assessed in a study of 1,145,467 young Swedish men followed for 30 to 51years (150). After adjusting for height, BMI, blood pressure and social position, grip strength was found to be strongly associated with disease risk, with a hazard ratio of 0.89 / kg increment in grip strength for coronary artery disease and 0.91/kg increment in grip strength for intra-cerebral infarction i.e. the presence of either condition is associated with lower grip strength. The Honolulu Heart Study involving almost 4,000 men of Japanese descent similarly showed that a steeper decline in grip strength over 27 years was associated with chronic diseases such as coronary artery disease and stroke, as well as chronic obstructive pulmonary disease (COPD) and arthritis (151).

1.7.2 Functional limitations and disability

Grip strength in middle age has been found to predict self-reported functional limitations and disability in walking and self-care 25 years later (152). Low grip strength was similarly found to predict the onset of difficulty with activities of daily living (ADLs) 12-18 months later among 110 community dwelling older adults aged 67 – 98 years, and cut-offs of 12kg for 90% sensitivity and 25kg for 90% specificity are reported (153). Grip strength has also been found to predict disability in 1645 community dwelling Mexican men and women aged 67 years and older (154). Low grip strength has been found to be an independent predictor of driving cessation among drivers in the USA aged 75 years and older (155).

1.7.3 Cognitive decline

Low grip strength at baseline was predictive of an accelerated cognitive decline as measured by the MMSE in the Leiden 85-plus study (125) and remained significant after adjustment for activities of daily living (ADL) and independent activities of daily living (IADL) scores and walking speed. Similarly a meta-analysis of three studies found that weaker grip was associated with higher risk of cognitive decline and development of dementia (156). Lower cognitive scores on the MMSE have also been reported to be associated with a faster decline in grip strength among both American (157) and Mexican study groups (158).

1.7.4 Falls and fracture risk

A meta-analysis of nine community dwelling study populations found an association between lower grip strength and higher risk of subsequent fracture in seven studies, with null associations reported in the remaining two studies (156). In one of these studies physical performance on five tests (grip strength, leg power, walking speed, walking balance and repeated chair stands) was assessed in 5902 men aged 65 years and over. During a follow up period of 5.3 years, 77 hip fractures were confirmed, and performance in the worst quarter on at least 3 tests was associated with a higher risk of fracture (159). Low grip strength has been shown to be associated with lower 15 year fracture free survival in peri-menopausal women with normal bone mineral density at baseline (160).

1.7.5 Admission to hospital or care home

Weaker grip strength is associated with a greater risk of future admission to hospital. The Health Ageing and Body Composition study followed 3,011 community dwelling Americans aged 70-80 years for an average of 4.7 years. Those with the lowest quartile of grip strength had an estimated incident rate of hospitalization of 1.52 (95% CI 1.30, 1.78) compared to those in the highest quartile. Low grip strength has also been associated with a greater risk of admission to care homes. A study of 754 participants found that lower grip strength was associated with a greater likelihood of long term nursing home stay, hazard ratio 1.7 (95% CI 1.1, 2.7) after adjustment for age, sex, race, education and chronic conditions (161).

1.7.6 Outcomes of admission to hospital

In the acute hospital setting low grip strength has been shown to be associated with an increased risk of complications among patients with cirrhosis (162) and those undergoing surgery (97). Low grip on admission has been associated with longer lengths of hospital stay among general medical older patients (133), patients hospitalized with pneumonia (163) and cancer patients (164). Low grip strength has been shown to predict in-hospital mortality for intensive care patients (165) and death at 30 days and 1 year for patients hospitalized with pneumonia (163) (166). Low grip strength among patients with hip fracture has been shown to predict poor mobility at 6 months (167) and 12 months (168). Discharge home or to usual residence has been shown to be more likely for patients with higher grip strength (169).

One study of female patients with hip fracture suggest that a cut-off of <15 kg was associated with complications for patients aged >80 years (sensitivity 90%, specificity 48%) (170). Other studies use a value <85% reference value or control mean as a cut-off value with lower sensitivity but higher specificity e.g. for post operative complications (sensitivity 64%, specificity 71%) (97).

The association of grip strength with outcomes from non-acute hospital settings has been rarely studied. Only one study has evaluated grip strength in an in-patient rehabilitation setting, and demonstrated a significant correlation between lower admission grip strength and longer length of stay among patients with a mean age of 58 years (85) .

1.7.7 Mortality

A recent meta-analysis of 14 studies (total 53,476 community dwelling participants) from North America, Europe and Japan found that higher grip strength was associated with all-cause lower subsequent mortality after adjustment for age, sex and body size (171). The overall summary hazard ratio of mortality associated with a 1kg increase in grip strength was 0.97 (95% CI 0.96, 0.98), after adjustment for age, gender and body size as appropriate. A comparison of the lowest and highest quarters of grip strength across the studies generally found a greater mortality rate in the lowest quarter with an overall summary hazard ratio of 1.67 (95% CI 1.45, 1.93) again after adjusting for age, gender and body size. However the association between grip strength and mortality was weaker for those studies with younger participants at baseline (average age under 60 years compared to over 60 years), and also in studies with longer follow-up (11 years and over) rather than shorter (up to 10 years).

A prospective study following 4912 Japanese men and women aged 35-74 years at baseline for 27 years similarly found that lower grip strength was associated with increased all-cause mortality, as well as from heart disease, stroke and pneumonia (172). A prospective American study of women aged 65-101 years found that low grip strength was associated with all-cause, cardiovascular and respiratory mortality but not deaths from cancer (173). Low grip strength has been shown to be associated with mortality among 148 male out-patients with stable cardiac failure, with an estimated cut-off value of 32kg grip strength (174).

1.8 Research areas that remain to be addressed

Grip strength has been widely used as a measure of muscle strength in research studies. Most studies assessing the muscle strength of older people have recruited community dwelling participants, although some have been based in acute hospital settings. There are few studies of grip strength of older people in other healthcare settings such as rehabilitation or long term care, and further evidence is required on the epidemiology of grip strength of older people in these different healthcare settings. This includes investigation of the feasibility and acceptability of grip strength measurement as well as the development of appropriate reference ranges. Furthermore understanding of the influences on grip strength in different healthcare settings has not been addressed and similarly the link between grip strength and receipt of care, such as length of stay, has not been studied in this context.

1.9 Aim and objectives of this study

This aim of this thesis is to investigate the epidemiology of grip strength in four healthcare settings where to date it has been little explored: in-patient and out-patient rehabilitation, Parkinson's disease clinic and nursing homes. This overall aim will be achieved by studying:

a) the feasibility and acceptability of grip measurement among older people in these healthcare settings

b) the grip strength values recorded in each healthcare setting in comparison with published reference ranges

c) the clinical correlates of grip strength in the different healthcare settings

d) the association of grip strength with discharge outcomes for the rehabilitation inpatients.

Chapter 2 Methods

2.1 Study design

This was primarily a cross-sectional epidemiological study in four healthcare settings: hospital rehabilitation in-patients, patients referred for community physiotherapy, patients attending a Parkinson's disease clinic, and residents within nursing homes, all of whom lived within the same geographical area. Participants were recruited prospectively and consecutively between 2007 and 2010. After obtaining written informed consent, data on age, weight, BMI, current co-morbidities and medication were abstracted from the clinical records. Forearm length was measured to calculate height, and grip strength was measured three times in each hand using the Southampton protocol. Questionnaires on physical and cognitive function, frailty, falls and nutrition were administered. The in-patients were seen in the hospital within one week of admission and community physiotherapy patients were seen in their own homes within four weeks of the initial physiotherapy assessment. The Parkinson's disease patients and nursing home residents were clinically stable and were reviewed in 'research clinics' at the local community hospital or in their nursing homes respectively. The feasibility of grip strength assessment was evaluated and data on its acceptability was obtained by questionnaire and semi-structured interviews with a purposive sample of participants from each setting. A copy of the protocol is in appendix 2.

2.2 Study setting

The four healthcare settings were based in and around Romsey, a small market town with a stable population of approximately 50,000 people. Romsey Community Hospital was the setting for the hospital rehabilitation in-patients. It has 20 beds and admits patients from home and from two large acute hospitals in Southampton and Winchester. The ward therapists comprised 1.2 wte senior physiotherapists and a full time junior occupational therapist (OT) supervised by the senior OT, who also provided OT services to the community team.

The community rehabilitation team (therapy-centred) based in the hospital included three part-time community physiotherapists in addition to the full-time OT, and a team of generic rehabilitation assistants. A Parkinson's disease clinic was held twice monthly at Romsey Hospital, and patients who were known to the Parkinson's disease specialist nurse and living in the Romsey area were invited to take part in this study. Finally the managers of five nursing homes in and around Romsey agreed for their residents to be invited to participate in the study.

2.3 Study group and population

2.3.1 Inclusion and exclusion criteria

The study population was derived from patients registered with one of the three Romsey General Practice surgeries or the North Baddesley surgery, which together constitute the catchment population for admission to Romsey Hospital. A lower age limit was set in order to study grip strength in an older population. Thus people aged 70 years and over registered with one of the four GP surgeries and receiving care in the following healthcare settings were invited to participate in this study:

1. In-patient rehabilitation at Romsey Hospital
2. Community physiotherapy from the Romsey Community Rehabilitation Team
3. Resident in nursing homes within the Romsey area

We were also interested to study the impact of Parkinson's disease, as a chronic neurological degenerative condition, on grip strength, but set a lower age limit of 50 years and over for this group to reflect the age range of these patients.

Romsey Hospital and the nursing homes are also used for palliative and terminal care for some patients, in whom researching grip strength assessment would not have been appropriate, and so the following exclusion criteria were developed:

1) Patients unable to give written informed consent e.g. too unwell or confused.
2) Patients unable to hold the dynamometer eg arthritis, hemiplegia.

3) Patients in a terminal phase of illness
4) Researcher unable to review participants within one week of admission to hospital or four weeks of community referral e.g. annual leave
5) Patients leaving hospital before researcher review e.g. hospital transfer

The numbers of potential participants fulfilling these criteria were documented and formed part of the feasibility study.

2.3.2 Sample size

A study investigating the link between admission grip strength and length of hospital stay in acute medical wards involved 100 participants and demonstrated significant associations between grip strength and length of hospital stay (133). We estimated that recruiting up to 100 people in each setting would be feasible and informative in this study.

2.3.3 Recruitment

We had previously obtained permission from the hospital manager and the lead for Older Persons Services in the Hampshire Primary Care Trust to base the study in Romsey Hospital. In the few weeks prior to starting the study we held a series of staff awareness meetings with the ward nurses and therapists, the community therapists and the GPs looking after patients in the hospital. Most of these healthcare professionals also wanted to try the grip strength assessment themselves, and all were interested in and supportive of the study.

The aim was to recruit participants consecutively and prospectively within each setting. The in-patients ward ledger allowed all admissions, however brief, to be identified and entered onto a screening log by the lead researcher once or twice each week. After checking for any exclusion criteria, new potential participants were identified to the ward staff.

The community rehabilitation referrals were passed to the rehabilitation team by their secretary and then one of the three physiotherapists visited the patients at home in order of clinical priority, determined by the physiotherapists themselves. They asked potential participants if they were interested in the study and either gave them an information sheet (appendix 3) or (more usually) gained permission for the researcher to post one to them along with a letter of introduction, a tear off reply slip and a stamped addressed envelope. The researcher contacted the physiotherapists once or twice weekly to take the names of new referrals and similarly entered them onto a screening log. However the physiotherapists clinically reviewed more patients than they identified to the researcher and the lack of a system of logging their calls made this a convenience sample rather than a consecutive one.

A letter of invitation (appendix 4) was sent to all of the patients on the Parkinson's disease database from the Romsey area, outlining the study with a reply slip and a stamped addressed envelope to return if they were interested in participating. Those who did not reply were contacted by telephone once to check whether they wished to participate or not.

The lead researcher and a research nurse visited the nursing homes to discuss the study with the managers, and the research nurse subsequently explained the study to the care home staff and patients in individual meetings. One home was a BUPA nursing and residential home specializing in dementia care, while the other four nursing homes were privately owned and registered for general nursing care (all) and dementia care (two). The research nurse visited each nursing home in turn, and went through the list of residents with a senior member of staff to check who should not be approached e.g. because of illness or advanced dementia. All residents were entered onto the screening log.

2.3.4 Consent

As outlined above, potential in-patient participants were approached initially by a ward nurse, and then the researcher explained the study and gave an information sheet to those expressing an interest. An interval of at least 2 hours was allowed to enable the people approached to come to a decision about taking part in the study and any further questions were answered. However in some cases participants asked to get on with the data collection straight away for their own convenience. Hospital in-patients were offered a private room for the data collection, and curtains were drawn round the bed where this was conducted on the ward. All in-patients were assessed on their own.

The community referrals and the patients with Parkinson's disease were sent the information sheet with the reply slip and were given an opportunity for questions before signing the consent form (appendix 5) at the time of the assessment. Relatives were present for many of the community assessments, which were all conducted in their own homes, but data was obtained only from the participant. The Parkinson's disease patients were assessed in a clinic room at Romsey hospital, and many were accompanied by a relative.

The nursing home residents were mainly assessed alone in their own rooms within the home. A few were seen in communal rooms and a few were seen with family members or a member of staff present but they did not contribute to the answers provided.

In all cases an additional consent was obtained for the audio-taped interviews from patients identified as suitable during the interviewer's available time frame.

2.4 Development of the quantitative data collection proforma

2.4.1 Case record review

In each setting the clinical records were reviewed by the researcher and the following data abstracted on the data collection sheet (appendix 6):

1) demographic details including date of birth, gender, dates of admission (in-patients) or referral (community rehabilitation referrals), and of grip strength assessment
2) current weight and BMI

3) co-morbidities (active medical problems impacting on function)
4) current medications

2.4.2 Clinical assessment

In each setting the following assessments were made directly by the researcher:

2.4.2.1 Grip strength assessment

Grip strength was measured three times with each hand, alternating between right and left hands, using a Jamar hand dynamometer (Promedics, Blackburn, UK) according to the Southampton protocol (appendix 7). Participants were given standardised encouragement to squeeze the dynamometer as hard as possible. The repeat measures allowed both learning and tiring effects to be apparent for an individual. The dynamometers were calibrated at the start of the study and accuracy reviewed every few months thereafter. The highest of the six grip measurements was used to characterise maximum grip strength (kg) and hand dominance was recorded. This methodology has previously been used for grip strength assessment in the Hertfordshire Cohort Study (66) (175) (appendix 1).

2.4.2.2 Height estimation

Forearm length (cm) was measured as a proxy for height since many participants were unable to stand and reported height is often overestimated. This methodology has been validated in a UK population (176) using a conversion nomogram.

2.4.2.3 Frailty assessment

The Strawbridge Frailty Questionnaire (11) is a validated score for screening for frailty. It comprises 16 items in four domains covering 1) physical and 2) cognitive function, 3) appetite and weight loss, and 4) hearing and sight difficulties over the previous 12 months. Each item is self-rated on a 4 point scale from ‘rarely a problem’ / ‘no difficulty’ (score = 1 point) to ‘very often a problem’ / ‘a great deal of difficulty’ (score = 4 points). The total score ranges from 16 (no problems) to 64 (maximum difficulty in every item). Subjects are classified as frail if they score ‘3’ or ‘4’ points on any item in at least two domains.

2.4.2.4 Falls

The number of self-reported falls in the previous 12 months was also recorded although recognized to be potentially subject to recall bias.

2.4.2.5 Physical function

The Barthel Score (177) is widely used to measure physical function in both clinical and research settings, although it does suffer from a ceiling effect. The 100 point Barthel Score with five possible ratings for each of the 10 items was used as it is more sensitive to change than the original version which has three possible ratings per item. Items include washing and dressing, toileting and continence, feeding, and mobility. The total score ranges from 0 (totally dependent and incontinent) to 100 (fully independent in all aspects).

2.4.2.6 Cognitive function

Cognitive function has been found previously to be strongly associated with grip strength (125) and might be expected to vary within an older study population. The Mini-Mental State Examination (MMSE) is well established as both a clinical and research screening tool for assessing cognitive function (178). Eleven items cover orientation, registration, attention and calculation, recall, language and visuo-spatial awareness. The maximum score is 30 representing intact cognition, and scores less than 24 imply impaired cognitive function.

2.4.2.7 Nutritional assessment

Recent nutrition can be variable among older people, especially in-patients, and so a measure of nutrition and weight loss was required. The ‘MUST’ nutritional score (179) was developed in Southampton but is widely used nationally and internationally to identify people who are malnourished or at risk of malnourishment.

The in-patients’ clinical records contained current weights, and usually recorded weights from previous admissions or clinic attendance. Where a previous weight could not be found they were asked for recalled weight from approximately one year before. The community rehabilitation referrals were asked for their weight around one year before, and were weighed in their homes using stand-on scales.

The Parkinson’s disease patients were weighed using the scales in the out patients department, and since weight was recorded at each previous clinic visit, this was available for the preceding 12 months. The nursing home residents were routinely weighed on admission to the nursing home and monthly thereafter. Those who had lived in the home less than one year were asked for recalled weight from approximately one year before.

In all cases using the height estimation a body mass index (BMI) and ‘MUST’ score could be calculated.

2.5 Feasibility of grip strength assessment

Data was collected in all settings using the same data collection sheets and took approximately 20 minutes. The ward staff, community physiotherapists or nursing home staff identified patients/residents who they thought were too unwell or confused to participate, and these were then excluded. The remaining patients/residents were assessed for ability to give informed consent and ability to cooperate with the assessments. In each setting the number of potential participants fulfilling the exclusion criteria were documented, as well as issues with equipment failure or calibration; issues relating to the setting; difficulties in using the dynamometer; and the impact of sequential assessments and hand dominance on grip strength values.

2.6 Reproducibility of grip strength assessment and responsiveness to change

Test-retest reproducibility was evaluated on a sub sample of clinically stable hospital in-patients with grip strength less than 15kg, as the literature suggests that measurement error may be greater at lower grip strength readings (27). Grip strength was assessed twice two or three days apart at the same time of day.

The responsiveness of grip strength to change was determined by measuring grip strength and the Barthel score on admission and just prior to discharge in a sub-sample of 20 rehabilitation in-patients who had an admission lasting at least two weeks and demonstrated change in their clinical condition.

2.7 Acceptability of grip strength assessment

2.7.1 Quantitative data

The acceptability of grip strength assessment was briefly covered in three simple questions at the end of the data collection. All participants were asked if the grip measurement caused any pain (yes /no), if it tired them (yes/ no) and if they would do it again (yes / no / maybe). This was piloted along with the data collection proforma, on three patients prior to commencement of the study, but no alteration was required.

2.7.2 Qualitative data

2.7.2.1 Development of interview schedule

In order to further determine the acceptability of grip strength testing within healthcare settings, semi-structured interviews were held with patients who had recently completed grip strength testing. A semi-structured model was chosen as it allowed the interview to proceed in a conversational manner while covering key areas. The interview schedule (appendix 8) was developed incrementally building on previous experience of similar research. The interview centred on the grip strength measurement, asking about the participants' experience of the assessment and views on its purpose. The schedule and use of the recording equipment were piloted on several hospital in-patients to ensure their suitability for use in the study.

2.7.2.2 Recruitment and consent of interview participants

A purposive sample of participants was selected to represent a range of gender and age in each setting and a researcher carried out the interviews blinded to the participants' grip strength. The selection of participants largely depended on the availability of this researcher as it was important that the interviews took place within one week of the grip strength testing to maximize recall. Participants undergoing grip assessment during these time periods who had a MMSE of greater than 24/30 were invited to have the additional interview, as outlined in the original information sheet, and signed a specific consent for the audio-taping of the interview. This researcher was notified and contacted the participant to make arrangements for the interview.

2.7.2.3 Conduct of the interviews

The interviews were held in private either in the hospital or in the participants' homes or bedrooms. Participants were invited to have a family member or carer present if they wished. The interview followed the semi-structured schedule but could deviate from the schedule or take a different order to allow the conversation to flow. The schedule was reviewed regularly to adapt the questions or to include any emerging themes. The interview was audio-taped via a table-top microphone and the participant was anonymised throughout the recording. The interviews lasted around 10-15 minutes.

2.8 Quality assurance of the data collected

2.8.1 Training in use of quantitative data collection tools

Four researchers undertook data collection, each focussing on one healthcare setting. The lead (in-patient) researcher conducted a literature review of the methodology of grip strength assessment using the Jamar dynamometer, which was shared with the other researchers. In order to minimise observer error, the following steps were taken. The lead researcher held discussions and practice sessions with an experienced researcher to standardise her technique for grip strength assessment, which was carried out according to the standard protocol. The lead researcher checked inter-observer variability of grip strength assessment with this experienced researcher, and also assessed her own intra-observer variability. The lead researcher then taught the other researchers how to use the proforma, observed several initial assessments and checked their intra- and inter-observer variability of grip strength assessment prior to data collection.

All of the researchers were familiar with the clinical tools – the Barthel Score, the MUST nutritional assessment tool and the MMSE. The inpatient researcher was additionally familiar with the Strawbridge Frailty Questionnaire. A small pilot study of the data collection proforma was carried out on three hospital in-patients to establish the ease of its use, but no changes to the format were required.

2.8.2 Grip strength assessment: Inter and Intra-observer Variability Studies

2.8.2.1 Study One

The purpose of this study was to evaluate the accuracy and reproducibility of grip measurements between and within two investigators, the lead researcher and a researcher experienced in grip strength assessment.

Ten healthy volunteers (5 men, age range 23-60 years; 5 women, age range 23-56 years) from the investigators' host institution agreed to participate and gave verbal consent. Grip strength was assessed sitting in the same chair according to the standard protocol used in this study and was measured to the nearest 1 kg. Measurements were taken a total of six times, three times in each hand, alternating between hands. The investigators assessed volunteers' grip separately in all 10 participants in the morning (session 1) and afternoon (session 2) of the test day, and each investigator alternately assessed 5 volunteers first in each session. The aim of alternating the order of the investigator and the volunteer was to minimise the impact of participant learning and/or tiring effects on the assessment of observer differences. The calibration of the single dynamometer used was assessed against known weights before use.

Maximum (peak) grip strength was used for all analyses. A two sample students' t test was used to determine if there was any difference between the mean grip strength values obtained from the participants by the two investigators (inter-observer variability), and a one sample t test was used to determine if there was any difference between the values obtained in sessions 1 and 2 by each observer (intra-observer variability). An alpha value of 0.05 with a 95% confidence interval (CI) was used to reject the null hypothesis of no difference in the mean between and within investigators when a hypothesised mean difference of zero was used.

There were no statistically significant differences in measurements between the investigators, based on 20 observations from pooling the results of both sessions (Figure 2.1). The mean difference between observers (95% CI) was -1.2 kg (-2.9, 0.6), p=0.18. The 95% reference range for differences was -8.5 kg to 6.2 kg as represented by the lower and upper lines respectively on Figure 2.1.

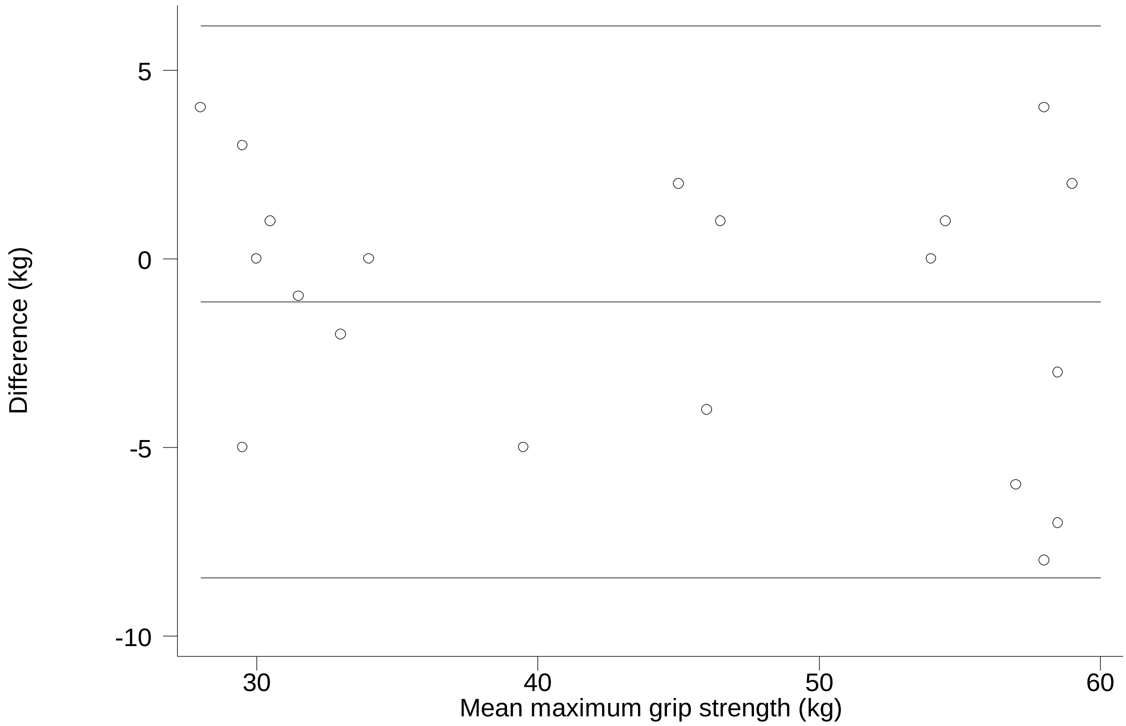

Figure 2.1 Bland Altman plot of inter-observer agreement in measurement of maximum grip strength in study one

There were also no statistically significant differences in measurements between sessions 1 and 2 for either researcher, based on 10 observations repeated over time. The mean difference over time (95% CI) for the lead researcher was -0.1 kg (-2.6, 2.4) p=0.93, with a 95% reference range of -7.0 kg to 6.8 kg (Figure 2.2). The mean difference over time (95% CI) for the other researcher was slightly greater at 1.6 kg (-0.3, 3.5) p=0.09, with a 95% reference range of -3.7 kg to 6.9 kg (Figure 2.3).

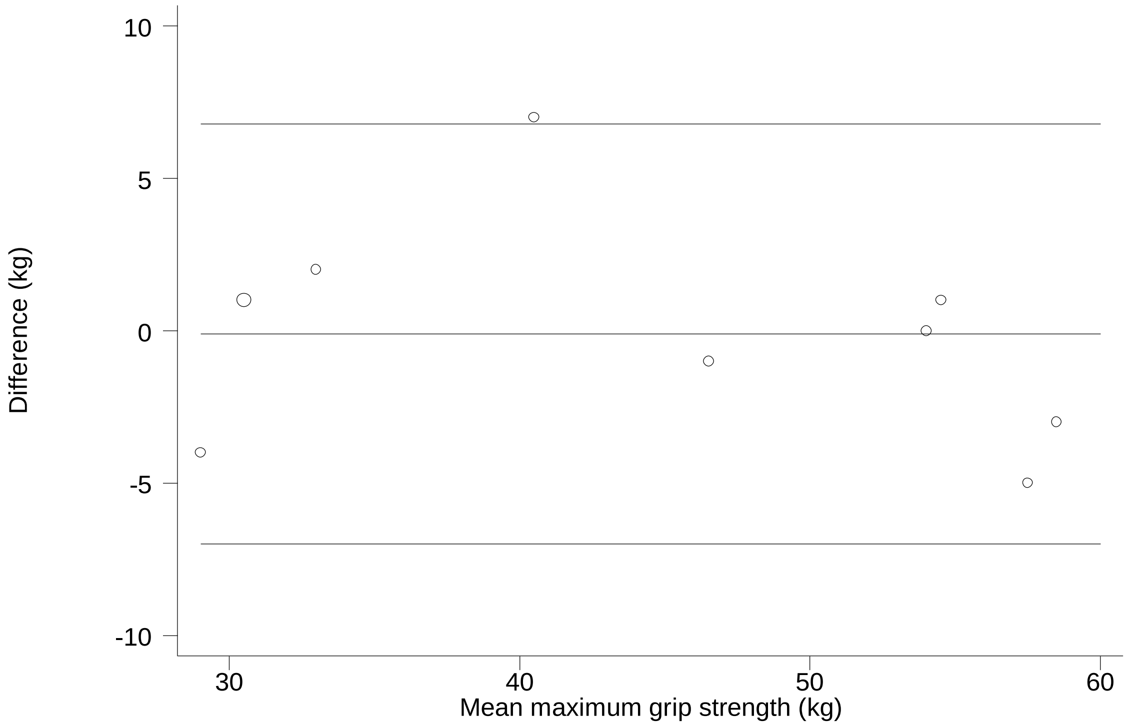

Figure 2.2 Bland Altman plot of intra-observer variability in maximum grip for the lead researcher

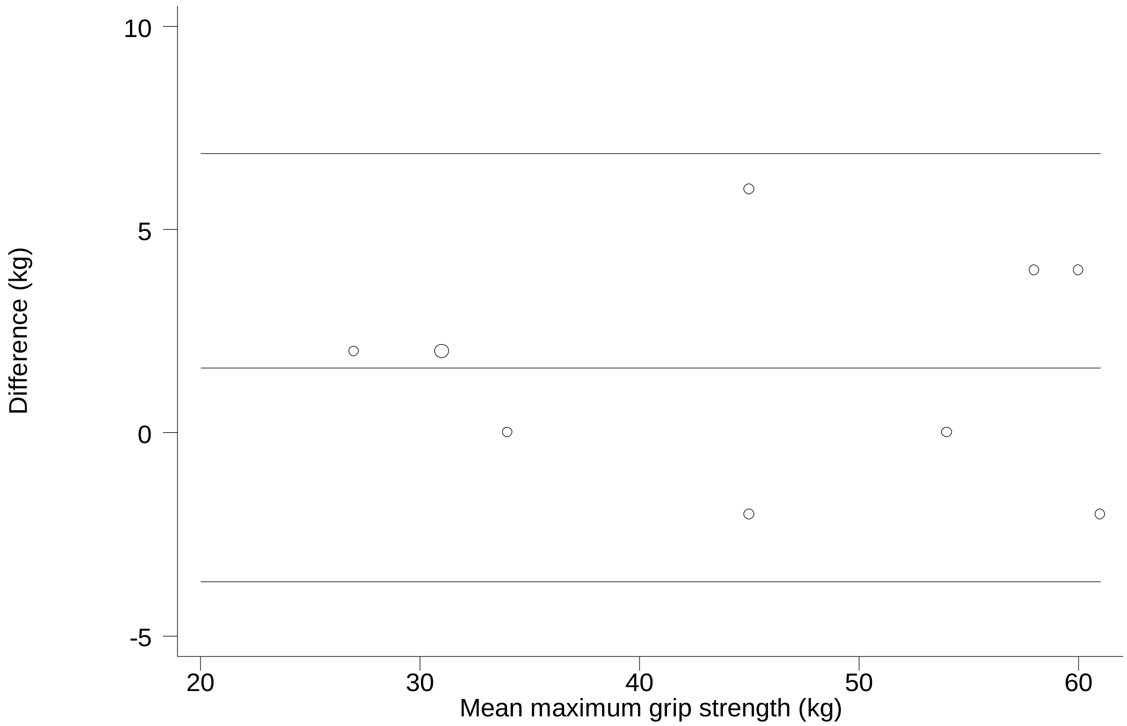

Figure 2.3 Bland Altman plot of intra-observer variability in maximum grip for the experienced researcher

2.8.2.2 Study Two

The purpose of this study was to evaluate the accuracy and reproducibility of grip measurements of two new researchers, using the lead researcher as the 'gold standard' for the inter-observer variability and repeating grip strength measurement to assess the new researchers' intra-observer variability.

Again two sessions were held with six healthy volunteers (three male, three female, age range 22-63). Grip strength was assessed twice in each hand according to the protocol with the order of assessor and volunteer balanced as before to minimize participant effects on measurer variability. Maximum grip strength was used for the analyses. A two sample t test was used to determine if there was any difference between mean grip strength attained from the participants by the researchers, and a one sample t test was used to determine if there was any difference between the values obtained in sessions 1 and 2 by the new researchers (intra-observer variability). An alpha value of 0.05 with a 95% confidence interval (CI) was again used to reject the null hypothesis of no difference in the mean between and within investigators when a hypothesised mean difference of zero was used.

There were no significant differences in measurements between the new researchers and the lead researcher, based on 12 observations from pooling the results of both sessions (Figure 2.4). The mean difference between the first new and lead researchers (95% CI) was -0.2 kg (-2.2, 1.8), p=0.86. The 95% reference range for differences was -7.1 kg to 6.8 kg. The mean difference between the second new and lead researcher (95% CI) was -0.6 kg (-2.5, 1.3), p=0.51. The 95% reference range for differences was -7.1 kg to 5.9 kg.

There were also no significant differences in measurements between sessions 1 and 2 for either new researcher, based on 6 observations repeated over time (Figure 2.5). The mean difference over time (95% CI) for the first new researcher was -1.3 kg (-4.8, 2.1) p=0.36, with a 95% reference range of -9.7 kg to 7.1 kg. The mean difference over time (95% CI) for the second new researcher was 0.8 kg (-2.5, 4.2) p=0.55, with a 95% reference range of -7.4 kg to 9.0 kg.

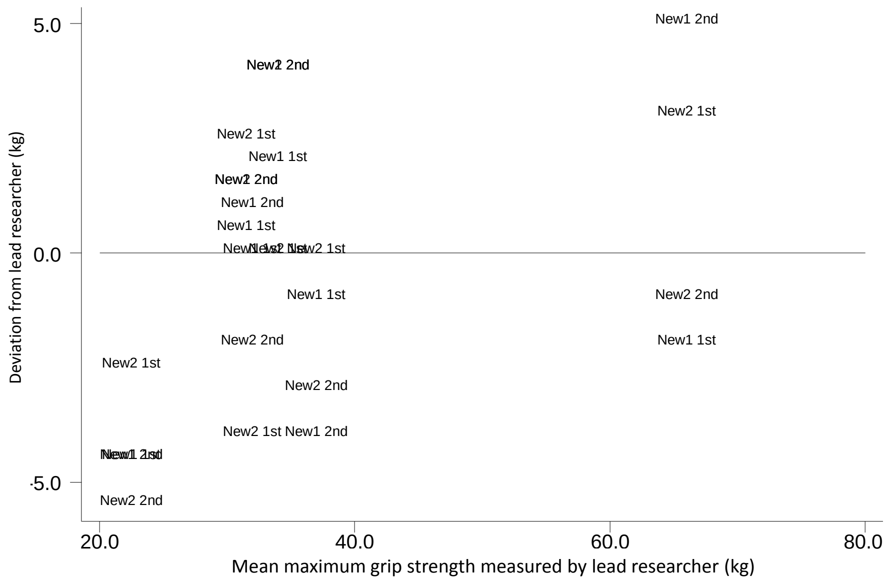

Figure 2.4 Bland Altman plot of variability in measurement of maximum grip comparing the new researchers with the lead researcher

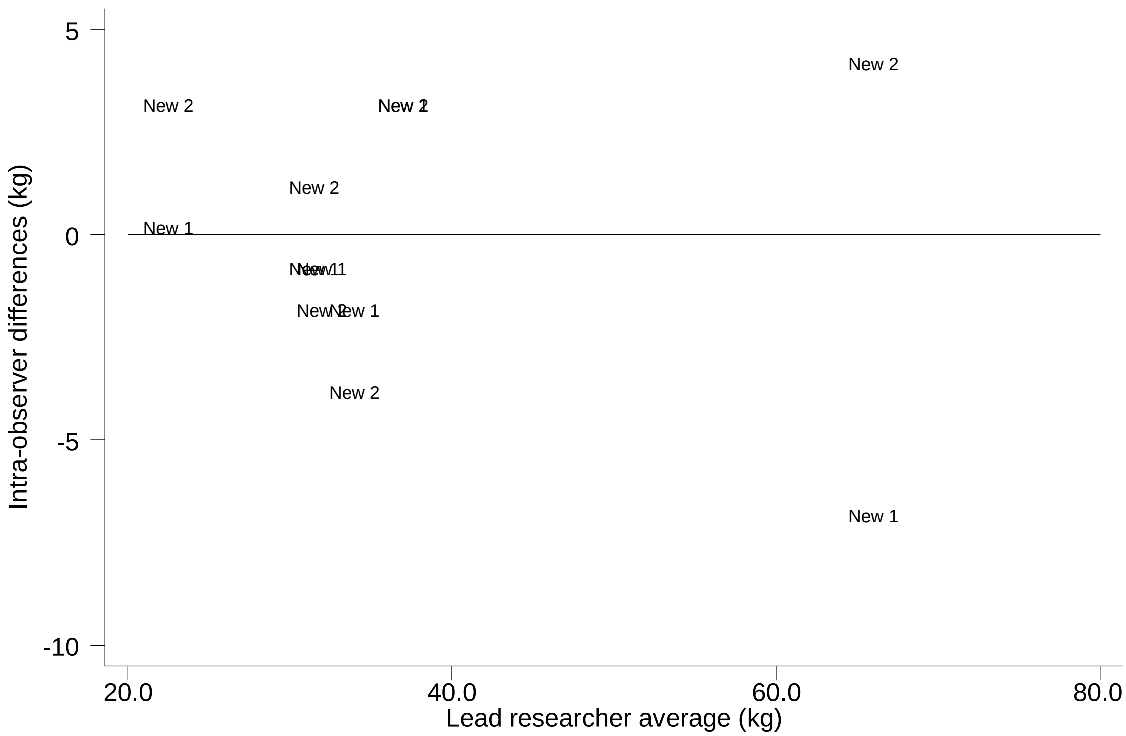

Figure 2.5 Bland Altman plot of intra-observer variability in measurement of maximum grip for both new researchers

2.8.2.3 Study Three

The purpose of this study was to evaluate the accuracy and reproducibility of grip measurements between the lead researcher and a new research nurse, using the lead researcher as the 'gold standard' for the inter-observer variability and repeating grip strength measurement to assess the research nurse's intra-observer variability.

Again two sessions were held with ten healthy volunteers (three male, seven female, age range 29-60). Grip strength was assessed twice in each hand according to the protocol with the order of assessor and volunteer balanced as before to minimize participant effects on measurer variability. Maximum grip strength was used for the analyses, which were performed using the protocol set out in study one. There were no significant differences in measurements between the investigators, based on 10 observations (Figure 2.6). The mean difference between observers (95% CI) was 0.0 kg (-0.7, 0.7), p=1.00 and the 95% reference range for differences was -1.9 kg to 1.9 kg.

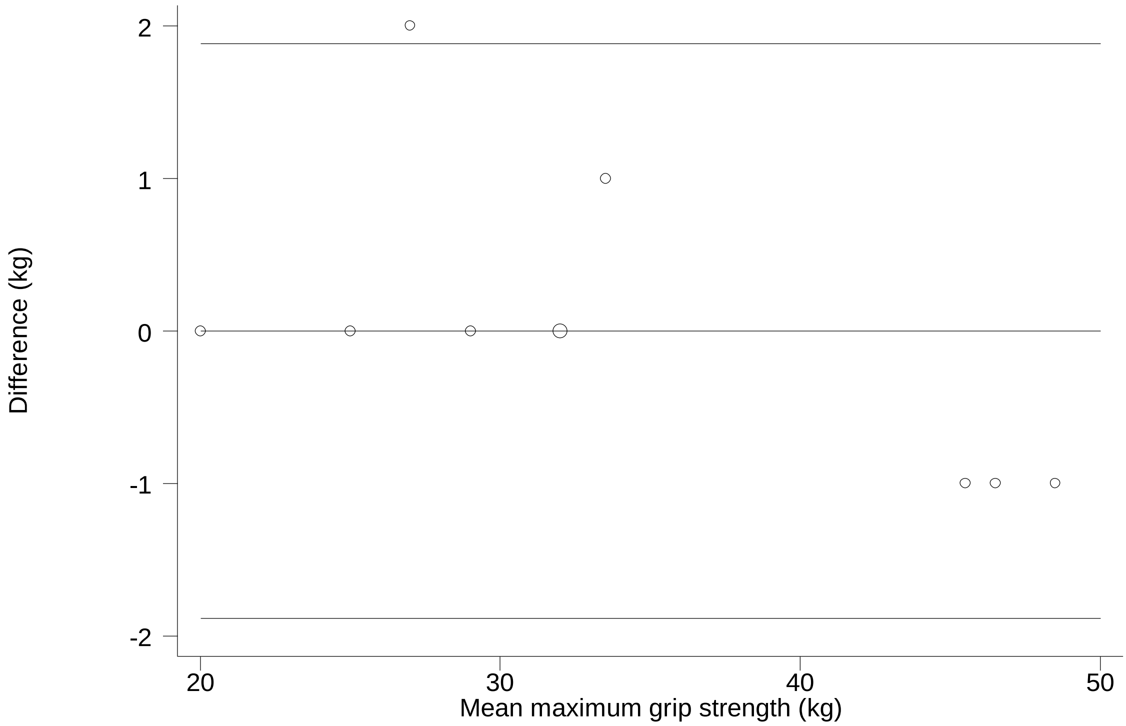

Figure 2.6 Bland Altman plot of variability in measurement of maximum grip comparing the research nurse with the lead researcher

There were also no significant differences in measurements between sessions 1 and 2 for the research nurse, based on 10 observations repeated over time (Figure 2.7). The mean difference over time (95% CI) for the research nurse was -1.5 kg (-3.5, 0.5) p=0.13, with a 95% reference range of -7.2 kg to 4.2 kg.

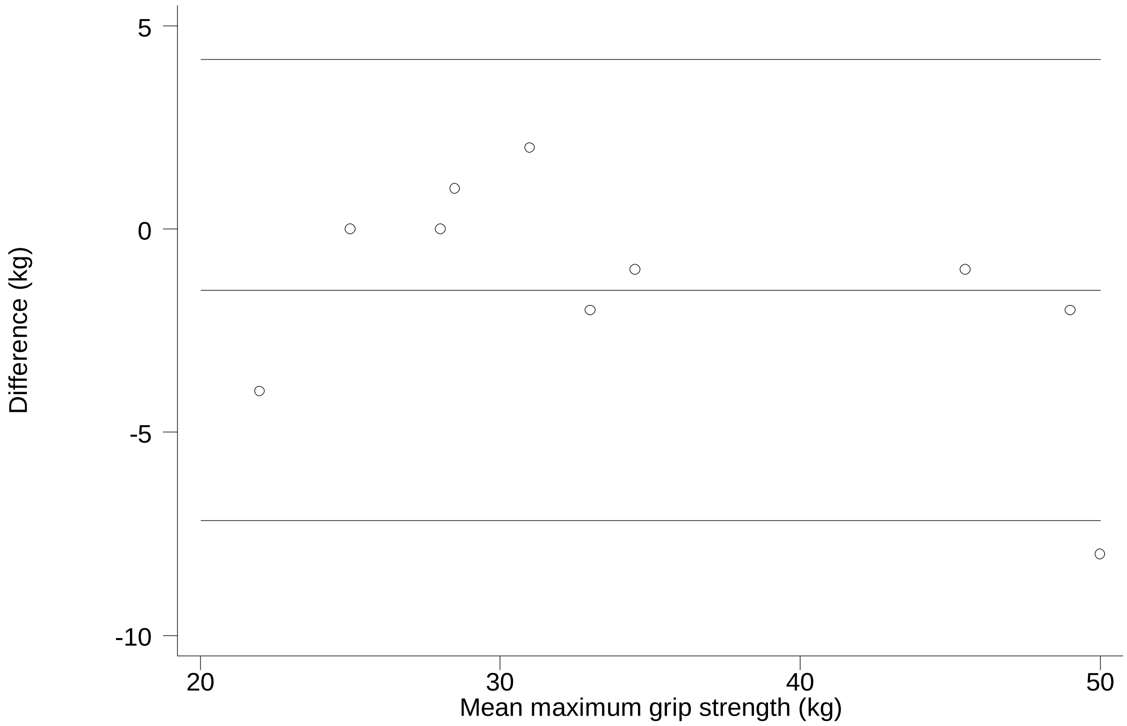

Figure 2.7 Bland Altman plot of intra-observer variability in measurement of maximum grip for the research nurse

The inter-observer and intra-observer variability studies from studies one, two and three were deemed to confirm competence and equivalence in assessment of grip strength for all four researchers.

2.8.3 Jamar Dynamometer Calibration and Accuracy

In order to minimise measurement error, the following steps were taken. Jamar dynamometers were used new from the factory and delivered calibrated. The accuracy was further checked by suspending known weights from the handle in position 2 as shown in Figure 2.8 below.

Figure 2.8 Assessing the accuracy of the Jamar against known weights

The Jamar handle is ergonomically shaped to fit a hand but altering the position of the weights on the handle did not alter the readings. The order of calibration was varied to avoid any error through constant loading such that accuracy with a 50N weight was assessed first, then 150N, 250N, 100N and 200N. A mean difference of <2 kg was deemed acceptable. The results of assessment of the Jamars' accuracy at intervals throughout the study were satisfactory (appendix 9).

2.9 Data analysis

The lead researcher devised the variable labels for the database which was created by double entry of the quantitative data followed by data cleaning. It was prepared for use with the Stata version 11 statistical package (STATA Corp. Texas, 2010).

2.9.1 Description of the participants in each healthcare setting

The participants' age, anthropometry, numbers of co-morbidities and medications, physical and cognitive function, nutritional status and falls were described using summary statistics: means (SD), medians (IQR) and number (%) are presented for each healthcare setting. Age, height, weight and BMI were normally distributed and therefore could be analysed using parametric tests including 2-sample t-tests and ANOVA. The number of co-morbidities and medications, Barthel score and MMSE were not normally distributed and were analysed using non-parametric statistical tests including Mann-Whitney and Kruskal-Wallis tests.

The Strawbridge frailty score, MUST score and number of falls in the last year were categorical variables. The MUST score was re-coded from five categories (scores of 0,1,2,3,and 4) to three categories (score 0,1,2-4) as this was clinically valid and the numbers of participants in the higher scores were very low. Even so the Fisher's exact test was required as the numbers for some categories were less than 5. The number of falls was similarly re-coded into three categories: none, one and two or more, and again this categorization is used clinically. There was a large range in the number of repeat falls (0 – 352 falls in the last year, although only 28 people had fallen more than five times) and again the numbers were very small with the higher counts, therefore the Fisher's exact test was required even with three categories.

Comparison of men and women within each setting was calculated using the 2-sample t-test, Mann-Whitney test and Fisher's exact test as appropriate, and the statistical significance was presented using P-values. Comparison of men and of women across the settings was performed using ANOVA, Kruskal-Wallis test and Fisher's exact test and again the statistical significance was presented using P-values. There were highly significant differences in height between men and women in each setting, and in weight in every setting except community physiotherapy referrals. Height and weight are known to influence grip strength and so it was decided to analyse the results for men and women separately within each setting.

2.9.2 Feasibility of grip strength measurement

Descriptive statistics were used to evaluate the response rates and reasons for exclusion in each setting, and field notes documented equipment failure and any difficulties encountered while carrying out the assessments. The impact of sequential assessment ('learning' and 'tiring' effects) were calculated for left and right hands of men and women using a 1-sample t-test based on mean maximum grip values for each attempt. The impact of hand dominance on mean maximum grip strength was evaluated for men and women using a 2-sample t-test.

2.9.3 Reproducibility of grip strength measurement and responsiveness to change

Test-retest reproducibility for hospital in-patients with low grip was described for men and women using a 2-sample paired t-test.

The responsiveness to change was evaluated using three methods. The difference in the values obtained for grip strength on admission and discharge was described using a 2- sample paired t-test. The standardised mean response (the mean change / standard deviation of the change) and the effect size, (the mean change / the standard deviation of the initial measurement) were calculated. The difference in Barthel scores obtained on admission and discharge was similarly described using these three methods.

2.9.4 Acceptability of grip strength measurement

The acceptability of grip strength assessment was determined by analysis of the interviews, and the quantitative data from the three brief questions completed by all participants.

The quantitative data was described using number (%) for men and women in each setting, and differences within and between settings were calculated using Fisher's exact test and the statistical significance was presented using P-values.

The characteristics of the interviewees were compared with those of the remaining participants in each setting, in order to evaluate how representative they were of the sample in general. Data was described using mean (SD) and median (IQR), and differences between men and women in both groups were calculated using the 2-sample t-test and Mann Whitney rank-sum test as appropriate.

The patient interviews were audio-taped with express consent from the participants and the audiotapes were transcribed verbatim. The texts were read, coded and evaluated for themes by two researchers independently and then together, looking for commonality and differences within and between the healthcare settings. Themes that emerged from early interviews were explored in subsequent interviews for validity in those settings. This allowed further questioning on any emerging themes and clarified when data saturation was achieved.

2.9.5 Description of grip strength

The maximum grip strength was described using means (SD) and percentiles for men and women in each setting, and means (SD) were also presented adjusted for age. The mean maximum grip strength was compared within settings using a 2-sample t-test, and between settings using ANOVA.

The correlation of maximum grip strength with age, height, weight and BMI for men and women in each setting was described using Pearson's correlation coefficient and statistical significance was presented using P-values. It is generally accepted in the literature that age and height as well as gender influence grip strength, and a strong correlation between maximum grip strength and weight was found for both men and women. Since height and weight were also strongly correlated, a weight-for-height variable was created for inclusion in regression analysis.

2.9.6 Correlates of maximum grip strength in each setting

The associations of maximum grip with participants' clinical characteristics - the number of co-morbidities and medications, the Barthel and MMSE scores, the Strawbridge frailty and MUST scores and the number of falls during the last year - were analysed individually for men and women separately in each setting using linear regression analysis. Results were presented both unadjusted and adjusted for age, height and weight-for-height, using regression estimates with confidence intervals, and statistical significance was indicated using P-values.

The clinical characteristics that were identified as being significantly associated with maximum grip strength in age and anthropometry adjusted univariate analyses in any of the healthcare settings were taken forward to a mutually adjusted model of grip strength in relation to age, anthropometry and clinical characteristics for men and women separately. Results were presented again using regression estimates with confidence intervals, and statistical significance indicated using P-values.

2.9.7 Clustering of co-morbidities

The prevalence of participants' active co-morbidities was described by setting and gender using number (%). Additionally a cluster analysis was carried out with the aim of identifying general patterns of clustering of common co-morbidities among older people in the healthcare settings. Ward's hierarchical agglomerative clustering technique was used to identify clusters of co-morbidities for men and women separately, and visual inspection of the cluster dendrograms was used to identify the number of clusters. The clusters were described by considering the prevalence of each individual co-morbidity which had been included in the cluster analysis, by the identified clusters. The association of co-morbidity clusters, and number of co-morbidities, with mean maximum grip strength was evaluated for men and women separately using ANOVA and regression analysis respectively.

2.9.8 Associations between baseline characteristics and discharge to usual residence among rehabilitation in-patients

Length of stay would have been used as the principal outcome variable in a regression analysis if all of the participants had been discharged to their usual residence. However 26 participants' lengths of stay were 'censored' in that some were cut short e.g. hospital transfer or death, and some were probably extended by the need to find a new care home. The choice of discharge to usual residence as the outcome measure and of Cox's proportional hazards regression for the analysis allowed the data from these censored 26 participants to be included.

The univariate associations between each baseline characteristic and discharge to usual residence were analysed for men and women separately using Cox's proportional hazards regression, both unadjusted and adjusted for age and anthropometry. The associations between discharge to usual residence and each characteristic in turn were then explored after adjustment for age, anthropometry and those factors that were associated with outcome in the age and size adjusted models. A final model of this mutually adjusted model was presented.

Evaluation of the associations between individual co-morbidities and discharge to usual residence among male and female rehabilitation in-patients proved impossible due to the small sample sizes. The association of co-morbidity clusters, and number of co-morbidities, with grip strength and with discharge to usual residence were explored for men and women separately using Cox's proportional hazards regression.

2.10 Ethics approval

The study protocol was finalised and submitted for the SUHT research and development review process in September 2007. Full documentation was submitted to the Southampton and South West Hampshire Research Ethics committee (B) on 18th October, and the lead researcher attended the meeting on 28th November. The committee requested a few minor changes to the documentation and the vice chair was able to approve the study on 19th December 2007 (appendix 10). Full SUHT approval was obtained on the 21st January 2008.

Two substantial amendments approved in May 2008 and February 2009 have allowed evaluation of test-retest reliability among participants with grip strength less than 15 kg, and evaluation of grip strength and Barthel scores at discharge for hospital in-patients. (appendix 10)

The names and hospital numbers of participants appear only on the paper screening logs, which are kept in locked filing cabinets in University of Southampton property. All computer records show only the unique project identification number for each participant, and all computer files are password protected in accordance with local data protection policy. The audiotapes and transcriptions have only the participant number as an identifier and all quotes in reports are non-attributable to any individual. The researchers assessing participants at home were fully aware of the university lone worker policy and carried mobile telephones.

Chapter 3 Results: Description of participants

3.1 Recruitment in each healthcare setting

3.1.1 Hospital rehabilitation in-patients

101 patients were prospectively and consecutively recruited to the study from a sample of 161 patients admitted to Romsey Hospital between February and December 2008. 60 patients were not included for the following reasons: 12 too unwell; 12 severely confused; 4 refused; 11 discharged or transferred before review; 21 could not be seen by the researcher within one week of admission because of annual leave

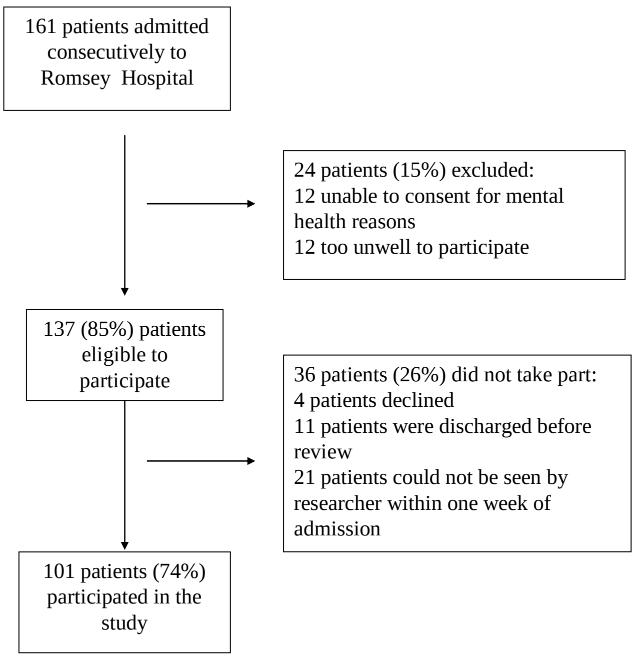

Figure 3.1 Hospital rehabilitation in-patients recruitment CONSORT statement

The lead researcher visited the hospital once or twice a week and checked the ward lists for admissions and discharges. This enabled a comprehensive screening log to be maintained and thus capture of the 11 patients with brief admissions who had been admitted and discharged quickly between researcher visits. All of the patients who were recruited had data collected directly after obtaining written informed consent and within one week of admission to Romsey hospital. The median delay between admission and data collection was 4 days (IQR 2-6, range 1-7). The patients were all assessed in the morning, on the ward and on their own.

The 101 patients comprised 37 men (mean age 82.6 years, range 73.0 to 92.6) and 64 women (mean age 84.9 years, range 70.3 to 99.4). 40.6% of the patients were admitted from an acute hospital for rehabilitation as part of step-down care, and 59.4% were admitted directly from home. The most common category of co-morbidity was cardiovascular (84%), followed by uro-genital (46%). Comparison of the patients recruited with those not recruited was only possible for age, as gender was not recorded for those not recruited and they were identified only by initials on the screening log: those not recruited had a mean age of 84.6 years.

3.1.2 Community rehabilitation referrals

47 patients referred for community physiotherapy with the community rehabilitation team were recruited to the study between May 2008 and November 2009 from a sample of 103 eligible patients. 56 patients were not recruited for the reasons outlined in Figure 3.2. Patients were referred by several sources including General Practitioners and acute hospitals, and the three physiotherapists triaged and prioritized the referrals for subsequent home assessments. The researcher contacted the physiotherapists at least weekly to maintain a screening log of new referrals seen by them, and aimed to contact the patients by telephone if the physiotherapists had given them an information sheet, or otherwise posted an information sheet prior to contacting the patient. In practice, due to the heavy workload of the therapists, an information sheet always had to be posted, and this delayed recruitment such that the timescale between initial physiotherapy assessment and grip strength measurement had to be increased from two to four weeks. Recruitment was also reduced, as sometimes more than four weeks had elapsed since the initial physiotherapy

assessment and so patients became ineligible for the study. The median delay between initial assessment and data collection was 8 days (IQR 6-14, range 0-28).

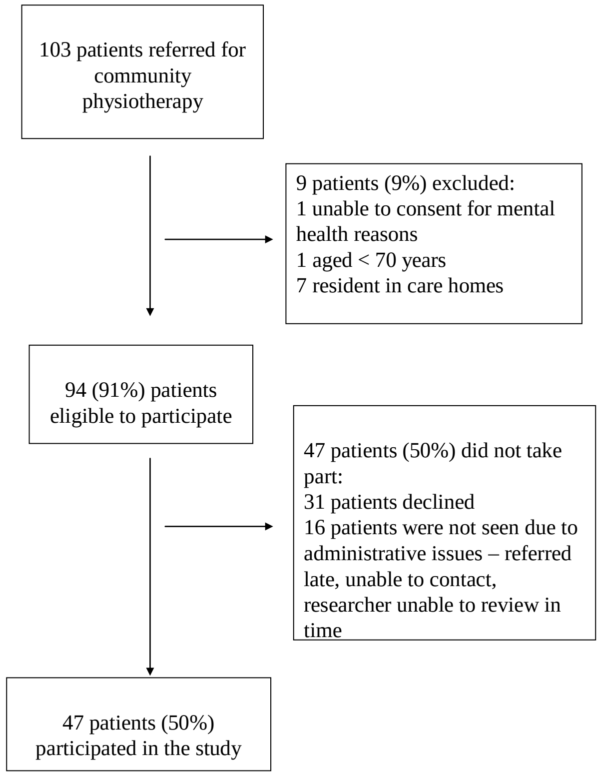

Figure 3.2 Community rehabilitation referrals recruitment CONSORT statement

Although the researcher regularly prompted the physiotherapists for details of recent new referrals, and they were very supportive of the study, it was apparent that they often forgot to give her details of all the patients whom they had seen. The three physiotherapists worked part-time so usually one or more of them were not available to give a list of recent referrals and since there was no centralised database for recording these details in their office, the researcher was dependent on speaking to the physiotherapists. Initially the team failed to refer some potential participants whom they judged to be too frail or unlikely to be interested, but this was addressed by further discussion of the study objectives after only a few weeks. The researcher attended the team meetings as far as possible to improve recruitment, however there was potential for selection bias and this was a convenience rather than a consecutive sample.

The 47 patients comprised 24 men (mean age 79.2 years, range 70 to 92) and 23 women (mean age 79.4 years, range 70 to 89). All participants were interviewed in their own homes, often with family members present. Ten (21.3%) had recently had elective joint replacement (knee or hip) and 57.8% had experienced at least one fall in the last 12 months.

3.1.3 Parkinson's disease clinic patients

57 patients with Parkinson's disease were recruited to the study between September 2008 and May 2009. They were on the database of the Parkinson's disease Nurse Specialist for the Romsey area, which was updated monthly and listed all of the Parkinson's disease patients in the Romsey area known to her. People with Parkinson's disease not referred by their GP to specialist services might not have been on the database, but it is likely that this would have been only a few people and with mild disease. The database did include people with Parkinson's disease who were resident in care homes. 80 patients on the database were contacted by post, with a letter outlining the study, an information sheet and a reply slip. 23 patients contacted were not recruited, for the reasons shown in Figure 3.3.

Following receipt of the reply slip, a researcher arranged to meet the patient either at Romsey Hospital or their home as they chose (six participants). They were free to have a relative or friend with them. Since these participants had a chronic condition there was no time constraint on time from first contact to data collection. The 57 patients comprised 34 men (mean age 71.3 years, range 52.9 to 85.4) and 23 women (mean age 72.6 years, range 61.6 to 86.1). Comparison of the patients recruited with those not recruited was only possible for age for the same reasons as the in-patient group: those not recruited had a mean age of 79.3 years.

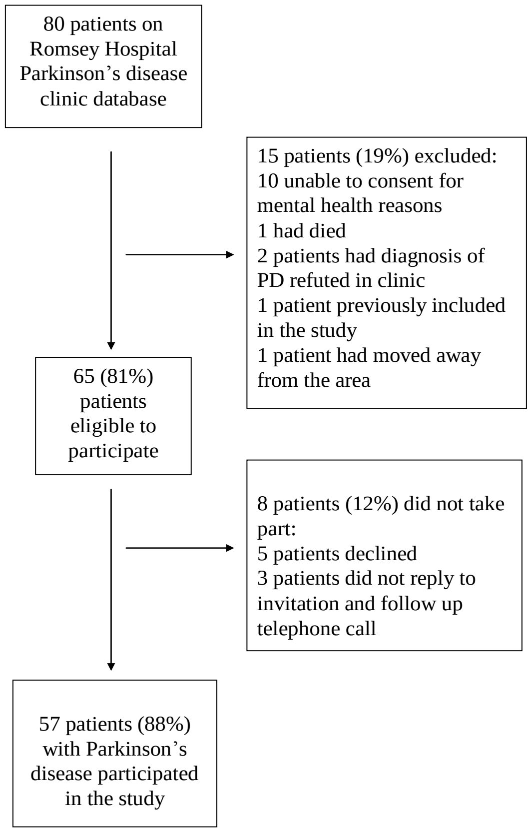

Figure 3.3 Parkinson's disease clinic patients recruitment CONSORT statement

3.1.4 Nursing home residents

There are three nursing homes in the town of Romsey, one nearby in North Baddesley, and several located within a few miles of Romsey, such that local people requiring higher levels of care are likely to move to one of these homes. 100 patients from five nursing homes were recruited between June 2009 and February 2010. The nursing homes were located in Romsey (two), in North Baddesley (one) and in nearby villages (two).

The researcher contacted each home and arranged a meeting to explain the study to the manager and senior staff. The nursing home staff identified residents who should not be approached for reasons of illness, or who lacked mental capacity to consent.

Information sheets were left for residents and their family members and the researcher returned a day or two later to address any concerns and obtain written informed consent from participants. Residents were mainly interviewed in their own room but occasionally in a private area of the main reception rooms if the participant preferred. Family members were present at times. Since these residents were medically stable there was no time constraint on time from first contact to data collection. The median duration of residence in the home was 298 days (IQR 106-727, range 12-4614). The 100 residents comprised 35 men (mean age 85.1 years, range 70.0 to 98.7) and 65 women (mean age 87.5 years, range 72.7 to 97.1).

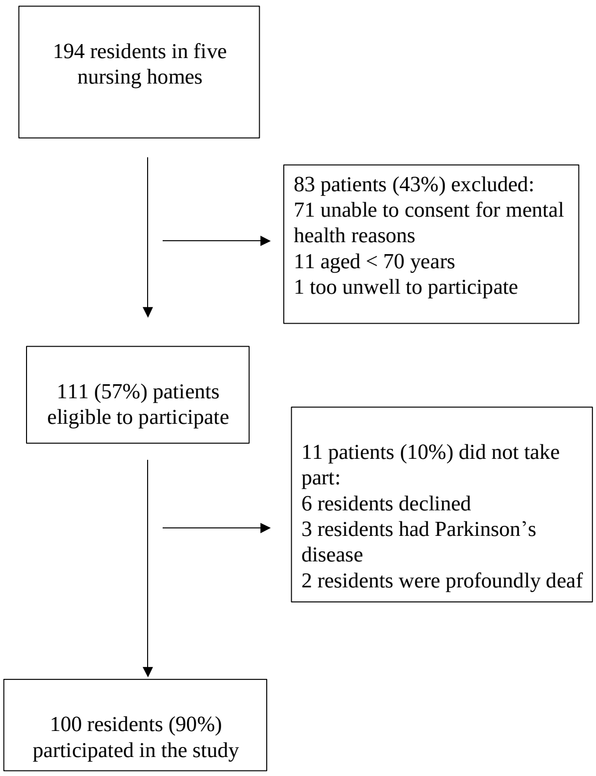

Figure 3.4 Nursing home residents recruitment CONSORT statement

3.2 Description of participants by setting

3.2.1. Individual characteristics

Table 3.1 shows the individual characteristics of the male and female participants from each setting. Within each setting men and women were of similar age, but there was a statistically significant difference in the ages of participants between settings, with the nursing home residents being the oldest, then the in-patients, followed by the community referrals and then the PD patients. The men were significantly taller than the women in each setting ($p<0.0001$), but were of similar height across the four settings, whereas the women differed significantly ($p<0.001$) with the community referrals being the tallest women and the nursing home residents the shortest. The men were heavier than the women (significant in all except the community referrals) and weight differed significantly across the settings for both genders, with the in-patients and the nursing home residents being the lightest ($p<0.001$). BMI was significantly different between men and women only in the PD patients ($p=0.02$), but again differed significantly between the settings for both genders.

3.2.2. Co-morbidities, medication, physical and cognitive function

As shown in Table 3.2, there was no significant difference in the number of co-morbidities between men and women within or between settings, with a median number of four for all participants except male PD patients who had a median of three. There was a significant difference in the number of medications for both men ($p=0.0003$) and women ($p=0.0007$) across settings, with in-patients taking the most (median of eight) and PD patients the least. There was no significant difference between men and women within the same setting for the number of medications.

Table 3.1 Description of participants: individual characteristics

Mean (SD)	**Hospital rehabilitation inpatients** Male (N=37)	Female (N=64)	**Community rehabilitation referrals** Male (N=24)	Female (N=23)	**Parkinson's disease clinic patients** Male (N=34)	Female (N=23)	**Nursing Home residents** Male (N=35)	Female (N=65)	**P value[1]**
Age (years)	82.6 (5.6)	84.9 (6.2)	79.2 (5.5)	79.4 (5.8)	71.3 (8.0)	72.6 (7.6)	85.1 (7.6)	87.5 (6.4)	*M: <0.001* *F: <0.001*
P value[2]	*P=0.07*		*P=0.88*		*P=0.53*		*P=0.10*		
Height (cm)	170.9 (3.5)	157.9 (4.0)	173.3 (4.7)	162.0 (5.4)	172.7 (4.5)	159.2 (5.4)	172.8 (5.7)	156.6 (5.3)	*M: 0.16* *F: <0.001*
P value[2]	*P<0.0001*		*P<0.0001*		*P<0.0001*		*P<0.0001*		
Weight (kg)	70.1 (11.9)	57.9 (15.7)	79.5 (13.6)	75.0 (17.0)	83.1 (14.0)	62.7 (14.4)	70.1 (11.0)	58.4 (11.4)	*M: <0.001* *F: <0.001*
P value[2]	*P=0.0001*		*P=0.33*		*P<0.0001*		*P<0.0001*		
BMI (kg/m^2)	24.0 (3.9)	23.1 (5.8)	26.5 (4.2)	28.6 (6.5)	27.9 (4.7)	24.6 (5.0)	23.4 (3.2)	23.9 (5.1)	*M: <0.001* *F: = 0.001*
P value[2]	*P=0.42*		*P=0.20*		*P=0.02*		*P=0.64*		

SD: standard deviation; N: number; M: male; F: female; cm: centimetres; kg: kilograms; BMI: body mass index; m: metre
Data for weight and BMI missing for 3 male and 1 female hospital inpatients, and 1 male community referral
[1]P value for differences between settings by gender calculated using ANOVA
[2]P value for differences between gender within settings calculated using 2-sample t-test

Table 3.2 Description of participants: co-morbidities, medication, physical and cognitive function

	Hospital rehabilitation inpatients		**Community rehabilitation referrals**		**Parkinson's disease clinic patients**		**Nursing Home residents**		**P value**[1]
Median (IQR)	Male (N=37)	Female (N=64)	Male (N=24)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=35)	Female (N=65)	
Number of co-morbidities	4 (3,5)	4 (3,5)	4 (3,5.5)	4 (3,5)	3 (2,5)	4 (2,5)	4 (3,6)	4 (3,5)	*M: 0.16* *F: 0.29*
P value[2]	*P=0.63*		*P=0.37*		*P=0.91*		*P=0.63*		
Number of medications	8 (7,10)	8 (6,11)	6 (3.5,7.5)	7 (4,8)	4.5 (2,7)	4 (3,6)	6 (5,7)	7 (5,8)	*M: 0.0003* *F: 0.0007*
P value[2]	*P=0.87*		*P=0.77*		*P=0.93*		*P=0.44*		
Barthel score (100 point)	62 (31,78)	69.5 (48,83)	99.5 (92,100)	96 (91,100)	98 (93,100)	98 (93,100)	46 (29,73)	44 (31,58)	*M: 0.0001* *F: 0.0001*
P value[2]	*P=0.12*		*P=0.21*		*P=0.61*		*P=0.52*		
MMSE	24 (21,26)	25 (20,27)	28 (24,30)	28 (25,30)	28.5 (26,29)	29 (29,30)	15 (13,20)	17 (12,24)	*M: 0.0001* *F: 0.0001*
P value[2]	*P=0.94*		*P=0.54*		*P=0.0007*		*P=0.58*		

IQR: inter-quartile range; N: number; M: male; F: female; MMSE: mini mental state examination;
Data for MMSE missing for 1 male community referral
[1]P value for differences between settings by gender calculated using Kruskal-Wallis test
[2]P value for differences between gender within settings calculated using Mann Whitney rank-sum test

Table 3.3 Description of participants: Strawbridge frailty and MUST scores, and number of falls in the last year

	Hospital rehabilitation inpatients		Community rehabilitation referrals		Parkinson's disease clinic patients		Nursing Home residents		P value[1]
Number (%)	Male (N=37)	Female (N=64)	Male (N=24)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=35)	Female (N=65)	
Frail on Strawbridge scale	20 (57)	30 (50)	14 (58)	15 (75)	23 (68)	9 (39)	29 (83)	55 (85)	*M: 0.08* *F: <0.001*
P value[2]	*P=0.53*		*P=0.34*		*P=0.06*		*P=1.000*		
MUST score:									
0	21 (68)	28 (47)	20 (87)	21 (92)	28 (82)	18 (78)	29 (83)	48 (74)	*M: 0.32*
1	4 (13)	11 (18)	1 (4)	1 (4)	5 (15)	3 (13)	4 (11)	6 (9)	*F: 0.002*
2-4	6 (19)	21 (35)	2 (9)	1 (4)	1 (3)	2 (9)	2 (6)	11 (17)	
P value[2]	*P=0.17*		*P=1.000*		*P=0.76*		*P=0.31*		
Falls in past year:									
0	8 (22)	16 (25)	8 (33)	12 (52)	19 (56)	12 (52)	20 (57)	35 (54)	*M: 0.006*
1	11 (31)	19 (30)	4 (17)	4 (17)	6 (18)	4 (17)	10 (29)	15 (23)	*F: 0.03*
2 or more	17 (47)	28 (45)	12 (50)	7 (31)	9 (26)	7 (31)	5 (14)	15 (23)	
P value[2]	*P=0.96*		*P=0.40*		*P=0.94*		*P=0.59*		

MUST: Malnutrition Universal Screening Tool; %: percentage; N: number; M: male; F: female
Data for Strawbridge missing for 2 male and 4 female hospital inpatients and 3 female community referrals
Data for MUST missing for 6 male and 4 female hospital inpatients, and 1 male community referral
Data for falls missing for 1 male and 1 female hospital inpatient
P value[1] for differences between settings by gender calculated using Fisher's exact test
P value[2] for differences between gender within settings calculated using Fisher's exact test

The Barthel scores were similarly high among the male and female community referrals and PD patients, and lowest among nursing home residents. This is reflected in the statistically significant difference for both men and women between settings (p=0.0001). The MMSE results follow a similar pattern, with high scores among community referrals and PD patients, and lowest scores found in nursing home residents, with significant differences for both genders between settings (p=0.0001). However there was a significant difference between male and female PD patients, with lower scores for the men (p=0.0007).

3.2.3.Strawbridge frailty and MUST scores, and number of falls in the last year

The nursing home residents had the highest proportion of participants classified as frail using the Strawbridge scale at 83% for men and 85% for women, and there was no significant difference within settings for men and women (table 3.3). The female PD patients were the only group to have less than 50% classified as frail, and the difference between settings was only significant for women (p<0.001).

There was no significant difference in MUST scores between men and women within each setting, but there was a difference between women across the settings (p=0.002) with the poorest nutritional scores among the female in-patients.

Men and women within each setting experienced similar numbers of falls, but there was a significant difference for both sexes across settings with nursing home residents experiencing the least (men p= 0.006; women p=0.03).

Chapter 4 Results: Clinimetric properties of grip strength measurement in healthcare settings

4.1 Feasibility of grip strength assessment

4.1.1 Equipment and environment issues

The aim was to assess all participants sitting in a chair with arms, such that their elbow could be flexed at 90 degrees with their shoulder abducted, their lower arm supported and with their feet flat on the floor, in line with the standard protocol.

The in-patients were assessed in the late morning usually sitting by their bed in an upright chair, However sometimes participants were resting on the bed and could not easily be moved, and so their grip strength was assessed sitting as upright as possible in bed with the Jamar case as a rest for their lower arms, such that their elbow was flexed as close to 90 degrees as possible. The curtains usually provided sufficient privacy as the assessments were conducted outside visiting hours, and noise was not a problem.

The community rehabilitation referrals all chose to be seen at home rather than Romsey Hospital. Almost all were weighed on standing scales but on one or two occasions the scales didn't work (deep pile carpet). However if those participants had weighed themselves with bathroom scales within the past one to two days, a recalled weight was accepted. Additionally recalled weight was used for one lady who was wheelchair bound and could not stand to have a weight checked. There were no issues with measuring grip strength, which was mainly carried out in an arm chair. However two homes were restricted for space, and on several visits there were dogs or young grandchildren present, which was distracting for the researcher.

The PD patients were mainly seen in a room in the out-patients department which allowed accurate assessment of weight using the seated scales there. These participants all had their grip strength assessed in a chair. Four patients were seen at home, and weighed using their own scales. The accuracy of these scales was checked by the researcher who was weighed on both the patients' and the clinic scales. There were no issues with the environment in those seen at home.

The nursing home residents were mainly assessed in a chair or wheelchair, but a few were assessed in bed with the Jamar case to support their lower arm as outlined above. The assessment was interrupted by a fire alarm on a few occasions and the researcher sometimes requested to turn off the radio or television. The response rate for participation in each setting is shown in Table 4.1.

The Jamar dynamometers were regularly assessed for accuracy against known weights, and the instrument used for the nursing home assessments had to be changed part-way through as it was found to be underestimating grip strength by 6 kg. It had apparently been recently dropped, underlining the need for the assessor to support its weight. 13 participants from the last nursing home visited were all re-assessed to ensure the accuracy of the readings taken (an additional five residents were too unwell to be reassessed and one was at home). The mean difference in the two readings for these participants was 0.56kg (range -2kg to + 7kg) and the 2nd reading was the one used in subsequent data analysis. The other dynamometers retained their accuracy despite frequent use in different places (Appendix 9).

4.1.2 Participants' ability to hold the dynamometer

Only one hospital in-patient (with advanced peripheral neuropathy) could not hold the dynamometer at all, and six female in-patients with arm fractures or hemiparesis could only grip with one hand. This was more of an issue among the nursing home residents, several of whom could not grip the dynamometer because of painful arthritic hands. The community referrals and PD patients could all hold the dynamometer with both hands.

As shown in Table 4.1, a number of potential participants were excluded because of lack of capacity to consent to the study. However in-patients with lower MMSE scores were able to grip the dynamometer with clear instruction and demonstration and appeared to give their maximal effort. Patients who were partially sighted were

Table 4.1 Recruitment and reasons for non-participation by setting

	Hospital rehabilitation inpatients	Community rehabilitation referrals	Parkinson's disease clinic patients	Nursing Home residents
Total number of patients/residents screened	161	102	80	183
Ineligible (% of total)	24 (15)	8 (8)	10 (12.5)	72 (39)
Mental health issues (% of total)	*12 (7.5)*	*1 (1)*	*10*	*71 (38.5)*
Too unwell (% of total)	*12 (7.5)*	*0 (0)*	*0 (0)*	*1 (0.5)*
Died /moved away/in care home (% of total)	*0 (0)*	*7 (7)*	*0 (0)*	*0 (0)*
Eligible (% of total)	137 (85)	94 (92)	70 (87.5)	111(61)
Not recruited (% of eligible)	36 (26)	47 (50)	13 (18.6)	11 (10)
Declined (% of eligible)	*4 (3)*	*31 (33)*	*8*	*6 (5)*
Organisational issues (% of eligible)	*32 (23)*	*16 (17)*	*5*	*5 (5)*
Recruited (% of eligible)	101 (74)	47 (50)	57 (81.4)	100 (90)

%: percentage

able to hold the dynamometer once guided to it by the researcher. The assessment of grip strength three times with each hand took about five minutes.

4.1.3 Impact of sequential assessment on grip strength values

Each participant had three attempts to grip the dynamometer with each hand, and Table 4.2 shows the mean maximum grip values for each hand for each attempt.

Table 4.2 Maximum grip values for three attempts with each hand: impact of sequential attempts

	Male participants (N= 130)		**Female participants (N= 172)**	
Mean (SD)	**Left hand**	**Right hand**	**Left hand**	**Right hand**
1st attempt	21.3 (11.1)	22.1 (11.7)	9.3 (7.6)	10.6 (7.6)
2nd attempt	21.5 (12.1)	22.9 (12.3)	9.6 (7.8)	10.9 (7.8)
3rd attempt	21.5 (11.9)	22.9 (12.9)	9.2 (7.8)	11.0 (8.0)
Learning effect 2nd -1st attempt	0.1 (3.2)	0.8 (3.4)	0.3 (2.5)	0.25 (2.4)
P value	*P=0.64*	*P=0.008*	*P=0.07*	*P=0.17*
Tiring effect 2nd – 3rd attempt	-0.02 (2.6)	-0.03 (2.7)	0.4 (2.1)	-0.08 (1.9)
P value	*P=0.92*	*P=0.90*	*P=0.02*	*P=0.61*

N: number; SD: standard deviation
Data for maximum grip in three left and three right hands missing for 6 female hospital inpatients
Data for 3rd attempt with left hand missing for 1 additional female hospital inpatient
P value for differences between attempts calculated using 1-sample t-test

Men had higher values than women, and the mean maximum grip was higher in the right hand for both sexes. Men had a significant improvement overall between the first and second attempt (‘learning effect’) with the right hand only, and no lessening of their grip with the third attempt ('tiring effect'). The women showed little change overall in the three attempts with their right hand, but did have significant tiring effects with the third attempt with their left hand (p=0.02).

4.1.4 Impact of hand dominance

The mean maximum grip was compared between left and right handed male participants and also between left and right handed female participants. All but nine participants were able to determine a dominant hand. As shown in Table 4.3, in this sample there was no significant difference between the maximum grip strength attained by left or right handed men (p=0.82) and left or right handed women (p=0.75).

Table 4.3 Maximum grip strength and hand dominance

	Male participants (N= 130)		**Female participants (N= 175)**	
Mean (SD)	**Left handed (N=13)**	**Right handed (N=113)**	**Left handed (N=17)**	**Right handed (N=153)**
Maximum grip (kg)	26.8 (12.5)	25.9 (12.1)	13.5 (7.8)	12.8 (7.9)
P value	*P=0.82*		*P=0.75*	

N: number; SD: standard deviation
4 male and 5 female participants reported no hand dominance
P value for differences between left and right hand dominance calculated using 2-sample t-test

The grip strength of participants' dominant and non-dominant hands was compared for men and women, as shown in Table 4.4. The right handed participants had significantly stronger grip with their dominant hand. There were relatively few left handed participants, and while the women had a significantly stronger grip with their dominant hand, there was no significant difference in grip strength between left and right hands for the left handed men. The lack of difference between dominant and non-dominant hands for left handed men is in line with previous research although the small number of left handed participants and much larger sample of right handed participants limits the conclusions that can be drawn from these findings.

Table 4.4 Maximum grip strength in participants' dominant and non-dominant hands

	Male participants		**Female participants**	
Mean (SD)	**Left hand**	**Right hand**	**Left hand (N=17)**	**Right hand (N=153)**
Maximum grip (kg) for left dominant participants	25.9 (12.0) (N=13)	23.1 (12.3) (N=13)	13.1 (8.6) (N=15)	11.5 (7.8) (N=15)
P value	*P=0.11*		*P=0.04*	
Maximum grip (kg) for right dominant participants	23.1 (11.7) (N=113)	24.9 (12.5) (N=113)	10.3 (7.9) (N=149)	12.2 (8.0) (N=149)
P value	*P=0.0008*		*P=0.0000*	

SD: standard deviation; N: number
4 male and 5 female participants reported no hand dominance
P value for differences between dominant and non-dominant hand calculated using paired t test

4.1.5 Reproducibility: Test-retest reproducibility of low maximum grip strength values

The Jamar is claimed to be less reliable when measuring lower grip strength, and it became apparent that quite a few of the hospital inpatients had low grip strength. Thus test-retest reproducibility was assessed on a convenience sample of ten in-patients who were clinically stable, with maximum grip strength less than 15 kg. Grip strength was assessed twice within one week in the late morning by the lead researcher who was blind to the initial grip strength measurement when conducting the second assessment. The full results are available in appendix 11. The mean difference (95% CI) in the two readings was -0.3kg (-1.5, 0.9) p=0.58, with a 95% reference range of -3.6 kg to 3.0 kg.

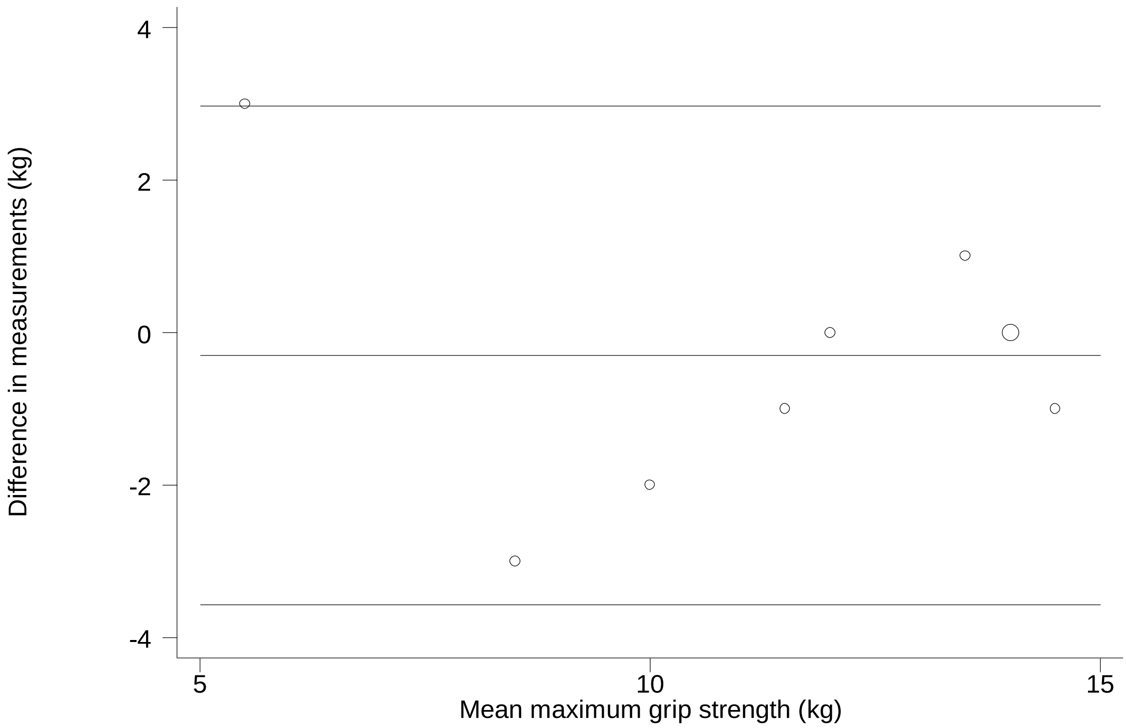

Figure 4.1 Test-retest reproducibility of low maximum grip strength values

4.1.6 Responsiveness of grip strength to change

Grip strength and Barthel score were assessed on admission and discharge among a sub-sample of 20 rehabilitation in-patients, and the results are shown in appendix 12.

The mean difference (95% CI) in the two grip strength readings was -0.3kg (-1.7, 1.07) p=0.65, with a 95% reference range of -6.1 kg to 5.5 kg. This represents a mean improvement of 0.3 kg in grip strength at discharge compared to admission. The standardised mean response was 0.10 and the effect size was 0.05. For both of these measures a value of 0.2 – 0.5 is considered a low responsiveness, 0.51 – 0.8 is moderate and >0.8 shows a high level of responsiveness, as outlined on page 25 section 1.4.4.4. Thus grip strength demonstrated a low level of responsiveness to a period of rehabilitation in this group of participants.

The mean difference (95% CI) in the two Barthel score readings was – 8.6 points (-17.14, -0.06) p=0.05, with a 95% reference range of -45.1 points to 27.9 points. This similarly represents a mean improvement of 8.6 points in the total Barthel Score by discharge compared to admission. However the standardised mean response was 0.47 and the effect size was 0.33, which both represent an overall low level of responsiveness to a period of rehabilitation among this group of participants.

4.2 Acceptability of grip strength assessment

4.2.1 Questions asked of all participants

The acceptability of grip strength assessment was studied in all of the participants by three short questions at the end of the assessment, asking if they had found the grip strength measurement tiring or painful, and whether they would repeat the assessment. Table 4.4 shows that over 90% of in-patients, community referrals and PD patients, and 79% of male and female nursing home residents did not find it tiring. Amongst the men, 89% of in-patients and 100% of men in the other settings did not find the assessment painful, whilst for the women, this ranged from 87% PD patients to 100% community referrals. All of the community referrals, PD patients and male in-patients would repeat the test, as would 97% of the female in-patients and male nursing home residents, and 90% of the female nursing home residents.

4.2.2 Interviews with a sample of participants

Additional qualitative data on participants' perceptions of the acceptability of grip testing was obtained through individual interviews using the semi-structured interview schedule previously described (Appendix 8). Interviews were conducted with six hospital in-patients, two community physiotherapy referrals, eight Parkinson's disease patients and four residents from one nursing home. This proved to be most difficult to conduct in a timely fashion for the community physiotherapy referrals, who frequently remained socially active and so were unavailable. The interviews with the unaccompanied in-patients were carried out at Romsey hospital either by the bedside (four) or in a private room (two). The community physiotherapy referrals were interviewed in their homes. The Parkinson's disease patients' interviews were all carried out in a private room at Romsey hospital; four patients were accompanied by their spouse, who variably contributed their views. The nursing home residents were interviewed in the home, two unaccompanied in the library, and two in their own rooms with family members present but who did not contribute to the interview.

Table 4.5 Acceptability of grip strength assessment to all study participants

	Hospital rehabilitation in-patients		**Community rehabilitation referrals**		**Parkinson's disease clinic patients**		**Nursing Home residents**		**P value[1]**
Number (%)	Male (N=37)	Female (N=63)	Male (N=23)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=34)	Female (N=62)	
Did not find assessment tiring	34 (92)	57 (91)	22 (96)	23 (100)	32 (94)	23 (100)	27 (79)	49 (79)	*M: 0.18* *F: 0.04*
P value[2]	*P=1.00*		*P=1.00*		*P=0.38*		*P=1.00*		
Did not find assessment painful	33 (89)	58 (92)	23 (100)	23 (100)	34 (100)	20 (87)	34 (100)	56 (90)	*M: 0.03* *F: 0.35*
P value[2]	*P=0.72*		*P=1.00*		*P=0.06*		*P=0.09*		
Would repeat the assessment	37 (100)	61 (97)	23 (100)	23 (100)	34 (100)	23 (100)	33 (97)	56 (90)	*M: 0.71* *F: 0.03*
P value[2]	*P=0.53*		*P=1.00*		*P=1.00*		*P=0.05*		

N: number; %: percentage; M: male; F: female
Data for all three items missing for 1 female in-patient, 1 male community referral, and 1 male and 3 female nursing home residents
P value[1] for differences between settings by gender calculated using Fisher's exact test
P value[2] for differences between gender within settings calculated using Fisher's exact test

4.2.3 Comparison of the interviewees with the remaining study participants

Table 4.6 compares the characteristics of the interview group with those of the remaining participants. It can be seen that there was no statistically significant difference in age, maximum grip strength, Barthel score or MMSE score between the two groups for men or women, so that on this basis the interview group was representative of the study group as a whole.

Table 4.6 Comparison of interview group with remaining participants: age, maximum grip strength, physical and cognitive function

	Male participants		**Female participants**	
	Not interviewed (N=120)	**Interviewed** (N=10)	**Not interviewed** (N=165)	**Interviewed** (N=10)
Mean (SD)				
Age (years)	79.6 (8.3)	80.8 (12.3)	83.6 (8.2)	82.3 (5.0)
P value[1]	*P=0.67*		*P=0.62*	
Maximum grip strength	25.5 (11.8)	27.7 (16.6)	12.8 (7.7)	14.6 (9.6)
P value[1]	*P=0.58*		*P=0.48*	
Median(IQR)				
Barthel score	81 (45, 97.75)	78 (60, 96.5)	68 (40.5, 90)	77.5 (40.5, 97.25)
P value[2]	*P=1.00*		*P=0.49*	
MMSE	25 (17, 29)	26 (24.75, 27.5)	25 (17, 28)	25 (22, 28.5)
P value[2]	*P=0.26*		*P=0.39*	

SD: standard deviation; N: number; IQR: inter-quartile range; MMSE: mini mental state examination
Data for MMSE missing for 1 male community referral
P value[1] for differences between groups calculated using 2-sample t-test
P value[2] for differences between groups calculated using Mann Whitney rank-sum test

4.2.4 Interviewees experience of using the Jamar dynamometer

4.2.4.1 Understanding the instructions

Eight participants (in-patients, community referrals and Parkinson's disease patients) commented on their ease of understanding the instructions about grip assessment and taking part in the study. They all found it quite straightforward:

She brought in the device, gave me a fairly straightforward description of what it was intended to do, unpacked it all, and my engineer-type mind started thinking: that's an interesting little toy, and basically we went from there. It was more of a case of questions and answers afterwards. 4.1.1. In-patient (grip strength 14 kg)

Well, just a grip test to find out whether there is a correlation between strength of grip and muscle weakness or Parkinson's or various diseases…. I had to squeeze a machine as hard as I could with both hands, well one at a time really. And the measurements were taken down and then I was asked lots of questions on lifestyle really.14.1.1.PD (grip strength 52 kg)

One participant commented that it was difficult to use a pen, used for signing the consent form and completing the MMSE (writing a sentence and copying pentagons):

Mrs Roberts came around and introduced herself and said she would ask me various questions, about twenty or thirty questions, some might seem silly to me. I had to sign a few statements and tick some boxes. I found it quite easy. I tend to stumble a bit with my pen, in controlling my pen so a little bit out of line, otherwise it was alright. 1.1.1. In-patient (grip strength 12 kg)

4.2.4.2 The Jamar dynamometer itself

Seven participants commented positively on the shape of the Jamar, recognizing that it was designed for ease of grip:

The grip seemed to be quite a central arrangement. It suited my hand anyway. 4.1.2. In-patient (grip strength 14 kg)

Well, I felt it was alright. I didn't get any difficulty with it. 16.1.2 Community referral (grip strength 22 kg)

Not really, it was, this is what, you only had to look at the machine and you'd say that you could get a grip on it. It's not like a one finger sort of thing.8.1.2.PD (grip strength 41 kg)

Not really, it was sort of handshake, fitted in my grip quite easily. No I think anybody would find it quite easy to use.14.1.2.PD (grip strength 52 kg)

However there was recognition that some people may find it difficult to use:

Yes, it was quite a bulky device. Thinking about when you, I suppose thinking of the person you might be aiming to use it. It could turn out to be quite heavy. 4.1.2. In-patient (grip strength 14 kg)

Indeed two of the nursing home patients were unable to grip the dynamometer because of its size.

Well, I remember that I couldn't use it hardly at all. I couldn't cause I've only got those two fingers and that one finger, I can't really use it, but I couldn't hardly do anything. It was very very poor. 20.1.4. Nursing home (grip strength 4 kg)

Six participants commented that the Jamar was rather heavy, even though it was supported by the interviewer. Four did not find it heavy at all, but there was recognition some others might do so.

Well, actually the doctor was holding the thing so all I had to do was just grip. I think it would have been rather heavy if I had been doing it on my own. Yes. 2.1.2. In-patient (grip strength 14 kg)

I think it might be heavy for some little old ladies, possibly, or even some little old gentlemen, but personally, I was okay.8.1.2.PD (grip strength 41 kg)

Eight participants commented on the lack of compressibility of the Jamar:

No, no, nothing seemed to move. I was expecting something to move back towards me or something, you know, get smaller, but nothing. I couldn't tell what I was doing, or how, how I was doing. 2.1.5. In-patient (grip strength 14 kg)

You know, it was as though I was squeezing a solid bit of metal. It worked, you know, I understand I produced quite a good figure on the dial. I didn't get any sort of feeling I was achieving anything. 4.1.5. In-patient (grip strength 14 kg)

No I just felt it was solid and that was it. 6.1.5. PD (grip strength 24 kg)

Four participants thought that more feedback on their performance might have enabled them to achieve a higher grip strength.

Yes, if I had a dial it would at least have told me if I was doing anything or not 'cause I was darned if I could tell otherwise. 2.1.5. In-patient (grip strength 14 kg)

And I wonder whether or not a little bit of slack movement before it started to have an effect. If you understand what I'm saying. 4.1.5. In-patient (grip strength 14 kg)

Supposing the machine is a structure that if it was connected to something like a hose release then it would feel like you've gone through a barrier. 8.1.5. PD (grip strength 41 kg)

4.2.5 Aspects of Participants' involvement with grip assessment

4.2.5.1 Effort expended

Ten participants commented that they had tried their best with the grip strength assessment:

Oh, sure, sure I squeezed as hard as I could. 2.1.3. In-patient (grip strength 14 kg)

Oh I did it one or a few times I think. Two or three times… I could have done it more I think. 16.1.3 Community referral (grip strength 22 kg)

I've done it three times on each side, gripping as fast as hard as I can. 11.1.3. PD (grip strength 20 kg)

Only just. Only just, I had to make a lot of effort. 20.1.3. Nursing home (grip strength 4 kg)

Two patients commented that they could only have managed another couple of attempts in total:

I might have managed once or twice more. I don't think I would have achieved any better figures. 4.1.3. In-patient (grip strength 14 kg)

Well that depends on how I feel each day I'm afraid. I'd say about four or five and then I would need a rest. 10.1.3. PD (grip strength 52 kg)

4.2.5.2 Grip strength and assessment order

Opinion was divided on the impact of assessment order on grip strength. Two participants felt that their first attempt was the best:

Well, I didn't read the gauge and I said to Joe, that at the beginning it was a bit easier, more strength, than the one at the end. There was a bit of time in between. And I had already done it once. 10.1.4.PD (grip strength 52 kg)

No, I think probably the first squeeze was the hardest. 14.1.4.PD (grip strength 52 kg)

However others felt that their later attempts were better:

On the third time I knew to push a bit further. I found it quite easy, the third time, I found it quite easy. 1.1.4. In-patient (grip strength 12 kg)

I think I might have had a more determined try on the second or third attempt. Apart from that, I could feel no difference.4.1.4.In-patient (grip strength 14 kg)

When you get to the third time when it is the last time, you put most effort in. 9.1.3.PD (grip strength 35 kg)

Still others felt that their efforts had been constant throughout their attempts:

I don't know if it changed or not because I did it the same way each time. 5.1.4. In-patient (grip strength 11 kg)

I found it easy all the time…21.1.4.Community referral (grip strength 18 kg)

No I've got a strong grip all the time dear. 18.1.4. Nursing home (grip strength 16 kg)

I didn't notice any difference in my strength. 19.1.4. Nursing home (grip strength 18 kg)

4.2.5.3 Grip strength and hand dominance

Most participants felt that their dominant hand was the stronger:

Well, my left hand is slightly weaker than my right but I am right handed. 12.1.4.PD (grip strength 25 kg)

Well I would think the right because that is the one I use most.13.1.4.PD (grip strength 28 kg)

However one man felt his grip was fairly equal with both hands:

I wouldn't like to say because when I was working I was a bricklayer you see, so I used a trowel in my left hand and I picked up the bricks in my right hand. 7.1.4.In-patient (grip strength 27 kg)

Another participant thought his non-dominant hand had been better:

Well I thought my right hand was better. But the doctor seemed to think my left hand. It seemed very common but I thought he seemed to think my left hand was my better hand. 6.1.4.PD (grip strength 24 kg)

4.2.5.4 Discomfort associated with grip strength assessment

No participants felt that the assessment had been painful:

No, no, I didn't find it painful. 16.1.6 Community referral (grip strength 22 kg)

Yes, it didn't hurt or anything like that.8.1.6.PD (grip strength 41 kg)

It wasn't as uncomfortable as having your blood pressure taken.13.1.8.PD (grip strength 28 kg)

Not whatsoever dear. 18.1.6. Nursing home (grip strength 16 kg)

However there was recognition from three participants that it could be tiring:

Well, it was enough for those particular muscles to start feeling the strain, I think, because you do have to put as much into it as you can, therefore it does tire you if you keep on doing it.3.1.7.In-patient (grip strength 10 kg)

Yes. But that to me seems quite natural, if you do the same thing, eventually you get tired.10.1.7.PD (grip strength 52 kg)

Interestingly this view was not shared by other in-patients or any of the nursing home residents:

No, not at all. I could have kept on for a long time.7.1.7.In-patient (grip strength 27 kg)

No, I'm always doing exercises. 18.1.7. Nursing home (grip strength 16 kg)

No, I didn't do it long enough or often enough for that. 19.1.7. Nursing home (grip strength 18 kg)

4.2.6 Participants' views on the routine use of grip strength assessment

4.2.6.1 Rationale for grip strength measurement

16 participants replied to the question on the rationale of grip strength assessment but only two people associated grip strength with general weakness:

Well, I think it's all generally fitted in with the poor physical power I possess, because I've lost a lot of physical power. 3.2.1. In-patient (grip strength 10 kg)

Well I suppose it's for older people, a strength test. 21.2.1. Community referral (grip strength 18 kg)

Everyone else felt that strength in their arms and legs were separate:

I don't know because I have weaknesses in other parts of the body at the moment but the hands are not affected. So I hesitate to give a sensible opinion on that. 4.2.1. In-patient (grip strength 14 kg)

I don't think so, would it? Strength anywhere. Well, I've still got pain in my hip here.

It hasn't made any difference to that. 5.2.1. In-patient (grip strength 11 kg)

Well, does it? No, I wouldn't have thought so, only your arms.16.2.1.Community referral (grip strength 22 kg)

I wouldn't think so. I would think a sedentary worker who worked a machine, or something that demanded a lot of hand pressure they would score pretty well. 19.2.1. Nursing home (grip strength 18 kg)

Eight participants felt that grip assessment was specifically related to their hands and/or specific functional tasks:

If I could hold onto my sticks I should think. 5.2.1. In-patient (grip strength 11 kg)

Your hand muscles. I can't see that it would do much for your biceps.14.2.1.PD (grip strength 52 kg)

To see what strength you have in your hands for doing things about the house and everything you have to do.12.2.1.PD (grip strength 25 kg)

4.2.6.2 Utility of routine grip strength measurement

All of the participants felt that this would be a useful and acceptable routine assessment:

A routine test. Yes, I would have thought it seems like quite a sensible idea, a practical idea. 4.2.2. In-patient (grip strength 14 kg)

I think people would just take it in their stride.10.2.2.PD (grip strength 52 kg)

Well, I would like to know anything. I would like to know anything, I am not afraid of *knowing what's happening or anything. Just frustrates me that I can't do anything. Cause it is only since last April that all this has happened. 20.2.2. Nursing home (grip strength 4 kg)*

However location of the assessment was important for one participant:

Yes, but it would be easier if it was brought to our house, I think.5.2.2. In-patient (grip strength 11 kg)

Several people commented that the assessment could be an opportunity to try to improve their health:

It would protect them for the future if they so wish 11.2.2.PD (grip strength 20 kg)

Well, it would be helpful if they could suggest something that you could have to help you when you were getting frailer, yes.12.2.2.PD (grip strength 25 kg)

Yes, yes, I would want to know if I was getting weaker…. Well I would try to do more exercise and try and live a healthier lifestyle, I guess.14.3.2.PD (grip strength 52 kg)

Well, to see that how much in the future that your grip gets less and less. And whether you can do anything to maintain that grip.8.2.2.PD (grip strength 41 kg)

However two participants did not think there would be much scope for improvement*:*

I don't know. When you get older, I don't know, do you? I mean you don't get your same strength back when you get older, do you? 21.2.3. Community referral (grip strength 18 kg)

I don't think it would help you but it might relax your mind. 9.2.2. PD (grip strength 35 kg)

Two participants commented that they would know that they were getting weaker, but another felt that this may not be the case:

I know I'm gradually getting weaker. I know better than you because I'm living with it. I know what I can and can't do. 10.2.2. PD (grip strength 52 kg)

I think you would probably realise it yourself but you would probably want confirmation of what you think. 9.2.2. PD (grip strength 35 kg)

No, they may not realise they are getting frailer themselves.14.2.2.PD (grip strength 52 kg)

Two participants felt that there could be therapeutic aspects to the grip strength assessment itself:

There are such similar devices, are there not, for strengthening hands, which I have seen people using, and, you know, I would have thought this device being a measuring device, could have performed both tasks.4.2.3. In-patient (grip strength 14 kg)

Well, I find it difficult to turn the tops of jars. To help that perhaps. 11.2.3. PD (grip strength 20 kg)

Two people commented on the use of serial measurements for comparison:

I suppose you compare various people and if they have got any… 13.2.2.PD (grip strength 28 kg)

Yes, quite happy, yes. Because it would be good to get a comparison I expect. 12.2.2. PD (grip strength 25 kg)

4.2.6.3 Negative aspects of routine grip strength measurement

Only two people commented specifically on aspects of routine screening that might worry them:

The muscles are getting weaker. I think that would slightly worry me. Obviously if it was explained correctly and how low the muscles can give. 9.2.5. PD (grip strength 35 kg)

To be told whether they are getting stronger or not. Well it would be encouraging if they were told they were fairly strong I suppose. But whether it would be helpful to be told that you were a lot weaker than last time, I don't know.12.2.5.PD (grip strength 25 kg)

4.2.6.4 Passive acceptance of medical assessments

Six participants expressed their views on medical assessments, and all were accepting of them even if they did not understand exactly why or what was being done:

No idea. I've long ago given up wondering why. I just do it and that's that. No idea. Like going around to the surgery, I only go around there if I'm summoned, not otherwise. 2.2.4. In-patient (grip strength 14 kg)

Well, I mean. We are of an age when if you come to a doctor's surgery, you do what is asked of you. I'm not saying they beat you up or anything but you do what is acceptable. So we tend to take a lot of things for granted, you know. If you want to do a pressure check, you do a pressure check. 8.2.4. PD (grip strength 41 kg)

Ah, doctors, they test your blood all the time, it's a sort of addiction. 19.2.4. Nursing home (grip strength 18 kg)

4.2.7 Summary of acceptability of grip strength assessment

The only potential problems envisaged were local issues with participant's hand:

I think most people would be good at it, don't you? Unless they had arthritis in their wrist or something like that. They would all be good, wouldn't they? 21.1.8. Community referral (grip strength 18 kg)

Only if they have got a cut hand or something like that. That would give difficulty. 9.1.8. PD (grip strength 35 kg)

I imagine they would if their hands were less, you know, if they had less mobility in their hands it might do. Someone with arthritic hands perhaps would find it difficult.12.1.8.PD (grip strength 25 kg)

Ten participants commented that this was an easy test to do:

Well, quite straightforward. 5.1.8. In-patient (grip strength 11 kg)

I thought very good, very much like a funfair ride, you know, when you could win a bag of chips if press and get to a certain mark. I didn't find it difficult. 9.1.8. PD (grip strength 35 kg)

No hardship to test it, only takes a few minutes. 19.1.8. Nursing home (grip strength 18 kg)

Chapter 5 Results: Grip strength and its associations with individual characteristics in the four healthcare settings

5.1. Description of maximum grip strength by gender and setting

Grip strength was normally distributed and the distribution of grip strength by setting for men and women is shown graphically in Figure 5.1. There was a significant difference between the mean maximum grip strength of men and women within each setting ($p<0.0001$) and between settings ($p<0.0001$) (Table 5.1). For the male participants the PD patients had the highest grip strength (mean (SD) 37.9 (9.4) kg), followed by the community referrals (31.1 (6.4) kg), in-patients (21.7 (7.7) kg) and nursing home residents (14.2 (7.8) kg). The women followed a similar pattern with the PD patients having the highest grip strength (mean (SD) 22.1 (8.6) kg), then the community referrals (19.6 (6.9) kg), in-patients (13.6 (5.0) kg) and nursing home residents (6.6 (3.5) kg).

The PD patients were all assessed in the afternoon due to the researchers' availability. They were all assessed in the 'on' state and were clinically stable with regard to their PD. It would be expected that grip strength would be much lower when participants were in the 'off' state or sub-optimally medicated. Typically late afternoon can be a time when PD patients experience more bradykinesia and these patients were seen between 2pm and 4pm. However the grip strength of the PD patients was similar to reference ranges quoted for community dwelling adults, which implies that these patients were indeed in the 'on' state.

5.2 Correlation of maximum grip strength with age, height, weight and BMI

Grip strength is known to be influenced by gender, age, and height, and in Tables 3.1-3.3 it can be seen that the men and women in this study differed more significantly in height and weight than in any other descriptive variable measured. Table 5.2 describes the correlation of maximum grip strength with age, height, weight and BMI for men and women in each setting.

Increasing age was associated with a reduction in maximum grip strength in all groups except the female community referrals and nursing home residents. This was only significant for the female in-patients (p=0.03) and PD patients (men p=0.002; women p=0.04). The higher correlation with the PD patients may reflect their younger age range (53-85 years for men and 61-86 years for women). The nursing home residents' ages ranged from 70-98 years for men and from 72 - 97 years for women.

The correlation of grip strength with height was also less clear than expected, with increasing height correlating with higher grip strength among PD patients, female in-patients, male community referrals and male nursing home residents, but with a significant correlation only among female PD patients (p=0.02).

Weight was more strongly correlated with grip strength than height for men and women in all settings; this was only significant for male in-patients (p=0.002) and male PD patients (p=0.03). BMI is derived from height and weight and was positively correlated in men and women in all settings, but only significantly so among male in-patients (p=0.001).

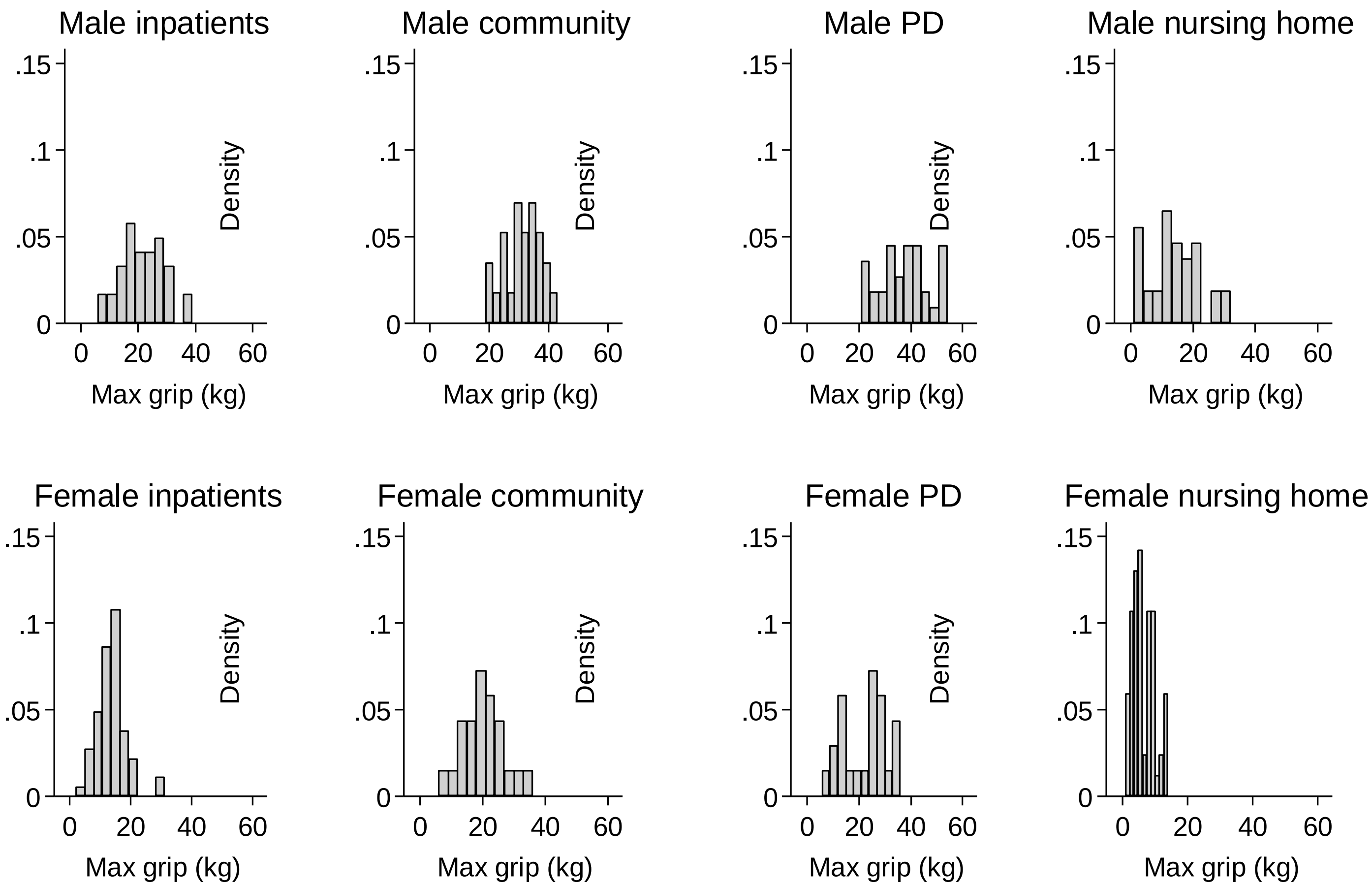

Figure 5.1 Distribution of maximum grip strength for male and female participants from four healthcare settings

Table 5.1 Description of participants: maximum grip strength by gender and setting

Grip strength (kg)	Hospital rehabilitation in-patients		Community rehabilitation referrals		Parkinson's disease clinic patients		Nursing Home residents		*P value*[1]
	Male (N=37)	Female (N=64)	Male (N=24)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=35)	Female (N=65)	
Mean (SD)	21.7 (7.7)	13.6 (5.0)	31.1 (6.4)	19.6 (6.9)	37.9 (9.4)	22.1 (8.6)	14.2 (7.8)	6.6 (3.5)	*M:<0.0001* *F: <0.0001*
P value[2]	*P<0.0001*		*P<0.0001*		*P<0.0001*		*P<0.0001*		
Percentiles									
1st	6	2	19	6	21	6	1	1	
5th	7	6	19	9	24	10	3	2	
10th	12	8	22	12	24	10	4	3	
20th	14	10	25	14	29	14	5	3	
25th	17	11	26.5	15	31	14	8	4	
50th (median)	22	14	32	20	39	25	14	6	
75th	27	16	35.5	24	44	28	20	9	
90th	31	19	39	28	52	34	26	12	
95th	37	21	39	30	52	34	30	13	
99th	39	31	43	36	54	36	32	14	
									***P value*[3]**
Mean (SD)*	24.2 (8.0)	14.3 (5.0)	30.6 (7.4)	17.7 (7.6)	30.7 (8.3)	16.9 (7.8)	18.9 (9.5)	8.4 (5.0)	*M:<0.0001* *F: <0.0001*

kg: kilograms; N: number; SD: standard deviation; M: male; F: female
[1]P value for differences between settings by gender calculated using ANOVA
[2]P value for differences between gender within settings calculated using 2-sample t-test
*Grip strength adjusted for age
[3]P value for differences between settings adjusted for age calculated using ANOVA

Table 5.2 Correlation of maximum grip strength (kg) with age, height, weight and BMI

r correlation coefficient	Hospital rehabilitation in-patients		Community rehabilitation referrals		Parkinson's disease clinic patients		Nursing Home residents	
	Male (N=37)	Female (N=64)	Male (N=24)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=35)	Female (N=65)
Age (years)	-0.26	-0.28	-0.14	0.07	-0.52	-0.44	-0.12	0.16
P value	*P = 0.17*	*P = 0.03*	*P = 0.50*	*P = 0.74*	*P = 0.002*	*P = 0.04*	*P = 0.48*	*P = 0.21*
Height (cm)	-0.02	0.23	0.20	-0.03	0.28	0.48	0.28	-0.08
P value	*P = 0.89*	*P = 0.07*	*P = 0.36*	*P = 0.90*	*P = 0.11*	*P = 0.02*	*P = 0.10*	*P = 0.51*
Weight (kg)	0.51	0.22	0.24	0.22	0.3	0.21	0.18	0.21
P value	*P = 0.002*	*P = 0.08*	*P = 0.27*	*P = 0.32*	*P = 0.03*	*P = 0.33*	*P = 0.30*	*P = 0.09*
BMI (kg/m^2)	0.53	0.20	0.20	0.23	0.28	0.10	0.08	0.23
P value	*P = 0.001*	*P = 0.11*	*P = 0.37*	*P = 0.29*	*P = 0.11*	*P = 0.66*	*P = 0.65*	*P = 0.07*

kg: kilograms; N: number; cm: centimetres; BMI: body mass index; m: metre
Data for weight and BMI missing for 3 male and 1 female hospital in-patients, and 1 male community referral
P value for correlations by gender and setting calculated using Pearson's correlation coefficient

5.3. Clinical correlates of grip strength

Having demonstrated that grip strength was broadly associated with age, height and weight in these data, subsequent analyses of grip strength in relation to clinical characteristics were conducted with and without adjusting for age and anthropometry. Height and weight were correlated (r=0.32, p= 0.0003 for men and r=0.31, p<0.0001 for women), and so a sex-specific standardised residual of weight-for-height was calculated which was independent of height and could therefore be included with it in regression models, without potential multi-colinearity problems.

5.3.1 Association of maximum grip strength with co-morbidities, medication, physical and cognitive function

Table 5.3 shows the data for these associations for men and Table 5.4 the data for women in each setting. Lower grip strength was associated with a higher number of co-morbidities for men and women in all settings except the nursing home residents, but this was only significant for the male community referrals (p=0.01, adjusted p=0.02). The number of medications was not significantly associated with grip in any setting for either sex.

A higher Barthel score was associated with stronger grip among the men in each setting, and after adjustment for age, height and weight-for-height, remained significant among the male in-patients (p=0.04), community referrals (p=0.04) and nursing home residents (p=0.005). A higher Barthel score was significantly associated with stronger grip for the female in-patients and nursing home residents, but after adjusting for age, height and weight-for-height, only remained significant for the in-patients (p<0.001).

The MMSE was not associated with grip among men in any setting, and among women a higher score was only significantly associated with stronger grip among the in-patients and nursing home residents. Again after adjusting for age, height and weight-for-height, this association remained robust only for the female in-patients (p=0.001).

5.3.2 Association of maximum grip strength with Strawbridge frailty and MUST scores, and number of falls in the last year

Table 5.5 shows these associations for men and Table 5.6 the data for women in each setting. A higher Strawbridge frailty score was associated with reduced grip strength in female nursing home residents (p=0.01; p=0.02 adjusted), but there was no association for any other group of participants.

Among the male participants a higher (worse) MUST score was only associated with lower grip strength in male in-patients (p=0.05) but this was attenuated by adjusting for age, height and weight-for-height. Among the female participants the situation was similar with only the in-patients having a significant association with higher MUST score and lower grip strength, and this association was robust to adjustment (p=0.03). The significant associations among in-patients may reflect the greater spread of MUST scores across participants from this group than the other healthcare settings.

The number of falls in the last year was not associated with grip for any of the men. Among the women a higher number of falls was associated with lower grip strength for the community referrals (p=0.007), and remained significant after adjusting for age, height and weight-for-height (p=0.03).

Table 5.3 Associations of maximum grip (kg) with co-morbidities, medication, physical and cognitive function in male participants

Average change in maximum grip / unit change in clinical characteristic (95% CI)	**Hospital rehabilitation in-patients** Male (N=37)	**Community rehabilitation referrals** Male (N=24)	**Parkinson's disease clinic patients** Male (N=34)	**Nursing Home residents** Male (N=35)
Number of co-morbidities	-0.84 (-2.72, 1.03)	-1.81 (-3.20, -0.42)	-1.07 (-3.00, 0.86)	1.20 (-0.62, 3.03)
P value[1]	*P=0.37*	*P=0.01*	*P=0.27*	*P=0.19*
P value[2]	*P=0.34*	*P=0.02*	*P=0.95*	*P=0.42*
Number of medications	0.06 (-0.78, 0.91)	-0.17 (-0.94, 0.61)	-0.43 (-1.55, 0.69)	-0.15 (-1.66, 1.36)
P value[1]	*P=0.88*	*P=0.66*	*P=0.44*	*P=0.84*
P value[2]	*P=0.39*	*P=0.97*	*P=0.58*	*P=0.56*
Barthel score	0.12 (0.03, 0.21)	0.55 (0.13, 0.94)	0.48 (0.13, 0.82)	0.16 (0.05, 0.27)
P value[1]	*P=0.01*	*P=0.01*	*P=0.008*	*P=0.005*
P value[2]	*P=0.04*	*P=0.04*	*P=0.22*	*P=0.005*
MMSE	0.34 (-0.10, 0.78)	0.48 (-0.38, 1.33)	0.17 (-0.94, 1.28)	0.19 (-0.31, 0.69)
P value[1]	*P=0.12*	*P=0.26*	*P=0.75*	*P=0.45*
P value[2]	*P=0.23*	*P=0.57*	*P=0.51*	*P=0.39*

kg: kilograms; %: percentage; CI: confidence intervals; N: number; MMSE: mini mental state examination
Data for MMSE missing for 1 male community referral
Results presented for unadjusted maximum grip values in linear regression analysis
P value[1] for associations calculated using unadjusted maximum grip values in linear regression analysis
P value[2] for associations calculated using maximum grip values adjusted for age, height and weight for height in linear regression analysis

Table 5.4 Associations of maximum grip (kg) with co-morbidities, medication, physical and cognitive function in female participants

Average change in maximum grip / unit change in clinical characteristic (95% CI)	**Hospital rehabilitation in-patients** Female (N=64)	**Community rehabilitation referrals** Female (N=23)	**Parkinson's disease clinic patients** Female (N=23)	**Nursing Home residents** Female (N=65)
Number of co-morbidities	-0.00 (-0.85, 0.84)	-0.69 (-2.52, 1.14)	-0.47 (-2.74, 1.80)	0.32 (-0.30, 0.94)
P value[1]	*P=0.99*	*P=0.44*	*P=0.67*	*P=0.30*
P value[2]	*P=0.97*	*P=0.63*	*P=0.85*	*P=0.27*
Number of medications	0.07 (-0.28, 0.41)	0.48 (-0.36, 1.33)	0.44 (-0.79, 1.68)	0.19 (-0.11, 0.49)
P value[1]	*P=0.70*	*P=0.25*	*P=0.47*	*P=0.20*
P value[2]	*P=0.98*	*P=0.24*	*P=0.55*	*P=0.19*
Barthel score	0.09 (0.04, 0.13)	0.14 (-0.02, 0.30)	0.06 (-0.25, 0.37)	0.05 (0.00, 0.10)
P value[1]	*P<0.001*	*P=0.09*	*P=0.69*	*P=0.03*
P value[2]	*P<0.001*	*P=0.13*	*P=0.67*	*P=0.06*
MMSE	0.40 (0.20, 0.61)	0.44 (-0.56, 1.44)	2.87 (-2.00, 7.74)	0.13 (0.01, 0.25)
P value[1]	*P<0.001*	*P=0.37*	*P=0.23*	*P=0.03*
P value[2]	*P=0.001*	*P=0.41*	*P=0.71*	*P=0.13*

kg: kilograms; %: percentage; CI: confidence intervals; N: number; MMSE: mini mental state examination
Results presented for unadjusted maximum grip values in linear regression analysis
P value[1] for associations calculated using unadjusted maximum grip values in linear regression analysis
P value[2] for associations calculated using maximum grip values adjusted for age, height and weight for height in linear regression analysis

Table 5.5 Associations of maximum grip (kg) with Strawbridge frailty and MUST scores, and number of falls in the last year in male participants

Average change in maximum grip in comparison with baseline group (95% CI)	**Hospital rehabilitation in-patients** Male (N=37)	**Community rehabilitation referrals** Male (N=24)	**Parkinson's disease clinic patients** Male (N=34)	**Nursing Home residents** Male (N=35)
Frail vs not frail	1.53 (-4.02, 7.09)	0.66 (-4.92, 6.23)	2.38 (-4.69, 9.45)	-3.14 (-10.30, 4.03)
P value[1]	*P=0.58*	*P=0.81*	*P=0.50*	*P=0.38*
P value[2]	*P=0.43*	*P=0.87*	*P=0.12*	*P=0.38*
MUST score:				
1 vs 0	-1.75 (-9.41, 5.91)	0.85 (-13.64, 15.34)	-4.06 (-13.29, 5.18)	-2.35 (-10.89, 6.18)
2-4 vs 0	-6.67 (-13.17, -0.17)	0.35 (-10.14, 10.84)	-12.86 (-32.21, 6.50)	5.90 (-4.80, 18.59)
P value[1]	*P=0.05*	*P=0.92*	*P=0.13*	*P=0.50*
P value[2]	*P=0.55*	*P=0.69*	*P=0.92*	*P=0.34*
Falls:				
1 vs 0	-1.08 (-8.66, 6.51)	2.5 (-5.83, 10.84)	3.42 (-5.39, 12.24)	-5.75 (-11.66, 0.16)
2 or more vs 0	1.02 (-5.98, 8.02)	-0.67 (-6.88, 5.55)	-4.91 (-12.53, 2.70)	2.25 (-5.38, 9.88)
P value[1]	*P=0.68*	*P=0.77*	*P=0.28*	*P=0.80*
P value[2]	*P=0.87*	*P=0.86*	*P=0.73*	*P=0.52*

kg: kilograms; MUST: Malnutrition Universal Screening Tool; %: percentage; CI: confidence intervals; N: number

Data for Strawbridge missing for 2 male hospital in-patients; data for MUST missing for 6 male hospital in-patients and 1 male community referral; data for falls missing for 1 male hospital in-patient

Results presented for unadjusted maximum grip values in linear regression analysis

P value[1] for trends across categories calculated using unadjusted maximum grip values in linear regression analysis

P value[2] for trends across categories calculated using maximum grip values adjusted for age, height and weight for height

Table 5.6 Associations of maximum grip (kg) with Strawbridge frailty and MUST scores, and number of falls in the last year in female participants

Average change in maximum grip in comparison with baseline group (95% CI)	**Hospital rehabilitation in-patients** Female (N=64)	**Community rehabilitation referrals** Female (N=23)	**Parkinson's disease clinic patients** Female (N=23)	**Nursing Home residents** Female (N=65)
Frail vs not frail	-1.20 (-3.81, 1.41)	-3.80 (-11.78, 4.18)	3.62 (-4.04, 11.27)	-2.89 (-5.16, -0.62)
P value[1]	*P=0.36*	*P=0.33*	*P=0.34*	*P=0.01*
P value[2]	*P=0.21*	*P=0.76*	*P=0.09*	*P=0.02*
MUST score:				
1 vs 0	-1.49 (-5.00, 1.99)	-0.24 (-14.11, 13.63)	1.67 (-10.04, 13.38)	0.60 (-2.31, 3.52)
2-4 vs 0	-3.79 (-6.61, -0.96)	-14.24 (-28.11, -0.37)	-1.00 (-15.00, 13.00)	-2.35 (-4.60, -0.10)
P value[1]	*P=0.009*	*P=0.07*	*P=0.99*	*P=0.07*
P value[2]	*P=0.03*	*P=0.19*	*P=0.91*	*P=0.49*
Falls:				
1 vs 0	0.63 (-2.73, 3.99)	-2.33 (-9.56, 4.90)	-3.17 (-13.53, 7.20)	-0.92 (-3.07, 1.22)
2 or more vs 0	-0.29 (-3.40, 2.81)	-8.44 (-14.40, -2.49)	4.15 (-4.38, 12.69)	-0.39 (-2.54, 1.76)
P value[1]	*P=0.78*	*P=0.007*	*P=0.38*	*P=0.61*
P value[2]	*P=0.88*	*P=0.03*	*P=0.55*	*P=0.48*

kg: kilograms; MUST: Malnutrition Universal Screening Tool; %: percentage; CI: confidence intervals; N: number
Data for Strawbridge missing for 4 female hospital in-patients and 3 community referrals
Data for MUST missing for 4 female hospital in-patients; data for falls missing for 1 female hospital in-patient
Results presented for unadjusted maximum grip values in linear regression analysis
P value[1] for trends across categories calculated using unadjusted maximum grip values in linear regression analysis
P value[2] for trends across categories calculated using maximum grip values adjusted for age, height and weight for height

5.3.3 Mutually adjusted analysis of the variables significantly associated with maximum grip strength, by gender and setting

The clinical characteristics that were identified as being significantly associated with maximum grip strength in age and anthropometry adjusted univariate analyses in any of the healthcare settings were taken forward to a mutually adjusted model of grip strength in relation to age, anthropometry and clinical characteristics for men and women separately, as shown in Tables 5.7 (for men) and 5.8 (for women). After mutual adjustment, age, height, weight-for-height and Barthel score were significantly associated with grip strength in several healthcare settings for men and women. The number of co-morbidities was only significantly associated with grip strength for male community referrals and the number of falls in the last year was only significantly associated with grip strength for female community referrals. The Barthel score was the clinical characteristic most consistently associated with grip strength across gender groups and healthcare settings.

Table 5.7 Mutually adjusted associations with maximum grip (kg) in male participants

Average change in maximum grip / unit change in clinical characteristic (95% CI)	**Hospital rehabilitation in-patients** (N=34)	**Community rehabilitation referrals** (N=23)	**Parkinson's disease clinic patients** (N=34)	**Nursing Home residents** (N=35)
Age (years)	-0.25 (-0.65, 0.16)	0.11 (-0.35, 0.57)	-0.45 (-0.85, -0.05)	-0.01 (-0.34, 0.32)
P value	*P=0.22*	*P=0.62*	*P=0.03*	*P=0.94*
Height (cm)	0.25 (-0.38, 0.89)	0.19 (-0.32, 0.70)	0.39 (-0.31, 1.09)	0.41 (-0.02, 0.84)
P value	*P=0.43*	*P=0.44*	*P=0.27*	*P=0.06*
Weight-for-height	0.30 (0.10, 0.49)	0.12 (-0.07, 0.30)	0.08 (-0.15, 0.30)	0.05 (-0.21, 0.31)
P value	*P=0.004*	*P=0.20*	*P=0.49*	*P=0.72*
Barthel score	0.09 (0.01, 0.17)	0.45 (0.04, 0.86)	0.23 (-0.15, 0.61)	0.16 (0.06, 0.27)
P value	*P=0.04*	*P=0.03*	*P=0.22*	*P=0.005*
Number of co-morbidities	Not associated in univariate analysis	-1.81 (-3.18, -0.45)	Not associated in univariate analysis	Not associated in univariate analysis
P value		*P=0.01*		

kg: kilograms; %: percentage; CI: confidence intervals; N: number
Data for weight missing for 3 male in-patients and 1 male community referral
P value for associations calculated using unadjusted maximum grip values in linear regression analysis

Table 5.8 Mutually adjusted associations with maximum grip (kg) in female participants

Average change in maximum grip / unit change in clinical characteristic (95% CI)	**Hospital rehabilitation in-patients** (N=63)	**Community rehabilitation referrals** (N=23)	**Parkinson's disease clinic patients** (N=23)	**Nursing Home residents** (N=65)
Age (years)	-0.18 (-0.36, -0.01)	-0.10 (-0.66, 0.46)	-0.39 (-0.87, 0.08)	0.12 (-0.02, 0.25)
P value	*P=0.04*	*P=0.72*	*P=0.10*	*P=0.08*
Height (cm)	0.14 (-0.13, 0.41)	0.05 (-0.45, 0.55)	0.62 (-0.06, 1.30)	-0.01 (-0.19, 0.16)
P value	*P=0.30*	*P=0.83*	*P=0.07*	*P=0.87*
Weight-for-height	0.09 (0.01, 0.16)	0.01 (-0.18, 0.21)	-0.02 (-0.29, 0.26)	0.06 (-0.01, 0.14)
P value	*P=0.03*	*P=0.89*	*P=0.91*	*P=0.11*
Barthel score	0.10 (0.06, 0.14)	0.15 (-0.01, 0.30)	0.06 (-0.22, 0.34)	0.05 (-0.001, 0.09)
P value	*<0.001*	*P=0.06*	*P=0.67*	*P=0.06*
Number of falls in last year	Not associated in univariate analysis	-4.09 (-7.32, -0.85)	Not associated in univariate analysis	Not associated in univariate analysis
P value		*P=0.02*		

kg: kilograms; %: percentage; CI: confidence intervals; N: number
Data for weight missing for 1 female in-patient
P value for associations calculated using unadjusted maximum grip values in linear regression analysis

5.4 Further exploration of the association of grip strength with co-morbidities

It was of interest to explore whether grip strength was associated with any particular co-morbidity, or co-morbidity profile, as well as the total burden of co-morbidities. Each participant in all four study settings had all of their active co-morbidities recorded and the total prevalence of the most common ones by gender and setting are shown in Table 5.9. There was great variation in the prevalence of individual co-morbidities within and between settings. Unsurprisingly the presence of Parkinson's disease dominated the active co-morbidities among the patients recruited from the specialist Parkinson's database.

5.4.1 Clustering of co-morbidities: methods

A cluster analysis was carried out with the aim of identifying general patterns of clustering of common co-morbidities among older people in the healthcare settings. It was decided to exclude the Parkinson's clinic patients from the clustering of co-morbidities; this prevented the clustering process from attempting to separate these patients from the others, rather than identifying general patterns of clustering of common co-morbidities among older people. The sample for clustering of co-morbidities therefore comprised men and women from the in-patient and community rehabilitation settings and nursing home residents.

Ward's hierarchical agglomerative clustering technique was used to identify clusters of co-morbidities for men and women separately. All of the co-morbidities listed in Table 5.9 were included in the cluster analysis. Visual inspection of the cluster dendrograms was used to identify the number of clusters. The clusters were described by considering the prevalence of each individual co-morbidity within the identified clusters.

Table 5.9 Prevalence of participants' main co-morbidities by setting and gender

	Hospital rehabilitation in-patients		**Community rehabilitation referrals**		**Parkinson's disease clinic patients**		**Nursing Home residents**	
Percentage of total	Male (N=37)	Female (N=64)	Male (N=24)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=35)	Female (N=65)
Diabetes	18.9	9.4	25.0	4.3	5.9	0.0	11.4	7.7
Hypertension	37.8	21.9	25.0	26.1	17.6	43.5	20.0	29.2
Stroke	21.6	7.8	12.5	13.0	0.0	0.0	25.7	12.3
IHD	8.1	4.7	12.5	4.3	14.7	4.3	11.4	4.6
Cardiac failure	2.7	12.5	4.2	8.7	0.0	4.3	11.4	12.3
COPD	13.5	9.4	16.7	0.0	2.9	0.0	8.6	3.1
Chest infection	13.5	10.9	0.0	0.0	0.0	0.0	5.7	6.2
Osteoarthritis	8.1	20.3	50.0	30.4	32.4	34.8	0.0	13.8
Joint replacement	2.7	3.1	45.9	47.8	20.6	17.3	14.3	13.9
Osteoporosis	2.7	18.8	4.2	21.7	2.9	13.0	0.0	9.2
Fracture	18.9	39.1	4.2	4.3	11.8	0.0	17.2	20.0
Anaemia	2.7	6.3	0.0	4.3	2.9	0.0	5.7	1.5
UTI	16.2	12.5	0.0	0.0	0.0	0.0	8.6	13.8
Poor mobility	0.0	1.6	4.2	0.0	0.0	0.0	20.0	20.0
Falls	27.0	34.4	4.2	8.7	0.0	0.0	42.9	27.7
Dementia	13.5	10.9	4.2	4.3	0.0	0.0	42.9	33.8
Depression	13.5	3.1	8.3	0.0	5.9	13.0	5.7	9.2
Parkinson's disease	10.8	7.8	8.3	4.3	100.0	100.0	5.7	4.6

N: number; IHD: Ischaemic heart disease; COPD: Chronic obstructive pulmonary disease; UTI: Urinary tract infection

5.4.2 Clustering of co-morbidities: results

5.4.2.1 Men

Figure 5.2 shows the top twenty branches of the cluster dendrogram for men from the in-patient and community rehabilitation settings and nursing homes. Visual inspection suggested two or five clusters, but description of the prevalence of co-morbidities by potential cluster status showed a clearer separation between clusters if two were chosen.

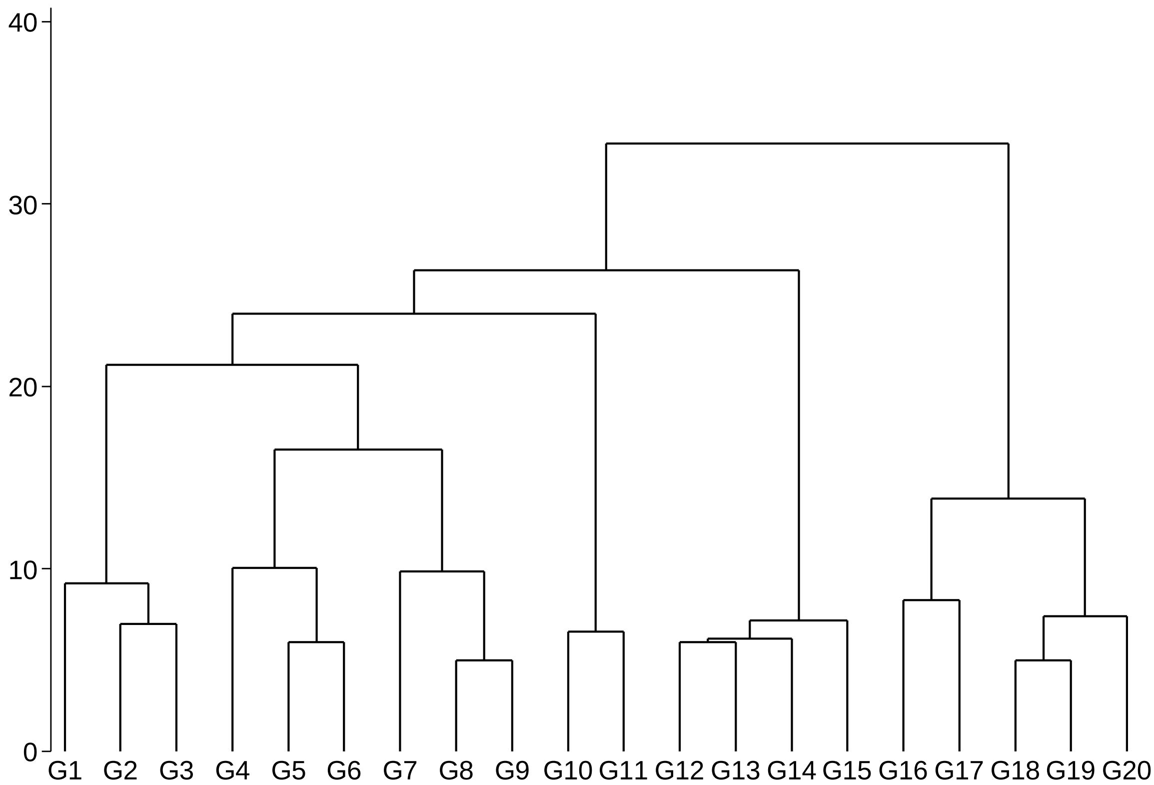

Figure 5.2 Cluster dendrogram for men (top twenty branches)

Figure 5.3 shows the prevalence of individual co-morbidities by co-morbidity cluster among men and shows that the cluster analysis had successfully identified two clear clusters. The 75 men in cluster one were characterised by a markedly higher prevalence of diabetes mellitus, stroke disease and osteoarthritis in contrast with the 21 men in cluster two. The 21 men in cluster two were characterised by a markedly higher prevalence of falls, dementia, fractures and poor mobility than the 75 men in cluster one.

Cluster one included 84% of the in-patients, all of the community referrals, and 57% of the nursing home residents. Cluster two consisted of 16% of the in-patients and 43% of the nursing home residents.

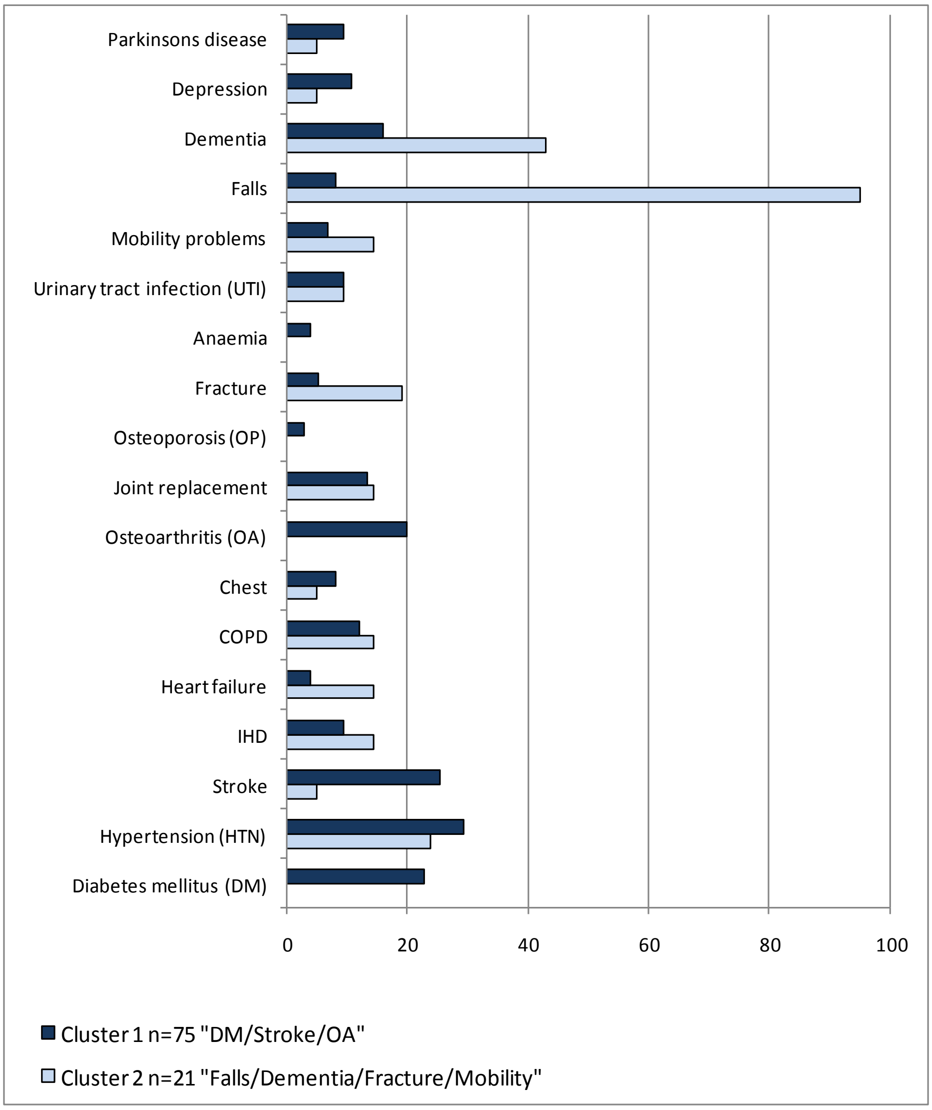

Figure 5.3 Prevalence of individual co-morbidities by co-morbidity cluster among men from in-patient and community rehabilitation settings and nursing homes

5.4.2.2 Women

Figure 5.4 shows the top twenty branches of the cluster dendrogram for women. Visual inspection suggested three clusters of co-morbidities.

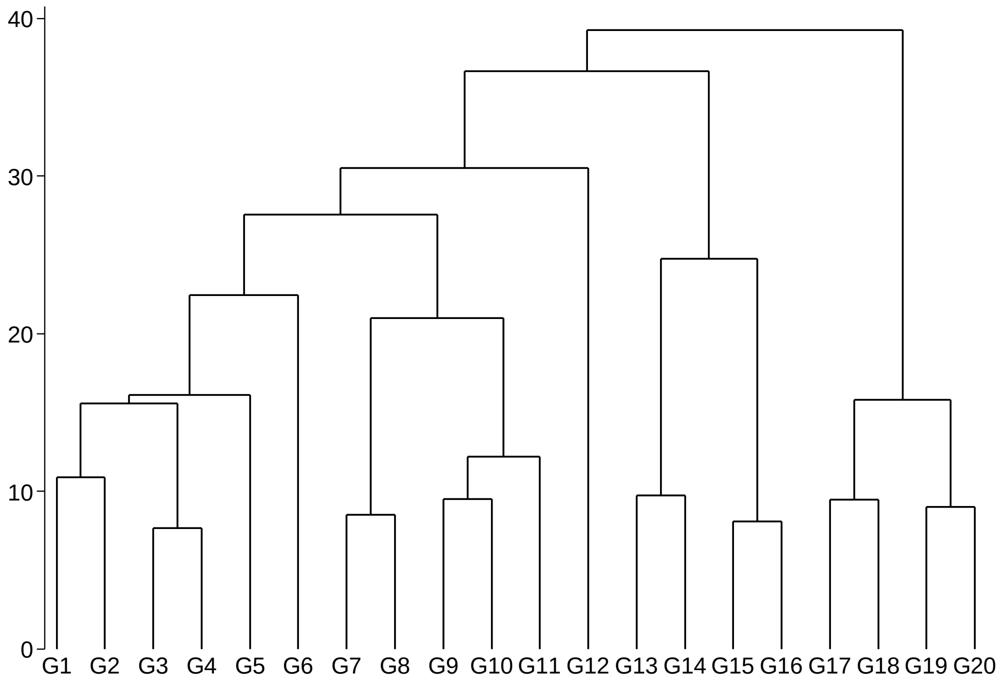

Figure 5.4 Cluster dendrogram for women (top twenty branches)

Figure 5.5 shows the prevalence of individual co-morbidities by co-morbidity cluster among women and shows that the cluster analysis had successfully identified three clear clusters. The 97 women in cluster one had a high prevalence of stroke, joint replacement and mobility problems in comparison with the women in clusters two and three. The 28 women in cluster two had a high prevalence of falls, fracture, osteoarthritis, osteoporosis and heart failure in comparison with women in clusters one and three. The 27 women in cluster three had a high prevalence of dementia, depression, urinary tract infection (UTI) and hypertension in comparison with women in clusters one and two.

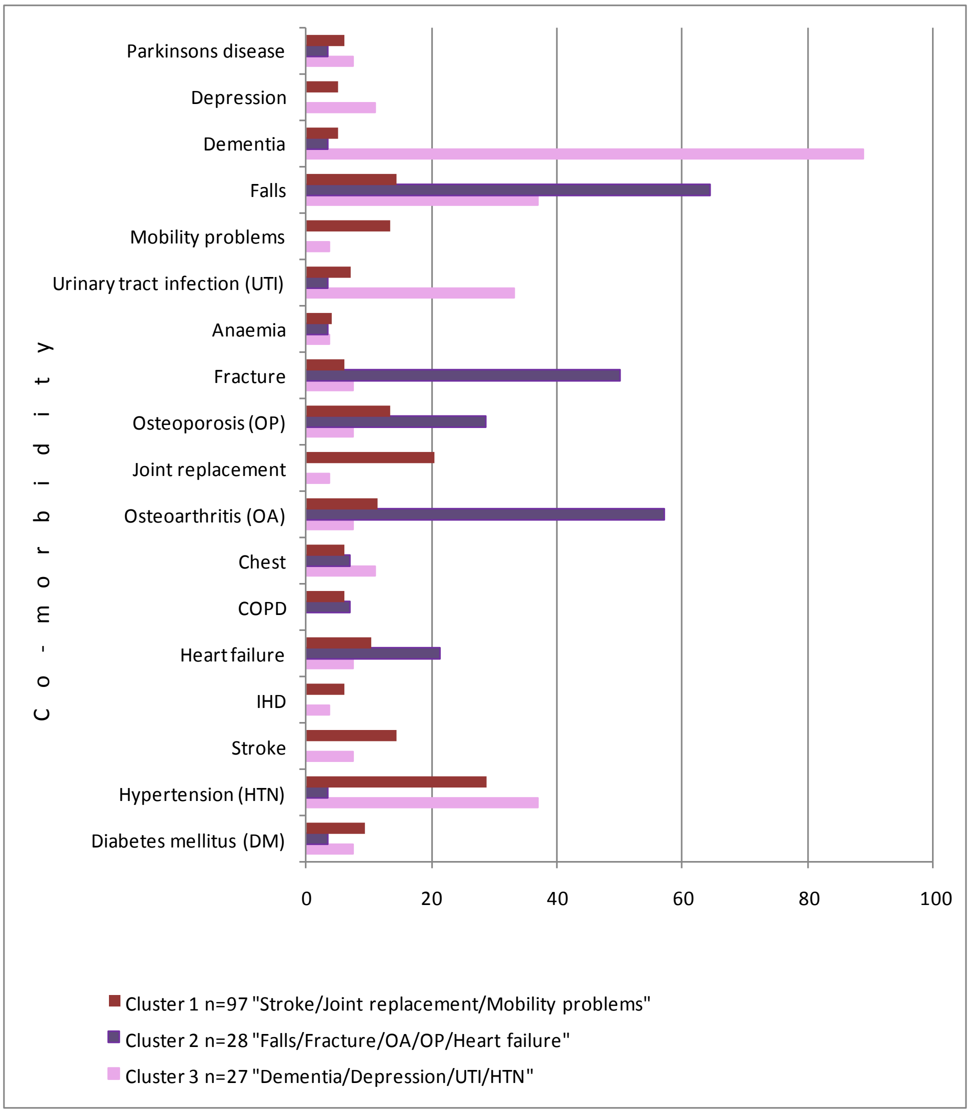

Figure 5.5 Prevalence of individual co-morbidities by co-morbidity cluster among women from in-patient and community rehabilitation settings and nursing homes

Cluster one included 59% of the in-patients, 87% of the community referrals, and 60% of the nursing home residents. Cluster two consisted of 30% of the in-patients, 9% of the community referrals and 11% of the nursing home residents. Cluster 3 consisted of 11% of the in-patients, 4% of the community referrals and 29% of the nursing home residents.

5.4.3 Associations between co-morbidity clusters and grip strength

Table 5.10 shows mean maximum grip strength by co-morbidity clusters, and number of co-morbidities, for men and women. The differences in grip strength across clusters were large, and statistically significant, in both men and women.

Mean maximum grip strength for men in cluster 1 (characterised by diabetes mellitus, stroke and osteoarthritis) was 23.0 kg in comparison with an average of only 15.5 kg for the men in cluster 2 (characterised by falls, dementia, fracture and mobility problems), p=0.002. The magnitude of this difference was similar to the maximum difference in average grip strength between men with different numbers of co-morbidities.

Mean maximum grip strength for women in cluster 3 (characterised by dementia, depression, urinary tract infection and hypertension) was only 8.0 kg in comparison with a mean of 12.0 kg for the women in cluster 1 (characterised by stroke, joint replacement and mobility problems) and a mean of 13.1 kg for the women in cluster 2 (characterised by falls, fracture, osteoarthritis, osteoporosis and heart failure), p=0.002. The magnitudes of the differences in average grip strength between clusters were as marked as the typical differences in average grip strength between women with different numbers of co-morbidities.

Table 5.10 Mean maximum grip strength by co-morbidity clusters and number of co-morbidities

Mean (SD)	Grip strength (kg)		Grip strength (kg)
MEN		**WOMEN**	
Co-morbidity cluster		***Co-morbidity cluster***	
Cluster 1:n=75 Diabetes/stroke/OA	23.0 (9.6)	Cluster 1: n=97 Stroke/joint replacement/mobility problems	12.0 (7.1)
Cluster 2: n=21 Falls/Dementia/Fracture /Mobility	15.5 (8.5)	Cluster 2: n=28 Falls/fracture/OA/OP/heart failure	13.1 (5.4)
	$P=0.002^{a}$		
		Cluster 3: n=27 Dementia/depression/UTI/HTN	8.0 (5.3)
			$P=0.008^{a}$
Number of co-morbidities		***Number of co-morbidities***	
1 (n=5)	31.6 (9.3)	1 (n=4)	21.0 (6.2)
2 (n=17)	28.9 (14.3)	2 (n=20)	16.1 (9.8)
3 (n=34)	28.1 (12.9)	3 (n=37)	11.6 (6.5)
4 (n=23)	24.7 (11.6)	4 (n=58)	12.2 (7.3)
5 (n=24)	21.5 (11.9)	5 (n=27)	13.7 (9.5)
6 (n=19)	23.1 (11.0)	6 (n=15)	14.1 (7.4)
7 (n=7)	26.0 (8.6)	7 (n=9)	8.2 (3.9)
8 (n=1)	26.0 (0.0)[c]	8 (n=5)	12.4 (6.5)
	$P=0.03^{b}$		$P=0.10^{b}$

Kg: kilograms; SD: standard deviation; n: number; OA: osteoarthritis; OP: osteoporosis; UTI: urinary tract infection; HTN: hypertension

[a]P-values for differences in grip strength between clusters obtained from one-way analysis of variance (ANOVA).

[b]P-values for the trend in the change in grip strength versus co-morbidities obtained from regression analysis.

[c] SD of zero as only one observation

Chapter 6 Results: Grip strength, other individual characteristics and discharge from in-patient rehabilitation to place of usual residence

6.1 Discharge destinations among rehabilitation in-patients

This chapter relates to the 101 rehabilitation in-patients only (37 men and 64 women) who had a median length of stay of 26 days (range 2 to 98 days). Most were discharged to their usual residence as shown in Table 6.1. There was no gender difference in pattern of discharge to usual residence: hazard ratio for discharge to usual residence 0.91 (95% confidence interval (95%CI) 0.38, 2.15, p=0.82) for women compared with men.

Table 6.1 Discharge destination of rehabilitation in-patients

Number (%)	Male (N=37)	Female (N=64)	Total (N=101)
Usual residence	29 (78.4)	46 (71.9)	75 (74.3)
New care home	5 (13.5)	12 (18.8)	17 (16.8)
Hospital transfer	3 (8.1)	5 (7.8)	8 (7.9)
Death	0 (0.0)	1 (1.6)	1 (1.0)

N: number; %: percentage

6.2 Associations between baseline characteristics and discharge to usual residence among male rehabilitation in-patients

Length of stay would have been used as the principal outcome variable in a regression analysis if all of the participants had been discharged to their usual residence. However 26 were not, as shown in Table 6.1, and so these participants' lengths of stay were 'censored' in that some were cut short e.g. hospital transfer or death, and some were probably extended by the need to find a new care home. Thus using length of stay as the outcome measure would have reduced the sample size to 75 with concomitant reduction of statistical power, and potentially introduced ascertainment bias by possibly excluding the frailer and/or sicker participants. The choice of discharge to usual residence as the outcome measure and of Cox's proportional hazards regression for the analysis allowed the data from the censored 26 participants who were not discharged to their usual residence to be included. A hazard ratio greater than 1.00 indicates that discharge to usual residence is more likely for each additional increment in the baseline variable. Similarly a hazard ratio less than 1.00 indicates that discharge to usual residence is less likely for each additional increment in the baseline variable.

Table 6.2 shows the associations between baseline characteristics and discharge to usual residence among male rehabilitation in-patients in unadjusted and adjusted analyses. The univariate unadjusted analyses demonstrated that shorter stature, higher Barthel score and a lower number of co-morbidities were associated with a greater likelihood of discharge to usual residence, and these associations remained significant in the adjusted models.

An increase in grip strength was associated with a slightly greater chance of discharge home in the univariate analysis but this was not significant (hazard ratio 1.05 (95% CI 0.99, 1.11, p=0.14). Adjustment for age and anthropometry (height and weight-for-height) strengthened the association between grip strength and discharge to usual residence such that a one kilogram increase in grip strength was associated with a hazard ratio of 1.09 (95% CI 1.01, 1.17), p=0.02, for discharge to usual residence (Table 6.2). However this association was attenuated by additional adjustment for Barthel score and the number of co-morbidities in the fully adjusted model. The final model depicts for clarity that age, anthropometry, grip strength, Barthel score and the number of co-morbidities were the key characteristics associated with discharge to usual residence in the adjusted models.

Table 6.2 Univariate association between baseline variables and discharge to usual residence for male in-patients

Men (N=37)	*Univariate analyses*[a]			*Adjusted for age & size*[b]			*Fully adjusted*[c]			*Final model*[d]		
	HR	**(95%CI)**	***p***	**HR**	**(95%CI)**	***p***	**HR**	**(95%CI)**	***p***	**HR**	**(95%CI)**	***p***
Age (years)	0.96	(0.90,1.04)	*0.33*	1.01	(0.93,1.09)	*0.90*	1.03	(0.96,1.11)	*0.40*	1.03	(0.96,1.11)	*0.40*
Height (cm)	0.83	(0.73,0.95)	*0.01*	0.82	(0.71,0.95)	*0.01*	0.72	(0.59,0.87)	*0.00*	0.72	(0.59,0.87)	*0.00*
Weight for height (SD score)	1.00	(0.97,1.04)	*0.88*	1.00	(0.97,1.04)	*0.85*	1.02	(0.98,1.07)	*0.32*	1.02	(0.98,1.07)	*0.32*
Maximum grip (kg)	1.05	(0.99,1.11)	*0.14*	1.09	(1.01,1.17)	*0.02*	1.02	(0.92,1.12)	*0.75*	1.02	(0.92,1.12)	*0.75*
Barthel score	1.02	(1.00,1.04)	*0.01*	1.03	(1.01,1.05)	*0.00*	1.03	(1.00,1.05)	*0.03*	1.03	(1.00,1.05)	*0.03*
Co-morbidities (number)	0.75	(0.53,1.05)	*0.09*	0.62	(0.42,0.92)	*0.02*	0.65	(0.44,0.95)	*0.03*	0.65	(0.44,0.95)	*0.03*
Medications (number)	1.08	(0.96,1.22)	*0.18*	1.02	(0.89,1.15)	*0.82*	1.07	(0.93,1.23)	*0.36*			
MMSE	1.09	(1.00,1.18)	*0.05*	1.07	(0.97,1.17)	*0.16*	1.06	(0.96,1.16)	*0.26*			
Strawbridge frailty	1.17	(0.53,2.56)	*0.70*	1.27	(0.54,3.02)	*0.59*	1.28	(0.48,3.43)	*0.62*			
MUST score category	1.06	(0.67,1.67)	*0.82*	0.80	(0.43,1.48)	*0.47*	0.50	(0.23,1.11)	*0.09*			
Falls in last year (number)	1.54	(0.93,2.56)	*0.09*	1.30	(0.73,2.30)	*0.37*	1.20	(0.65,2.21)	*0.56*			

HR: hazard ratio; CI:confidence interval; %: percentage; p: p-value; cm: centimetres; SD: standard deviation; kg: kilogram; MMSE: mini mental state examination.
P-values for association estimated using Cox's proportional hazards models.
[a] Univariate unadjusted associations between discharge to usual residence and each characteristic in the table in turn
[b] Associations between discharge to usual residence and each characteristic in the table in turn after adjustment for age, height and weight-for-height
[c] Associations between discharge to usual residence and each characteristic in the table in turn after adjustment for age, height, weight-for-height and also factors predictive of outcome in age and size-adjusted models i.e. grip strength, Barthel score and co-morbidities
[d] Recap of the 'final' mutually adjusted model for discharge to usual residence

6.3 Associations between baseline characteristics and discharge to usual residence among female rehabilitation in-patients

Table 6.3 shows the associations between baseline characteristics and discharge to usual residence among female rehabilitation in-patients in unadjusted and adjusted analyses.

Among women, univariate unadjusted analyses demonstrated that higher Barthel score, higher MMSE score, lower Strawbrige Frailty Score and fewer falls were associated with increased likelihood of discharge to usual residence. These associations remained statistically significant after adjustment for age and anthropometry. However when these baseline characteristics were included with age and anthropometry in the mutually adjusted model only a higher MMSE score ($p=0.01$) and fewer falls ($p<0.01$) retained a statistically significant association with increased likelihood of discharge to usual residence. Again this is shown for clarity in the final model (Table 6.3). There was a trend for higher grip strength to be associated with a greater likelihood of discharge to usual residence but this was not statistically significant.

Table 6.3 Univariate associations between baseline variables and discharge to usual residence for female in-patients

WOMEN (n=64)	*Univariate analyses*[a]			*Adjusted for age & size*[b]			*Fully adjusted* [c]			*Final model*[d]		
	HR	**(95%CI)**	***p***	**HR**	**(95%CI)**	***p***	**HR**	**(95%CI)**	***p***	**HR**	**(95%CI)**	***p***
Age (years)	1.03	(0.98,1.08)	*0.23*	1.03	(0.98,1.08)	*0.22*	1.08	(1.02,1.14)	*0.01*	1.08	(1.02,1.14)	*0.01*
Height (cm)	1.04	(0.96,1.13)	*0.31*	1.05	(0.96,1.14)	*0.26*	1.03	(0.94,1.13)	*0.58*	1.03	(0.94,1.13)	*0.58*
Weight for height (SD score)	1.01	(0.99,1.03)	*0.44*	1.01	(0.98,1.03)	*0.51*	1.00	(0.97,1.03)	*0.95*	1.00	(0.97,1.03)	*0.95*
Maximum grip (kg)	1.03	(0.98,1.08)	*0.25*	1.03	(0.98,1.09)	*0.25*	0.95	(0.88,1.03)	*0.22*			
Barthel score	1.02	(1.01,1.04)	*0.00*	1.03	(1.01,1.04)	*0.00*	1.01	(0.99,1.03)	*0.31*	1.01	(0.99,1.03)	*0.31*
Co-morbidities (number)	0.86	(0.70,1.05)	*0.14*	0.85	(0.70,1.04)	*0.12*	0.89	(0.72,1.11)	*0.31*			
Medications (number)	0.95	(0.87,1.04)	*0.29*	0.95	(0.87,1.05)	*0.31*	0.96	(0.86,1.07)	*0.44*			
MMSE	1.13	(1.05,1.20)	*0.00*	1.18	(1.09,1.28)	*0.00*	1.15	(1.04,1.27)	*0.01*	1.15	(1.04,1.27)	*0.01*
Strawbridge frailty	0.49	(0.26,0.90)	*0.02*	0.39	(0.21,0.76)	*0.01*	0.54	(0.25,1.13)	*0.10*	0.54	(0.25,1.13)	*0.10*
MUST score category	0.84	(0.59,1.19)	*0.33*	0.82	(0.53,1.27)	*0.37*	1.10	(0.67,1.81)	*0.70*			
Falls in last year (number)	0.52	(0.36,0.75)	*0.00*	0.48	(0.32,0.71)	*0.00*	0.44	(0.28,0.69)	*0.00*	0.44	(0.28,0.69)	*0.00*

HR: hazard ratio; CI:confidence interval; %: percentage; p: p-value; cm: centimetres; SD: standard deviation; kg: kilogram; MMSE: mini mental state examination.
P-values for association estimated using Cox's proportional hazards models.

[a] Univariate unadjusted associations between discharge to usual residence and each characteristic in the table in turn

[b] Associations between discharge to usual residence and each characteristic in the table in turn after adjustment for age, height and weight-for-height

[c] Associations between discharge to usual residence and each characteristic in the table in turn after adjustment for age, height, weight-for-height and also characteristics associated with outcome in age and size adjusted models i.e.Barthel score, MMSE, Strawbridge Frailty score and number of falls

[d] Recap of the 'final' mutually adjusted model for discharge to usual residence

6.4 Associations between co-morbidity clusters and discharge to usual residence among rehabilitation in-patients

Among male rehabilitation in-patients, the number of co-morbidities was among the clinical characteristics most markedly associated with discharge to usual residence (section 6.2). It was therefore of interest to explore whether any particular co-morbidity, or co-morbidity profile, as well as the total burden of co-morbidities, was associated with discharge to usual residence. Evaluation of the associations between individual co-morbidities and discharge to usual residence among male and female rehabilitation in-patients proved impossible since the sample sizes of 37 men and 64 women were insufficient to enable many of the Cox's proportional hazards models to converge on an estimated hazard ratio. A cluster analysis had previously been carried out with the aim of identifying general patterns of clustering of common co-morbidities among older people in the healthcare settings (section 5.4).

6.4.1 Results for men

31 (84%) of the 37 male rehabilitation in-patients were in co-morbidity cluster one and 6 (16%) in co-morbidity cluster two, and so statistical power was limited by the small sample size of the in-patient group. There was no significant difference in likelihood of discharge to usual residence by cluster status among men (p=0.36) although the magnitude of the hazard ratio, 0.61 (95% CI 0.21, 1.7), suggested a reduced likelihood of discharge home among men in cluster two (characterized by a high prevalence of falls, dementia, fracture and poor mobility). The male in-patients in cluster two also had a lower mean maximum grip strength than those in cluster one (18.8 kg compared to 22.2kg) but this was not statistically significant.

6.4.2 Results for women

For completeness the association between co-morbidity cluster and discharge to usual residence among women was explored, although there was no association with number of co-morbidities and discharge to usual residence as there had been in men (section 6.3). 38 (59%) of the 64 female rehabilitation in-patients were in co-morbidity cluster one, 19 (30%) were in cluster two, and 7 (11%) were in co-morbidity cluster three. There was no significant difference in likelihood of discharge to usual residence by cluster status between women in cluster one and two (hazard ratio for cluster two versus cluster one 0.73(95% CI 0.37, 1.42), p=0.35, but those in cluster three (characterized by a high prevalence of dementia, depression, urinary tract infection (UTI) and hypertension) were less likely to be discharged to usual residence (hazard ratio for cluster three versus cluster one, 0.09 (95% CI 0.01, 0.67), p=0.02). There was no significant difference in mean maximum grip strength between the three clusters although those in cluster three had the lowest grip strength (cluster one 13.6kg; cluster two 14.0 kg; cluster three 12.9kg).

Chapter 7 Discussion

7.1 Summary of study findings

This aim of this thesis was to investigate the epidemiology of grip strength in four healthcare settings where to date it has been little explored. Grip strength has been widely used as a measure of muscle strength in research studies. Most studies assessing the muscle strength of older people have recruited community dwelling participants, although some have been based in acute hospital settings. There are few studies of grip strength of older people in other healthcare settings such as rehabilitation or long term care, and further evidence is required on the epidemiology of grip strength of older people in these different healthcare settings. This includes investigation of the feasibility and acceptability of grip strength measurement as well as the development of appropriate reference ranges. Furthermore understanding of the influences on grip strength in different healthcare settings has not been addressed and similarly the link between grip strength and receipt of care, such as length of stay, has not been studied in this context.

Thus the specific objectives of this thesis were to study:

a) the feasibility and acceptability of grip measurement among older people in these healthcare settings

b) the grip strength values recorded in each healthcare setting in comparison with published reference ranges

c) the clinical correlates of grip strength in the different healthcare settings

d) the association of grip strength with discharge outcomes for the rehabilitation inpatients.

Older people were recruited from four different healthcare settings within one locality. The participants comprised 101 patients from a community hospital rehabilitation ward, 47 patients referred for community physiotherapy, 57 patients attending a Parkinson's disease clinic and 100 residents from five nursing homes.

Grip strength measurement was feasible and acceptable in these healthcare settings. Almost all of the participants recruited into the study could complete the grip strength assessment. The vast majority of participants did not find it tiring or painful. All of the community referrals, PD patients and male in-patients said they would repeat the test, as would 97% of the female in-patients and male nursing home residents, and 90% of the female nursing home residents. Qualitative data on participants' perceptions of grip strength measurement obtained through individual interviews with a purposive subgroup of participants was supportive of its use with older people in these healthcare settings.

Grip strength was normally distributed with a significant difference between the grip strength of men and women within each healthcare setting ($p<0.0001$) but importantly also between settings ($p<0.0001$). These differences persisted after adjustment for age. The values for the community referrals and PD patients were similar to those of the consolidated global norms published by Bohannon et al but the mean maximum grip strength of the in-patients, and particularly the nursing home residents, was far below published reference values based on healthy volunteers and community dwelling older people.

Age, body size and Barthel Score were the individual and clinical characteristics most consistently associated with grip strength in these settings. The number of co-morbidities was significantly associated with grip strength only for the male community referrals and the number of falls in the last year was significantly associated with grip strength only for the female community referrals.

Discharge outcomes were available for the 101 rehabilitation in-patients. Higher grip strength was significantly associated with a reduced length of stay among the men, such that each additional one kilogram increase in grip strength, adjusted for age and anthropometry, was associated with a 9 % increase in likelihood of discharge to usual residence (hazard ratio of 1.09 (95% CI 1.01, 1.17), $p=0.02$). There was a trend for higher grip strength to be associated with reduced length of stay among the women but this did not reach statistical significance.

7.2 Description of participants

7.2.1. Individual characteristics

305 participants were prospectively recruited into this study, from four healthcare settings based in and around the town of Romsey. The study sample comprised 101 rehabilitation in-patients, 47 patients referred for community physiotherapy, 57 patients with Parkinson's disease and 100 residents recruited from five local nursing homes. Men and women within each setting were similar in age and clinical characteristics including physical and cognitive function, although men were generally taller and heavier. By contrast there were significant differences in most of these characteristics for both men and women between the four healthcare settings.

There was a statistically significant difference in the ages of participants between settings, with the nursing home residents being the oldest, then the in-patients, followed by the community referrals and then the PD patients. The men were of similar height across the four settings, whereas the women differed significantly with the community referrals being the tallest women and the nursing home residents the shortest. Weight and BMI differed significantly across the settings for both genders, with the in-patients and the nursing home residents being the lightest.

There was little difference in the number of co-morbidities between men and women within or between settings, with a median number of four for all participants except male PD patients (median of three). There was a significant difference in the number of medications for both men and women across settings, with in-patients taking the most (median of eight) and PD patients the least. There was no significant difference between the number of medications taken by men and women within the same setting. By contrast the community dwelling participants of the Hertfordshire Cohort Study used a median of one medication (men: IQR 0,3) and two (women: IQR 1,4) (116).

There was a significant difference in Barthel scores and MMSE scores across the settings; both were highest among the male and female community referrals and PD patients, and lowest among nursing home residents. There was a significant difference in the MMSE scores between male and female PD patients, with lower scores for the men.

The nursing home residents had the highest proportion of participants classified as frail using the Strawbridge scale at 83% for men and 85% for women, and there was little difference within settings for men and women. MUST scores were similar between men and women within each setting, but there was a significant difference between women across the settings with the poorest nutritional scores among the female in-patients. Men and women within each setting experienced similar numbers of falls, but there was a significant difference for both sexes across settings with nursing home residents experiencing the least.

The majority of these differences between settings were highly statistically significant. The variation in age, body size, Barthel score, MMSE, Frailty score, MUST score, and number of falls was also clinically relevant and described groups of people with differing functional capabilities and levels of independence. In fact it is interesting that the number of co-morbidities was so constant across the settings. However, the presence of 3-5 co-morbid conditions is characteristic of geriatric rehabilitation (180), and so the median of 4 co-morbidities in each setting may be a confirmation that the participants in each setting did represent typical geriatric patients. A study of 105 older hip fracture patients also described a median of 4 chronic diseases per patient (168).

The four different healthcare settings represented aspects of the healthcare system available to older people within one geographical location. This was the only in-patient and community rehabilitation available within this locality, and the PD nurse specialists' database had been developed over many years and included patients seen by different consultants but who lived within the Romsey catchment area. There was one other nursing home locally but it had similar registration and a similar patient profile to those studied here. However the participants were predominantly of white Caucasian ethnicity and since grip strength is associated with ethnicity this may limit the generalisability of these grip strength values to patients of differing ethnicity. Frailty assessed by the Fried model has been shown to be more prevalent among

African Americans than among white Caucasian Americans (181) (15). It is also likely that the locality chosen, a market town in southern England, is not representative of other, particularly urban, areas of the UK. Therefore studies of older people in areas of greater ethnic diversity may find lower maximum grip strength values than reported here.

7.2.2 Recruitment and participation rates

There were differences in the recruitment process and participation rates between settings. All recruitment and data collection was prospective but whereas all of the eligible patients in the in-patient, PD and nursing home groups were consecutively recruited, the patients recruited to the community rehabilitation referral group formed a convenience sample which may have led to selection bias. This was mainly due to the lack of a database of patients reviewed by the physiotherapists (which led to difficulty in contacting all of their referrals), and also to delays in returning study information sheets, but these administrative issues are likely to have affected patients with weaker and stronger grip strength equally. However, additionally the physiotherapists initially declined to refer frailer patients, and although this was quickly addressed, this may have excluded some potential participants with lower grip strength values.

There were also differences in eligibility, participation rates and reasons for non-participation between the four healthcare settings. The prevalence of cognitive impairment precluding consent to the study varied between healthcare settings, resulting in 7.5% in-patients, 1% community referrals, 12.7% PD patients but 38.5% of the nursing home patients to be ineligible. These patients may well have had lower grip strength as there is a known association between grip strength and cognitive function, so the true mean grip strength of in-patients, PD patients and nursing home residents in particular may be lower than that described in this study. Those in-patients who were too unwell to participate would also likely have had lower grip strength.

A high proportion of those eligible from the in-patient (74%), PD (81.4%) and nursing home (90%) groups participated in the study. By contrast only 50% of those eligible in the community referral group were recruited. The expected sample size was not achieved for this group, despite a prolonged period of recruitment, and the small sample sizes in each setting reduced the power of the study.

A number of the in-patients could not be reviewed by the researcher within one week of admission, which is likely to have affected those with strong and weak grip equally. However 11 patients were discharged quickly, some of whom were sick hospital transfers and some were discharged home, so also likely a mix of people with weak and strong grip strength. A large number of the eligible (33%) community referrals declined, and administrative delays were also a factor in a further 17%. It is unclear what the grip strength of these patients would have been overall, but those who had busy social lives may have had stronger grip strength, and those who had more sedentary lifestyles may have had lower grip strength. Among the PD patients 8 declined and 5 did not reply to the invitation to participate. Again it is unclear what their grip strength would have been, and this is also the case for the few nursing home residents who did not participate. This methodological limitation could have introduced selection bias but the direction of this is unclear as those who did not participate probably included a mixture of people with stronger and weaker grip strength.

7.3 Feasibility of grip strength measurement

7.3.1 Participants

The majority of participants recruited into the study were able to complete the grip strength assessment. Only one hospital in-patient (with advanced peripheral neuropathy) could not hold the dynamometer at all, and six female in-patients with arm fractures or hemi-paresis could only grip with one hand. Several of the nursing home residents could not grip the dynamometer because of painful arthritic hands. The community referrals and PD patients could all hold the dynamometer with both hands. Patients who were partially sighted were able to hold the dynamometer once guided to it by the researcher. The assessment of grip strength three times with each hand took around five minutes. Inability to perform the measurement process is taken as a positive indicator of frailty in Fried's Frailty Score. However for those few participants able to use only one hand, grip strength values could be affected by the availability of the dominant or non-dominant hand, particularly for right-handed participants for whom the non-dominant grip strength may be lower.

Other studies have similarly found the majority of participants are able to complete grip strength assessment. In the Leiden 85+ study of 599 people including nursing home residents living in Leiden aged 85 years, 555 (93%) were able to complete the grip strength measurement (125). 44 participants were unable to do so, because of physical impairment (17), cognitive impairment (9), unable to follow instructions (5), declined (3) or other reasons (10).

The healthcare setting in this study did have an impact on the proportion of participants able to comply, and similar findings are reported from the few studies of grip strength in long term care residents. Hubbard et al found that 4/30 (13%) participants from a hospital continuing care ward were unable to complete grip strength assessment (for reasons unspecified), whereas all of the 40 day hospital and 40 community dwelling participants could do so (30). A number of potential participants were excluded from this study because of lack of capacity to consent to the study, particularly from the nursing home residents (38.5%). Cognitive impairment has been previously cited as a reason for non-completion of grip strength measurement among nursing home residents (182). However in-patients with lower MMSE scores were able to grip the dynamometer with clear instruction and demonstration and appeared to give their maximal effort, and it is likely that more of the nursing home residents could have complied with grip strength assessment without the need for research consent e.g. as part of clinical care (183).

7.3.2 Protocol and equipment

The standardised protocol was used in all but a few of the in-patients and nursing home residents, who had to be assessed sitting upright in bed rather than in a chair. The researcher ensured that this position enabled their upper body and arms to remain in the standardised position i.e. with the shoulder adducted, elbow flexed at 90^0, forearm supported and with the wrist in a neutral position. However the impact of this change in the position of their lower body is unknown. Previous studies have variably reported either no difference in grip strength with subjects sitting or standing (43) or higher grip on standing compared to sitting (44). There is no evidence on the effect on grip strength of lying in bed rather than sitting in a chair.

The Jamar dynamometers were regularly checked for accuracy against known weights and this proved to be an important measure, which ensured the early detection of one that had become inaccurate after being dropped. The mean difference between the original measurement and the repeat reading was only 0.56 kg although for the 13 individual participants rechecked this varied from –2kg to +7 kg, and the value is unknown for a further 6 participants who were unavailable to have a repeat measurement. Previous studies of test-retest reliability of grip strength measurement have described a measurement variation of between 5kg and 6kg (61) (184) and other authors report a similar value for the standard deviation of mean grip strength (56). Similar values were found during the intra-observer variability testing outlined in chapter 2 of this thesis and so it is unclear if the difference between the original and repeat readings represents a true difference between the dynamometers or just random subject variation. This degree of measurement variation should be taken into account when interpreting an individual participant's repeat grip strength estimation over time, or comparing the grip strength of individuals in cross-sectional analysis. However the mean test-retest reproducibility of grip strength measurement with the Jamar dynamometer has been shown to be very good for larger groups of participants both here and in published studies, thus comparison of participants' grip strength in different healthcare settings using mean maximum grip strength is appropriate.

7.3.3 Impact of sequential assessment on grip strength values

Participants' grip strength was assessed three times in each hand. Men had a significant improvement overall between the first and second attempt ('learning effect') with the right hand only, and no lessening of their grip with the third attempt ('tiring effect'). The women showed little change overall in the three attempts with their right hand, but did have significant tiring effects with the third attempt with their left hand (p=0.02).

A learning effect has previously been reported in the African American Health Project, which measured grip strength three times in the self-reported stronger hand of 853 participants (184). In both waves of data collection in 2001 and 2004 the authors report a learning effect between trials 1 and 2 but not between trials 2 and 3.

Tiring effects have also been previously reported. A Spanish study of community dwelling older adults described a reduction in grip strength with each of 3 attempts, but particularly between the 2nd and 3rd attempts (185). A similar Spanish study found that grip strength decreased from the 1st to the 3rd measurement for both men and women (70). Werle quantified a 'fatigue effect' for Swiss study participants, reporting a mean reduction in grip strength between the 1st and 3rd attempts of 1.3 kg for the right hand and 1.5 kg for the left hand between the 1st and 3rd trials (56). A far smaller effect was seen in this study, with the only statistically significant 'tiring' being a reduction of 0.4 kg (p=0.02) for the left hand of female participants.

The possible tiring and fatigue of participants has led some authors to question the use of three attempts with each hand. An Australian study aiming to establish reference ranges found that some subjects had fatigue and pain with 3 consecutive trials, and since preliminary examination of the data showed no difference with additional attempts, the protocol was altered to just one trial per hand (53). A recent UK study reports that one trial was a reliable and less tiring than three trials (57). However given the learning effects reported here and in other studies, two trials per hand may be the ideal number.

7.3.4 Impact of hand dominance

All but nine of the 305 participants were able to determine a dominant hand, and for 87% of both men and women this was their right hand. This is similar to results in other study populations in Australia (53), Switzerland (56), Malaysia (81) and Brazil (77). There was no statistically significant difference between the maximum grip strength of right or left handed men (p=0.82) and right or left handed women (p=0.75), and the maximum grip strength was the value recorded. Previous studies have reported higher grip strength in the dominant hand rather than right or left hand

(56) (70) (81) but the assessment of both hands and the recording of the maximum value achieved by either hand avoided this potential bias.

7.3.5 Test-retest reproducibility of maximum grip strength values

Test-retest reproducibility was formally assessed in the morning twice within one week on a convenience sample of ten in-patients with maximum grip strength less than 15 kg, who were clinically stable. The mean difference (95% CI) in the two readings was -0.3 kg (-1.5, 0.9) p=0.58, with a 95% reference range of -3.6 kg to 3.0 kg. This represents acceptable reproducibility and is similar to the test-retest reliability reported by the African American Health Project, where a mean difference of 0.4 kg between the two readings was reported (186). However Fess previously reported poor reliability of low grip strength readings (27). The results of this study may reflect the measures taken to minimise measurement error (training, assessment of inter- and intra-observer variability, calibration of the Jamar, use of a standardised protocol) and it is recommended that these measures are used for studies where the grip strength of frailer people is assessed.

7.3.6 Responsiveness of grip strength to change

Grip strength and Barthel score were assessed on both admission and discharge among a sub-sample of 20 rehabilitation in-patients whose admission lasted for at least two weeks. Grip strength remained very similar although the Barthel score improved overall. The mean difference (95% CI) in the two grip strength readings was -0.3kg (-1.7, 1.07) p=0.65, with a 95% reference range of -6.1 kg to 5.5 kg. By comparison the mean difference (95% CI) in the two Barthel score readings was – 8.6 points (-17.14, -0.06) p=0.05, with a 95% reference range of - 45.1 points to 27.9 points.

This is similar to the findings of a study of 105 patients with hip fracture whose grip strength remained almost unchanged throughout the admission and over a six month follow up period, while their motor function, as measured by the FIM score, improved (168). A study of general in-patient rehabilitation has also reported that by discharge grip strength had improved by only 1.0 kg (SD 4.0) p<0.05, and 3 months later by another 0.5 kg (SD 2.7), while ADL scores (Functional autonomy measurement system) had improved by 10 points ($p<0.001$) at discharge although no further improvement was seen at 3 months (180).

However significant clinical change can be masked by measurement variation, and so the standardised mean response and the effect size were calculated for this study as outlined in section 1.4.4.4. (page 25). For both of these measures a value of 0.2 – 0.5 is considered a low responsiveness, 0.51 – 0.8 is moderate and >0.8 shows a high level of responsiveness. For grip strength in this study the standardised mean response was 0.10 and the effect size was 0.05. For the Barthel score the standardised mean response was 0.47 and the effect size was 0.33. Thus the grip strength showed a low level of responsiveness to a period of rehabilitation while the Barthel score was somewhat more responsive although it only approached a moderate level of responsiveness.

The high level of test-retest reproducibility shown with the 10 ‘low grip’ and the 20 ‘admission-discharge’ rehabilitation in-patients reflects the use of the standardised protocol as well as the checking of inter- and intra-observer variability of the researchers to minimise this source of measurement error.

7.4 Acceptability of grip strength measurement

The acceptability of grip strength measurement was studied quantitatively in all of the participants using three short questions at the end of the assessment, which asked if they had found the grip strength measurement tiring or painful, and whether they would repeat the assessment. The vast majority of participants did not find it tiring or painful. All of the community referrals, PD patients and male in-patients said they would repeat the test, as would 97% of the female in-patients and male nursing home residents, and 90% of the female nursing home residents.

Additional qualitative data on participants’ perceptions of the acceptability of grip testing was obtained through individual semi-structured interviews within one week of the grip strength assessment. Interviews were conducted with six hospital in-patients, two community physiotherapy referrals, eight Parkinson's disease patients and four residents from one nursing home. The interviewees found the Jamar dynamometer straightforward to use but felt it could be quite bulky and heavy for some users, and that it could be difficult for people with arthritis or injuries of their hands. The participants all made a maximal effort to grip the dynamometer but were surprised by the lack of compressibility of the handle and felt that some feedback may have helped them achieve a higher grip strength. Opinion was divided as to whether their first or subsequent attempts were stronger, but most people felt that their dominant hand was stronger. No participants felt that the assessment had been painful, and while there was a recognition that it might be tiring, some of the nursing home residents disagreed. Only two interviewees associated grip strength with generalised muscle power rather than specific tasks related to hand function. Grip strength measurement was generally perceived as being potentially useful and acceptable as a routine assessment, although a convenient location was important. Some interviewees perceived the assessment as an opportunity to improve their health, whereas others did not see much scope for improvement, and two people felt that being told that they were getting weaker would be a source of worry.

This is the first study to demonstrate that grip strength measurement is acceptable to older people, particularly those undergoing rehabilitation, living with a chronic neurological condition and resident in care homes, for whom it may be most relevant but possibly most arduous. Only two studies have previously evaluated the acceptability of grip strength assessment. One used high completion rates as a proxy for acceptability (67) and the other study asked patients with arthritis which of three dynamometers they preferred (68). Acceptability may be gauged in different ways, for example a study of cognitive screening of older veterans used their consent to be screened as a measure of acceptability (187). A study of preference between two handheld indirect calorimeters used four questions with responses provided on a 5-point Likert scale to assess acceptability (188). However the experience and views of participants are crucial to the demonstration of acceptability yet rarely obtained in clinical studies: for example a systematic review of non-pharmacological interventions to reduce wandering in dementia identified 11 studies but none of the acceptability papers reported the patients' views (189).

This part of the study had some limitations. Firstly, the interview group was a small but purposive sample, and analyses demonstrated that this sub-group was indeed broadly representative of the whole study group in terms of age, grip strength, and physical and cognitive function. A second limitation was that most interview participants were interviewed several days after the grip strength measurement but the PD participants were interviewed straight away. This may have produced a bias in participants' clarity of recall but saturation of the data was achieved with this number of interviews.

However there were also several strengths. Firstly, the study sample included hospital in-patients and nursing home residents who were likely to have lower grip strength than community dwelling older people and may have found it more difficult to participate in research studies concerning grip strength. Secondly, in-depth interviews were conducted which allowed a greater understanding of the participants' views than a selection of closed response quantitative questions. Thirdly, the study was conducted by an experienced research team with expertise in interviewing older people in different health and social care settings. Finally the general views of all of the study participants were captured using the 3 broad questions on acceptability of grip strength measurement. The paper accepted for publication on the acceptability of grip strength assessment to older people in different healthcare settings is presented in Appendix 1.

7.5 Grip strength values in four healthcare settings

Grip strength was normally distributed in each healthcare setting. There was a significant difference between the grip strength of men and women within each healthcare setting independent of age ($p<0.0001$) and also between settings for both men and women ($p<0.0001$). For the male participants the PD patients had the highest grip strength (mean 37.9 kg), followed by the community referrals (mean 31.1 kg), in-patients (mean 21.7 kg) and nursing home residents (mean 14.2 kg). The women followed a similar pattern with the PD patients having the highest grip strength (mean 22.1 kg), then the community referrals (mean 19.6 kg), in-patients (mean 13.6 kg) and nursing home residents (mean 6.6 kg).

The grip strength values for the community referrals and PD patients are similar to those of the consolidated global norms published by Bohannon et al (69), but as shown in Table 7.1 the mean grip strength of the in-patients, and particularly the nursing home residents, was far below the published reference values based on healthy volunteers and community dwelling older people. This is in keeping with McAniff's study of rehabilitation in-patients, which reported the grip strength of adult in-patient rehabilitation patients to be lower than the reference range established by Mathiowetz (54), with mean grip strength values equivalent to 37.4% lower in the left hand and 43.2% lower in the right hand (85). The findings of this study are also in line with those of Gosselin who again reported grip strength of general rehabilitation in-patients to be much lower than published reference ranges (180).

However, unlike this study where the grip strength of community referrals receiving domiciliary rehabilitation was similar to reference range values, a retrospective case review of 41 patients undergoing domiciliary rehabilitation found their grip strength to be approximately 25% lower than that predicted by the reference range (86). The difference in grip strength in these studies may reflect differences in the patient groups as well as the difference between prospective and retrospective recruitment.

There have been very few studies of grip strength in Parkinson's disease. A study of six newly diagnosed untreated patients found that they used abnormally large grip forces during lifting and holding of an object (190). A second study to evaluate the prevalence of frailty among 50 stable PD patients with a mean age of 70 years, found that 16 (32%) met Fried's Frailty Criteria, 11 of whom had low grip strength although no grip values were reported (191).

The nursing home residents had the lowest age-adjusted grip strength, which was unsurprising as they were the most dependent group as judged by the lowest Barthel and MMSE scores. The mean grip strength for women was lower than the mean value of 14 kg for both men and women in care homes reported by Giuliani (87). This may

Table 7.1 Comparison of mean grip strength with reference values by gender and healthcare setting

	Men			Women		
Healthcare setting	**Mean Age (years)**	**Mean grip strength (kg) (% global norm)**	**Age adjusted global norm for grip strength* (kg)**	**Mean Age (years)**	**Mean grip strength (kg) (% global norm)**	**Age adjusted global norm for grip strength* (kg)**
In-patients	82.6	21.7 (72%)	30.1	84.9	13.6 (80%)	17.1
Community referrals	79.2	31.1 (94%)	33.0	79.4	19.6 (91%)	21.6
PD patients	71.3	37.9 (99%)	38.2	72.6	22.1 (91%)	24.2
Nursing home residents	85.1	14.2 (55%)	25.8	87.5	6.6 (39%)	17.1

Kg: kilograms; %: percentage

*Global norms derived from Bohannon (69) reflect the slightly younger age group in Giuliani's study (mean age 84 years), and the nature of the institutions, which included assisted living facilities, as well as the difference in size between this group of 100 residents from 5 homes, and her much larger group of 1,791 residents from 189 homes. Two other studies of grip strength in residential homes report higher values than here, with 24.8 kg for men and 15.5 kg for women in Portugal (23) and 26kg and 17.7 kg for men and women in Guyana (88). The Portuguese study sample was younger (mean age 78.7 and 80.6 years for men and women respectively) and included day centre attendees. There is insufficient data to compare the Guyanese study sample.

Grip strength has been shown to be associated with functional performance in one study of long-term care home residents (192). However the establishment of reference ranges for the grip strength of people in different healthcare settings is required to accurately identify those at greater and lesser risk of adverse outcomes both within and across the settings. This study has added to the literature in this area by including frail older people who are not normally recruited in community based studies, and demonstrating that their grip is lower than published values, and also that grip strength is associated with length of stay among the male in-patients.

The grip strength values reported in this study are the maximum from three attempts with each hand. The maximum value is likely to be greater than the mean value, and so the value utilised will impact on the comparison of grip strength values with published reference ranges. Maximum grip strength has been reported to be 1.0 kg higher than the mean of three 3 measures for women and 1.5 kg higher for men (24). However since this study used the maximum value this does not contribute to the low values for the in-patients and nursing home residents seen here. It is also reported that both maximum and mean values have a similar correlation with outcomes such as disability tests (185).

7.6 Association of grip strength with personal and clinical characteristics

7.6.1 Grip strength and individual characteristics

Increasing age was associated with a reduction in grip strength in all groups except the female community referrals and nursing home residents. This was only significant for the female in-patients (p=0.03) and PD patients (men p=0.002; women p=0.04). The higher correlation with the PD patients may reflect their younger age range (53-85 years for men and 61-86 years for women). The nursing home residents' ages ranged from 70-98 years for men and from 72 - 97 years for women. The lack of statistical significance for this association in all of the settings may well reflect the small sample sizes and narrow age ranges of men and women in each setting in this study as there is strong evidence that age is strongly associated with grip strength (72) (98).

The correlation of grip strength with height was also less clear than expected. Increasing height correlated with higher grip strength among PD patients, female in-patients, male community referrals and male nursing home residents, but with a significant correlation only among female PD patients (p=0.02). Weight was more strongly correlated with grip strength than height for men and women in all settings; this was only significant for male in-patients (p=0.002) and male PD patients (p=0.03). BMI, derived from height and weight, was positively correlated in men and women in all settings, but only significantly so among male in-patients (p=0.001). Again there is a large literature describing significant associations between grip strength and body size, and the small sample sizes in this study are the most likely reason for the lack of statistical significance in each setting in this study. However, men had significantly stronger grip strength than women in each setting, which is in line with other studies (104).

7.6.2 Grip strength and clinical characteristics

7.6.2.1. Co-morbidities

Lower grip strength was associated with a higher number of co-morbidities for men and women in all settings in univariate analysis except the nursing home residents, but this was only significant for the male community referrals (p=0.01). After mutual adjustment for age, height, weight-for-height and Barthel score, the number of co-morbidities was still significantly associated with grip strength for male community referrals (p=0.02).

There was great variation in the prevalence of individual co-morbidities within and between settings, although unsurprisingly the presence of Parkinson's disease dominated the active co-morbidities among the PD patients. Ward's hierarchical agglomerative clustering technique was used to identify clusters of co-morbidities for men and women separately and to explore whether grip strength was associated with any particular co-morbidity, or co-morbidity profile, as well as the total burden of co-morbidities. The PD patients were excluded to allow the process to identify general patterns of clustering of common co-morbidities among older people.

Among the men the cluster analysis identified two clear clusters. Mean maximum grip strength for 75 men in cluster 1 (characterised by diabetes mellitus, stroke and osteoarthritis) was 23.0 kg in comparison with an average of only 15.5 kg for the 21 men in cluster 2 (characterised by falls, dementia, fracture and mobility problems), p=0.002. Among the women the cluster analysis identified three clear clusters. Mean maximum grip strength for 27 women in cluster 3 (characterised by dementia, depression, urinary tract infection and hypertension) was only 8.0 kg in comparison with a mean of 12.0 kg for the 97 women in cluster 1 (characterised by stroke, joint replacement and mobility problems) and a mean of 13.1 kg for the 28 women in cluster 2 (characterised by falls, fracture, osteoarthritis, osteoporosis and heart failure), p=0.002.

The differences in grip strength between the clusters were large, and statistically significant, in both men and women, and the magnitude of this difference was similar to the difference in grip strength between men and women with different numbers of co-morbidities. Other studies have also reported an association between lower grip strength and a higher number of co-morbidities. Community dwelling participants in the ilSIRENTE study with 3 or more co-morbidities had a significantly lower grip strength than those without co-morbidity, although this association was attenuated by adjustment for age, gender, smoking, physical activity and cognitive performance (106).

Grip strength has been reported to be lower in community dwelling patients with diabetes, arthritis, and depression although not among those with hypertension or dyslipidaemia (186). By contrast other studies have shown an association between low grip strength and insulin resistance, dyslipidaemia and hypertension (107) (113). In this study, while the grip strength for each of the clusters was lower than published reference ranges, the grip strength of the men and women with dementia was the lowest.

All of the active co-morbidities listed in participants' case notes were recorded, but it is possible that some were not listed. Blood results were not checked so some co-morbidities such as dyslipidaemia may have been missed if participants were not on medication for the condition. However the results of this part of the study suggest that a simple count of the total number of active co-morbidities is as useful a determinant of grip strength as the type of co-morbidity with clustering providing additional information.

7.6.2.2. Number of medications

The number of medications was not significantly associated with grip strength in any setting for either gender. This is in contrast to other studies which report a reduction in grip strength with an increase in the number of medications (116). There was a significant difference between the healthcare settings for both men and women in the number of medications taken, and so the lack of association with grip strength may again reflect the small sample sizes in the study.

7.6.2.3 Barthel score

A higher Barthel score was associated with stronger grip among the men in each setting, and after adjustment for age, height and weight-for-height, the association remained significant among the male in-patients (p=0.04), community referrals (p=0.04) and nursing home residents (p=0.005). A higher Barthel score was significantly associated with stronger grip for the female in-patients and nursing home residents, but after adjusting for age, height and weight-for-height, only remained significant for the inpatients (p<0.001).

This was the clinical characteristic most strongly associated with grip strength, which is in line with other studies measuring physical function using outcome measures such as mobility (120), active leisure pursuits (121) and activities of daily living (125). The Barthel score was chosen for this study as it is widely used as a clinical outcome measure within rehabilitation settings in the NHS but it does have a recognised ceiling effect. It is likely that this could have affected the scores of the community referrals and the PD patients, but not the in-patients or the nursing home residents, and may be one reason why the association with grip strength was more significant for these settings.

7.6.2.4 Mini Mental State Examination Score

The MMSE was not associated with grip strength among men in any setting, and among women a higher score was only significantly associated with stronger grip among the in-patients and nursing home residents. Again after adjusting for age, height and weight-for-height, this association remained robust only for the female in-patients (p=0.001).

This measure of cognitive function was chosen as it is also widely used in the NHS, but again it may have had a ceiling effect among the community referrals and PD patients which may partly explain the lack of significant association within these settings. However in the cluster analysis dementia was a feature of those clusters with lowest grip strength, and this in keeping with the literature (131).

Mood was not directly measured in this study, other than as a listed co-morbidity, and so it could have acted as a confounding factor in the association of grip strength with the measured variables. Some authors have variably reported that depression is (186) or is not (193) associated with grip strength, and a positive affect has been reported to be associated with a lower risk of frailty using Fried’s frailty Score (194).

7.6.2.5 Strawbridge Frailty Score

A higher Strawbridge frailty score was associated with reduced grip strength in female nursing home residents (p=0.01; p=0.02 adjusted), but there was no association for any other group of participants. This is surprising if both the Strawbridge score and grip strength are considered to be markers of frailty. However while grip strength is often used as a general measure of muscle function, the Strawbridge frailty score includes four domains covering cognitive function, appetite and weight loss, and hearing and sight difficulties over the previous 12 months as well as physical function. The additional areas covered by the Strawbridge score may partly explain the lack of association with grip strength, although the small sample size may also be a factor. The debate over how best to measure frailty centres on this issue of whether frailty is a physical construct e.g. as measured using Fried's Frailty Score (10), or whether other aspects such as cognition and psychosocial issues should be included e.g. the Strawbridge score (11) or Rockwood's Frailty Index (12).

7.6.2.6 MUST nutrition score

Among the male participants a higher (worse) MUST score was only associated with lower grip strength in male in-patients (p=0.05) but this was attenuated by adjusting for age, height and weight-for-height. Among the female participants the situation was similar with only the in-patients having a significant association between higher MUST scores and lower grip strength, and this association was robust to adjustment (p=0.03).

The significant associations among in-patients may reflect the greater proportion of higher MUST scores in both men and women from this group compared to the other healthcare settings, and it is recognized that older in-patients are at risk of malnutrition both on admission and during their hospital stay. This association of nutritional status with grip strength is in keeping with other studies of in-patients (71) and grip strength has been recommended as a measure of nutritional status (134). Muscle function responds earlier than muscle mass or BMI to nutritional deprivation or restoration in younger people, but the situation is less clear cut in clinical trials in older people, possibly because of the reduction in muscle mass and grip strength which reflects frailty rather than nutrition (195).

The MUST score was chosen as the measure of nutritional status because it was used clinically in all of the healthcare settings in the study. The recorded value was abstracted from the case records and the competency of the clinical assessor to record an accurate value was assumed, in line with the clinical governance requirements for each setting. However the measurement was not repeated by the researcher in order to confirm this.

7.2.6.7 Number of falls

The number of falls in the last year was not associated with grip strength for any of the men. Among the women a higher number of falls was associated with lower grip strength for the community referrals (p=0.007), and remained significant after adjusting for age, height and weight-for-height (p=0.03). The in-patients and the community referrals had the highest proportion of repeat fallers, and a number of them were admitted or referred because of the falls. Other studies have reported an association between lower grip strength and falls among community dwelling older people (147) and rehabilitation inpatients (149).

The response to the question on falls was subject to recall bias as some participants may have forgotten about previous falls, and may have found it difficult to accurately remember how many falls they had experienced. However grouping the falls into categories of none, one and two or more falls helped minimize the need for additional accuracy among those falling repeatedly.

It is possible that a number of other factors not measured in this study may have contributed to the associations reported. For example higher levels of inflammatory markers are associated with increasing age, co-morbidity and low grip strength, in particular TNF-α and interleukin-6 (196) but were not measured in this study.

7.7 Grip strength and discharge to usual residence for rehabilitation in-patients

The 101 participants admitted to the community hospital rehabilitation ward had a median length of stay of 26 days (range 2 to 98 days) and 74.3% of them were discharged to their usual residence. The outcome measure 'increased likelihood of discharge to usual residence' allowed censored results to be included and reflected a shorter length of stay.

The univariate unadjusted analyses demonstrated that for male in-patients shorter stature, higher Barthel score and a lower number of co-morbidities were associated with a greater likelihood of discharge to usual residence, and these associations remained significant in the adjusted models. An increase in grip strength was associated with a slightly greater chance of discharge home in the univariate analysis but this was not significant (hazard ratio 1.05 (95% CI 0.99, 1.11, p=0.14). Adjustment for age and anthropometry (height and weight-for-height) strengthened the association between grip strength and discharge to usual residence such that a one kilogram increase in grip strength was associated with a hazard ratio of 1.09 (95% CI 1.01, 1.17), p=0.02, for discharge to usual residence (Table 6.2). However this association was attenuated by additional adjustment for Barthel score and the number of co-morbidities.

Among the female in-patients, univariate unadjusted analyses demonstrated that higher Barthel score, higher MMSE score, lower Strawbrige Frailty Score and fewer falls were associated with increased likelihood of discharge to usual residence. These associations remained statistically significant after adjustment for age and anthropometry. However when these baseline characteristics were included with age and anthropometry in the mutually adjusted model only a higher MMSE score (p=0.01) and fewer falls (p<0.01) retained a statistically significant association with increased likelihood of discharge to usual residence.

A cluster analysis was carried out with the aim of identifying general patterns of clustering of common co-morbidities among the in-patients. There was no significant difference in likelihood of discharge to usual residence by cluster status among men (p=0.36) although the magnitude of the hazard ratio, 0.61 (95% CI 0.21, 1.77), suggested a reduced likelihood of discharge home among men in cluster two (characterized by a high prevalence of falls, dementia, fracture and poor mobility). The male in-patients in cluster two also had a lower mean maximum grip strength than those in cluster one (18.8 kg compared to 22.2kg) but this was not statistically significant. However statistical power was limited by the small sample size of the in-patient group.

For completeness the association between co-morbidity cluster and discharge to usual residence among women was explored, although there was no association with number of co-morbidities and discharge to usual residence as there had been in men. There was no significant difference in likelihood of discharge to usual residence by cluster status between women in cluster one and two (hazard ratio for cluster two versus cluster one 0.73 (95% CI 0.37, 1.42), p=0.35, but those in cluster three (characterized by a high prevalence of dementia, depression, urinary tract infection (UTI) and hypertension) were less likely to be discharged to usual residence (hazard ratio for cluster three versus cluster one, 0.09 (95% CI 0.01, 0.67), p=0.02). There was no significant difference in mean maximum grip strength between the three clusters although those in cluster three had the lowest grip strength (cluster one 13.6kg; cluster two 14.0 kg; cluster three 12.9kg).

A study of younger rehabilitation in-patients (mean age 58 years) similarly found an association between admission grip strength and length of stay although there was no gender difference reported (85). Studies conducted in acute hospital settings among medical, surgical and cancer patients have reported low grip strength to be associated with longer lengths of stay and also increased complication rates (163) as well as increased mortality rates (167). Kerr et al (133) studying acute older medical in-patients demonstrated a 3% increase in the likelihood of discharge to usual residence for every additional one kilogram in grip strength adjusted for age and gender (hazard ratio 1.03, 95%CI 1.00, 1.07; p=0.05). A Portuguese study of hospitalised acute patients similarly found that each additional one kilogram of grip strength was associated with a 4% reduction of risk of having a longer than average length of stay (134). The greater increase in likelihood of discharge among the patients in this study may be due to the additional adjustment for body size and Barthel score, since both are known influences on grip strength.

Only one participant died in this study, so it was not possible to evaluate the association between grip strength and mortality. Two studies have reported an association between grip strength and mortality among men only, and two other studies have found this association with women but not men (197).

Some studies have reported cut-off values to predict which individuals may be at risk of specific outcomes. Kerr reported that cut-off values of 18kg for women and 31 kg for men were associated with a 25% increase in the likelihood of discharge home (133). However it was not possible to produce useful cut-off values from this part of the study, despite a similar sample size, and this may reflect differences between acute and rehabilitation in-patients.

There are several possible explanations for the association of low grip strength with longer length of stay and other adverse outcomes of admission to hospital. It could be that performance affects outcome, e.g. muscle weakness makes it more difficult to regain mobility after an acute illness. However adjustment for Barthel Score in this study, as a measure of physical performance, should have helped account for this possible confounding effect. Older age is associated with lower grip strength and the accumulation of more chronic diseases, which can lead to longer lengths of stay, but the grip strength values in this study were also adjusted for age.

Low grip strength may be a sub-clinical marker of disease or poor health status such as poor nutrition or sub-clinical stroke disease, which could have contributed to the longer length of stay. However the distribution of the MUST scores and discharge destinations in this study precluded adjustment for nutritional status. Finally grip strength could be reflecting exposure to risk factors earlier in life, such that those with lower grip have been exposed to more adverse risk factors and so are at risk of worse health later in life. This explanation is supported by evidence that resistance strength training of older people can improve their muscle strength and some functional activities e.g. walking speed, but has no impact on physical disability or health related quality of life. Length of stay is also subject to external influences such as the availability of health and social care, as well as personal choice. However, these are not related to grip strength and so the effect of these external influences would have been to reduce the likelihood of detecting an association between grip strength and discharge home.

There are a number of limitations and strengths to this part of the study. It only involved patients admitted for rehabilitation from one locality and all participants were Caucasian. Further research is therefore required to assess the generalisability of the findings to other populations. The exclusion of patients who were too unwell or too confused to consent to take part in the study may have excluded some with lower grip strength, whilst those excluded because they were discharged too quickly may have had higher grip strength. However the patients excluded were of a similar age to those who took part in the study and the study was designed to minimise selection bias through a single researcher screening all admissions. Furthermore the single assessor measured grip strength using a standard protocol with a calibrated dynamometer, regularly reassessed for accuracy, and regular intra- and inter-observer variability studies were carried out. This suggests that the differences in mean maximum grip strength between groups of in-patients described in this study were unlikely to be due to measurement error, and that grip strength was associated with length of stay among male rehabilitation in-patients.

7.8 Relevance of this research

This research has addressed several important questions central to the epidemiology of grip strength of older people in different healthcare settings, and has added to the literature in this area by including frail older people who are not normally recruited in community based studies reporting grip strength.

Grip strength measurement has been shown to be both feasible and acceptable to older people undergoing in-patient and out-patient rehabilitation, living with Parkinson’s disease and resident in care homes. Of note, independent mobility is not required. Thus it has the potential to be incorporated into a wide range of healthcare settings.

The range and variation in grip strength values within and between the different settings has been demonstrated, and in particular that the mean maximum grip strength of rehabilitation in-patients and care home residents is far lower than published reference ranges derived from community dwelling older people. Therefore appropriate setting-specific reference values are required in order to assess the prognostic implications of the grip strength of older people in these settings.

The individual and clinical determinants of grip strength in each setting have been described. Age and body size but also Barthel Score were consistently associated with grip strength. It is not surprising that physical function is closely associated with muscle strength, and it is likely that grip strength is acting in part as a marker for physical function. Thus grip strength assessment may be useful as a simple measure incorporating an assessment of physical function.

Finally grip strength appears to be associated with length of stay among male in-patients, with stronger grip associated with a greater likelihood of discharge to usual residence. This association with grip strength even among frailer people is important, since it provides support to the concept of intervening to improve the function of frail older people in rehabilitation and also care home settings. The establishment of reference ranges for the grip strength of people in different healthcare settings is required to accurately identify those at greater and lesser risk of adverse outcomes.

7.9 Translation to clinical practice

Grip strength is widely accepted to be a simple marker of current health status and to be associated with a risk of future adverse health outcomes, however it has not been adopted into clinical practice.

So why measure grip strength? Improvements in health and social care have successfully enabled more people to live for longer, but an ageing population presents challenges to the NHS. There is a need to identify people who require healthcare attention to avert adverse and costly outcomes, such as admission to hospital and care homes, among the increasing numbers of older people living into their 9th decade and beyond. Additionally with a government focus on managing chronic diseases outside hospitals, there is a drive to similarly assess people in their 70's: increasingly geriatricians are being involved in the planning and care for younger retired people with chronic diseases such as diabetes. Thus there is a real need for a simple assessment to identify people with poor current or future health to enable appropriate interventions to improve their health and also to avoid increasing NHS, social care and personal costs.

Methods of assessing older people include the Barthel or Strawbridge scores as described in this thesis. The Barthel score should be directly observed rather than reported by the subject to be valid and accurate, and in contrast to grip strength has a significant ceiling effect which can limit its usefulness in community dwelling people, as seen in this study. The Barthel score is based on physical function whereas the Strawbridge score includes cognitive domains, but both require accurate answers and can take longer to complete than grip strength measurement, which has a cost of staff time. The Strawbridge score has been superceded in the literature mainly by the Fried Frailty Score, but also by the Rockwood Frailty Index. The Rockwood Frailty Index is quite complicated and time-consuming and still remains a research tool. However grip strength is central to the Fried Frailty Score and so knowledge of the epidemiology of grip strength of older people in healthcare settings is important for translation to clinical practice.

This research has shown that grip strength measurement is a simple technique to use and highly acceptable even to frail older people resident in care homes. In fact the requirement to measure grip strength in a seated position is an advantage to people who may find independent mobility difficult and so grip strength may be particularly appropriate and the measurement of choice for people who are unable to perform other measures such as a timed walk, e.g. inpatients and care home residents.

This study has demonstrated that measuring grip strength 3 times with each hand was unnecessary, as the learning effect between the first and second attempts was statistically significant, but actually at <1kg it was not clinically significant. The 3rd attempt conferred no benefit and was found to be tiring among the women. There was no difference in grip strength between left and right handed participants, most of whom had a stronger grip in their dominant hand. Thus it would be reasonable to just measure maximum grip strength once or twice in just the participants' dominant hand.

Grip strength measurement is simple, quick and requires little training for the assessor. The inter- and intra- rater variability was low for all of the researchers, when using a standard protocol and calibrated Jamar dynamometer, which is in line with other studies. This would also make it an easy technique to use in clinical practice, with minimal training required for healthcare staff. However the dynamometer does need regular checks for accuracy and costs around £210 each. Care should be taken to avoid dropping it: a wrist strap is provided and the dynamometer should be supported when grip strength is assessed.

Grip strength could be used at GP practice level as part of an assessment of older patients' health, for example as part of an annual health check for older people or combined with the influenza mass vaccination. This thesis has demonstrated that it is not responsive to rehabilitation and appears to be a stable measure of current health status so it would also be useful to measure it when people are admitted to a healthcare setting as part of an initial assessment of health status. Similarly it could be useful in a clinic setting or within a comprehensive geriatric assessment as part of the assessment process to similarly identify those at risk of poor health.

The translation of grip strength measurement to clinical practice in healthcare settings does require the further development of appropriate reference ranges. These could be presented within a diagram to show the range of low, moderate and high risk to current and future health, using age adjusted grip strength values in a similar manner to tables depicting BMI ranges which are widely used in clinical settings. These could then be used to encourage people to exercise including resistance training, with evidence that even people in care homes with low grip strength can improve their strength. However further research is required to evaluate the use of grip strength measurement of older people in clinical practice.

7.10 Future research

Following on from this thesis there are several important questions that remain unanswered.

This was a relatively small study and larger studies are required to accurately define and publish reference ranges for the grip strength of older people in different healthcare settings. These studies should include participants with ethnically diverse backgrounds representative of urban populations in the United Kingdom.

Planned longer term follow-up of the participants in this study will allow further analysis of the association between grip strength and subsequent health among older people undergoing rehabilitation, living with a chronic neurological condition, and resident in nursing homes. Ethical approval has been granted for this and the relationship of grip strength and subsequent readmission to hospital, admission to care homes and mortality over a period of 2-3 years will be studied.

Further research is also required to evaluate the clinical use of grip strength measurement as part of the comprehensive geriatric assessment of older people in differing healthcare settings.

7.11 Conclusions

- This thesis has explored the epidemiology of grip strength measurement of older people in four different healthcare settings where it has been little studied.
- This study has recruited participants who are vulnerable and may be more difficult to study.
- It has provided evidence for high levels of both feasibility and acceptability of grip strength measurement of older people undergoing rehabilitation, living with a chronic neurological condition, and resident in nursing homes.
- This study has demonstrated the mean maximum grip strength values in each setting and shown that those of rehabilitation inpatients and nursing home residents are much lower than those in published reference ranges.
- Age, gender, body size and Barthel score have been demonstrated to be the characteristics most consistently associated with grip strength of older people in these healthcare settings.
- Grip strength appears to be associated with length of stay even amongst participants with low grip strength. Higher grip strength was associated with a greater likelihood of discharge to usual residence among the in-patients, reaching statistical significance among the men.
- The measurement of grip strength was feasible and acceptable, required only basic training, used portable, cheap equipment and was associated with discharge outcome. Furthermore it did not require independent mobility. This makes it potentially a very attractive bed-side assessment for use across a wide range of healthcare settings.

Summary of research contribution of candidate

Preparation phase

I devised the study with input from my supervisors, and wrote the protocol, patient information sheets, consent forms, and letters for patients' General Practitioners. I completed the initial Research Ethics Committee and Trust Research and Development submissions and all four subsequent amendments. I attended the Research Ethics Committee meeting in person to address queries from the members. I obtained permission from the PCT to carry out the study in the community hospital. I devised the data collection sheets and piloted them on three patients. I identified three assistant researchers (Jan Ritchie, Joe Butchart and Sergio Salomone) and trained them in the use of the data collection sheet and in the standard protocol for the assessment of grip strength. I organised the measurement of inter- and intra-observer variability of each researcher using healthy volunteers prior to data collection, and the regular checking of the Jamar accuracy throughout the study. I devised the semi-structured interview schedule and piloted it with a 4th researcher (Jon Sparkes). I obtained a grant from BUPA Giving to support the researcher to collect data from the care homes.

Data collection and analysis

I collected data on 101 inpatients at Romsey community hospital which was the first healthcare setting, and supervised the collection of the data in the other three healthcare settings. I visited the care homes with the researcher for the initial visit. I devised the variable labels for the database, which was cleaned by MRC staff. I completed STATA training and performed the descriptive analyses. I directed but was supported in the regression analyses by MRC statisticians.

The interviews were transcribed and then I coded the transcripts and led the analysis, discussing the emerging themes with the other researcher.

Writing of this thesis and other outputs

I wrote the thesis, which was discussed at stages with my supervisors. I devised the tables and CONSORT diagrams, formatted the thesis and used

Refman to produce the reference list. I carried out the literature review and was lead author on a review paper published in Age and Ageing July 2011. I wrote up the interview data as the paper published in Journal of Aging Research and Clinical Practice May 2012. I was the lead author on a paper accepted by Age and Ageing (May 2012) describing the association of grip strength with length of stay in rehabilitation inpatients. Additionally, based on this study, I have written a letter to Age and Ageing on outcome measures for care home research, given an oral presentation to the British Geriatric Society on the grip strength values found in the different healthcare settings, and presented a poster at the International Association of Geriatrics and Gerontology.

Appendices

Appendix 1: Publications, presentations and conference proceedings

1. Helen C Roberts, Holly Syddall, Cyrus Cooper, Avan Aihie Sayer. Is grip strength associated with length of stay in hospitalised older patients admitted for rehabilitation? Findings from the Southampton Grip Strength Study. Age and Ageing 2012: in press.

2. H.C. Roberts, J. Sparkes, H. Syddall, J. Butchart, J. Ritchie, C. Cooper, A.A. Sayer. Is measuring grip strength acceptable to older people? The Southampton Grip Strength Study. Journal of Aging Research & Clinical Practice 2012; 1 (2): 135-140.

3. Helen C Roberts, Hayley J Denison, Helen J Martin, Holly Syddall, Harnish P Patel, Cyrus Cooper, Avan Aihie Sayer. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. Age and Ageing 2011; 40: 423-429.

4. Helen C Roberts, Avan Aihie Sayer, Frazer Anderson, Clive Bowman. Finding the right outcome measures for care home research. Age & Ageing 2010; 39: 517

5. HC Roberts, J Ritchie, J Butchart, J Sparkes, KA Jameson and A A Sayer. Measuring grip strength in different community health and social care settings: what are median values and inter-quartile ranges among patients undergoing in-patient and out-patient rehabilitation, attending a Parkinson's Disease clinic, and nursing home residents? Age Ageing 2011; 40 supplement 1 i51.

6. J Sparkes, J Ritchie, J Butchart, SE Salomone, K Jameson , AA Sayer, HC Roberts. The acceptability of grip strength assessment in four health and social care settings. Age Ageing 2010; 39 supplement 2 ii2.

7. HC Roberts, J Ritchie, J Butchart, J Sparkes, D Padiarchy, H Syddall, K Jameson and AA Sayer. Is the assessment of grip strength feasible and acceptable in a community hospital setting?
   Poster presentation at the IAGG conference July 2009

IS MEASURING GRIP STRENGTH ACCEPTABLE TO OLDER PEOPLE? THE SOUTHAMPTON GRIP STRENGTH STUDY

H.C. Roberts[1,2], J. Sparkes[3], H. Syddall[2], J. Butchart[3], J. Ritchie[3], C. Cooper[2], A.A. Sayer[1,2]

Abstract: *Objectives:* To evaluate the acceptability of grip strength measurement among older people in different healthcare settings. *Design:* A cross-sectional study with quantitative and qualitative data collection. *Setting:* Four healthcare settings in one town in southern England. *Participants:* 101 community hospital rehabilitation inpatients, 47 community physiotherapy referrals, 57 patients attending a Parkinson's clinic at the hospital and 100 residents in care homes. *Measurements:* Grip strength, Barthel score, Mini Mental State Examination and outline questions on the grip measurement process were assessed on all participants. In-depth semi-structured interviews ascertained the views of a sub-sample of 20 participants on grip strength measurement. *Results:* The instructions were easily understood, most participants did not find the measurement painful or tiring, and almost all were prepared to repeat the assessment. Participants felt that this could be a useful and acceptable routine assessment, which some thought could be an opportunity to improve their health, while others were uncertain whether it would be helpful to be told that they were becoming weaker. Participants were generally accepting of medical assessments and felt that grip measurement was easy, unless there was a problem with an individual's hand. *Conclusions:* This is the first study to demonstrate that grip strength measurement is acceptable to older people undergoing rehabilitation, living with a chronic neurological condition or resident in care homes. The high level of acceptability found among older people in different healthcare settings in this study supports the use of grip strength measurement in routine clinical practice.

Key words: Grip strength, acceptability, older people, measurement.

Introduction

Grip strength is frequently measured in research studies and low grip strength is known to be associated with increased falls (1), longer length of hospital stay (2, 3), increased disability (4), poor nutrition (5), poor health-related quality of life (6) and increased mortality (7, 8). Grip strength was recently recommended for use in clinical settings for the assessment of sarcopenia (9), and the Jamar hand dynamometer (Lafayette Instrument Company, USA) is accepted as the gold standard by which other dynamometers are evaluated (10). A standardised protocol is recommended (11) and the measurement properties of the Jamar include high test-retest reproducibility over 12 weeks among community dwelling volunteers (mean age 75 years) (12) and excellent (r=0.98) inter-rater reliability (13). The feasibility of its use with older people has been shown in day centre and care home settings (14-16). However little is known about the acceptability of grip strength measurement to older people, particularly those undergoing rehabilitation, living with a chronic neurological condition or resident in care homes, for whom it may be most relevant but possibly most arduous.

Two studies have assessed the acceptability of grip strength measurement in adults. Helliwell (17) broadly assessed the acceptability of three dynamometers by asking 26 patients (mean age 63 years) with arthritis 'if you had to squeeze these devices each day as part of your assessment, which one would you prefer?' There is no information on the reasons for their preference, or on their views of grip strength measurement as part of routine clinical care. Harding evaluated grip strength in patients with chronic pain (18). Acceptability was measured by participant refusal rate and all 431 subjects (mean age 50 years) were able to complete the grip strength measurement. Neither study evaluated the Jamar dynamometer.

This study aimed to evaluate the views of older people in four healthcare settings on the acceptability of grip strength measurement with a Jamar dynamometer.

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Methods

Study design

A cross-sectional study of older people recruited from four healthcare settings in one town in southern England between 2008 and 2010. The study received full ethical approval.

Participants

305 participants were recruited from a community hospital rehabilitation ward (n = 101), people referred for community physiotherapy (n = 47), a Parkinson's disease (PD) clinic at the community hospital (n = 57), and five nursing homes (n = 100). Interviews were conducted with a purposive sub-group of 20 participants aiming to represent men and women from each setting, which comprised six rehabilitation inpatients, two community physiotherapy referrals, eight PD patients and four residents from one nursing home. Participants were eligible for interview if they had a mini mental state examination (MMSE) score of 24 points or more. Interviews were held within one week of grip strength measurement to maximise recall, with final participant selection dependent on researcher availability within that time frame.

Data collection

Grip strength was measured using a Jamar dynamometer squeezed three times with each hand using a standardised protocol (19). Participants were asked a few minutes later whether the grip strength measurement had caused them any pain, if it was tiring, and if they would be prepared to repeat the assessment. Physical and cognitive function were assessed using the Barthel score (20) and the MMSE (21).

The interviews followed a semi-structured schedule (Figure 1) but could deviate from the schedule and include additional questions to explore issues raised during earlier interviews, using a grounded theory approach (22). The interviews were audio-taped and lasted 10-15 minutes; participants were anonymised throughout the recording. Interviews were conducted until no new information emerged (data saturation).

Data analysis

The acceptability of grip strength measurement was described by gender and setting using frequency and percentage distributions and differences in acceptability between settings within gender groups, and between genders within settings, were compared using Fisher's exact test. The characteristics of study participants who were interviewed were contrasted with those not interviewed by using means and standard deviations or medians and inter-quartile ranges and were formally compared using a 2-sample t-test or Mann-Whitney rank-sum test.

The audiotapes were transcribed verbatim. The texts were read, coded and evaluated for themes by two researchers (HR and JS) independently and then together, looking for commonality and differences within and between the care settings. The coding framework that was developed was grounded in the data rather than decided a priori.

Thank you for agreeing to talk to me about the handgrip testing that was performed χ days ago. This interview is to discover how you found the testing of your hand strength but is not about the other questions you were asked. All the interviews will be
anonymised but please say if you do not want anything recorded.

- Can you tell me a little about what the research project involved.
- Did you understand the instructions given to you?
- How did you find using the grip tester?
- Was it comfortable? Did you find it tiring?
- Did it get easier after the first attempt?
- Do you think you could have done any better?
- Would you be prepared to perform this test regularly at the clinic or general practice?
  * If not, why not?
- What did you think the grip tester was testing? Why?

Thank you for your help. Do you have any questions about the research or what we have spoken about today? Are you happy for me to use our conversation in the research?

Figure 1. Grip strength interview schedule

Results

Grip strength measurement was highly acceptable in all four healthcare settings (Table 1). Most inpatients did not find it tiring (92% men, 91% women) or painful (89% men, 92% women). More than 96% of community physiotherapy referrals did not find grip strength measurement tiring and none experienced pain. Ninety-four percent of male PD patients and all female PD patients did not find the assessment tiring, and only a few female PD patients (13%) found it painful. 79% of the nursing home residents did not find the assessment tiring, and none of the male residents and only 10% of the female residents found it painful. Finally all of the male inpatients, male and female community physiotherapy referrals and male and female PD patients would repeat the assessment, as would 97% female inpatients and male nursing home residents, and 90% female nursing home residents.

The interview group was representative of the larger study group with regard to age, maximum grip strength, physical and cognitive function as shown in Table 2. The qualitative data analysis developed five main themes: understanding the instructions; the Jamar dynamometer itself; aspects of participants' involvement with grip strength measurement; routine use of grip strength measurement; and acceptability of grip strength measurement overall. These themes are presented using direct quotes selected to illustrate the commonality and diversity of views.

Table 1
Acceptability of grip strength assessment to all study participants

	Hospital rehabilitation inpatients		Community rehabilitation referrals		Parkinson's disease clinic patients		Nursing Home residents		P value[1]
Number (%)	Male (N=37)	Female (N=64)	Male (N=24)	Female (N=23)	Male (N=34)	Female (N=23)	Male (N=35)	Female (N=65)	
Did not find assessment tiring	34 (92)	57 (91)	22 (96)	23 (100)	32 (94)	23 (100)	27 (79)	49 (79)	M: 0.18 F: 0.04
P value[2]	*P=1.00*		*P=1.00*		*P=0.38*		*P=1.00*		
Did not find assessment painful	33 (89)	58 (92)	23 (100)	23 (100)	34 (100)	20 (87)	34 (100)	56 (90)	M: 0.03 F: 0.35
P value[2]	*P=0.72*		*P=1.00*		*P=0.06*		*P=0.09*		
Would repeat the assessment	37 (100)	61 (97)	23 (100)	23 (100)	34 (100)	23 (100)	33 (97)	56 (90)	M: 0.71 F: 0.03
P value[2]	*P=0.53*		*P=1.00*		*P=1.00*		*P=0.05*		

N: number; %: percentage; Data for all three items missing for 1 female inpatient, 1 male community referral, and 1 male and 3 female nursing home residents; P value[1] for differences between settings by gender calculated using Fisher's exact test; P value[2] for differences between gender within settings calculated using Fisher's exact test

Table 2
Comparison of the interview group with remaining study participants: age, maximum grip strength, physical and cognitive function

Mean (SD)	Male			Female		
	Not interviewed (N=120)		Interviewed (N=10)	Not interviewed (N=165)		Interviewed (N=10)
Age (years)	79.6 (8.3)		80.8 (12.3)	83.6 (8.2)		82.3 (5.0)
P value		P=0.67			P=0.62	
Maximum grip strength	25.5 (11.8)		27.7 (16.6)	12.8 (7.7)		14.6 (9.6)
P value		P=0.58			P=0.48	
Barthel score[a]	81 (45, 97.75)		78 (60, 96.5)	68 (40.5, 90)		77.5 (40.5, 97.25)
P value		P=1.00			P=0.49	
MMSE[a]	25 (17, 29)		26 (24.75, 27.5)	25 (17, 28)		25 (22, 28.5)
P value		P=0.26			P=0.39	

SD: standard deviation; N: number; MMSE: mini men tal state examination; Data for MMSE missing for 1 male who was not interviewed; P value for differences between groups calculated using 2-sample t-test or Mann Whitney rank-sum test; [a]Median and inter-quartile range (IQR)

Discussion

Understanding the instructions

Eight participants commented on their ease of understanding the instructions about grip assessment and taking part in the study. They all found it quite straightforward:

Well, just a grip test to find out whether there is a correlation between strength of grip and muscle weakness or Parkinson's or various diseases…. I had to squeeze a machine as hard as I could with both hands, well one at a time really. 14(PD)

The Jamar dynamometer itself

Seven participants commented positively on the shape of the Jamar, recognizing that it was designed for ease of grip:

The grip seemed to be quite a central arrangement. It suited my hand anyway. 4(inpatient)

Two of the nursing home patients were unable to grip the dynamometer because of its size, and six participants commented that the Jamar was rather heavy, even though it was supported by the researcher. Four did not find it heavy at all, but there was recognition some others might do so.

Well, actually the doctor was holding the thing so all I had to do was just grip. I think it would have been rather heavy if I had been doing it on my own. 2(inpatient)

Eight participants commented on the lack of compressibility of the Jamar and four thought that more feedback on their performance might have enabled them to achieve a higher grip strength.

Yes, if I had a dial it would at least have told me if I was doing anything or not 'cause I was darned if I could tell otherwise. 2(inpatient)

Aspects of Participants' involvement with grip strength measurement

Effort expended

Ten participants commented that they had tried their best with the grip strength assessment:

Only just. Only just, I had to make a lot of effort. 20(nursing home)

Three patients commented that they could only have managed another couple of attempts in total:

Oh I did it one or a few times I think. Two or three times…. I could have done it more I think. 16(community physiotherapy)

Grip strength and assessment order

Opinion was divided on the impact of assessment order on grip strength. Two participants felt that their first attempt was the best

Well, … at the beginning it was a bit easier, more strength, than the one at the end. There was a bit of time in between. And I had already done it once. 10(PD)

However others felt that their later attempts were better:

When you get to the third time when it is the last time, you put most effort in. 9(PD)

Still others felt that their efforts had been constant throughout their attempts:

I don't know if it changed or not because I did it the same way each time. 5(inpatient)

Grip strength and hand dominance

Most participants felt that their dominant hand was the stronger, one man thought his non-dominant hand had been better, but another felt his grip was fairly equal with both hands:

I wouldn't like to say because when I was working I was a bricklayer you see, so I used a trowel in my left hand and I picked up the bricks in my right hand. 7 (inpatient)

Discomfort associated with grip strength measurement

No participants felt that the measurement had been painful but there was recognition from three participants that it could be tiring:

Well, it was enough for those particular muscles to start feeling the strain, I think, because you do have to put as much into it as you can, therefore it does tire you if you keep on doing it. 3(inpatient)

Interestingly this view was not shared by other inpatients or any of the nursing home residents:

No, I didn't do it long enough or often enough for that. 19(nursing home)

Routine use of grip strength measurement

Rationale for grip strength measurement

16 participants replied to the question about the rationale for grip strength measurement but only two people associated grip strength with general weakness:

Well I suppose it's for older people, a strength test. 21 (community physiotherapy)

Everyone else felt that strength in their arms and legs were separate and eight participants felt that grip assessment was specifically related to their hands and/or specific functional tasks:

Your hand muscles. I can't see that it would do much for your biceps. 14(PD)

If I could hold onto my sticks I should think. 5(inpatient)

Utility of routine grip strength measurement

All of the participants felt that this would be a useful and acceptable routine assessment:

A routine test. Yes, I would have thought it seems like quite a sensible idea, a practical idea. 4(inpatient)

I think people would just take it in their stride. 10(PD)

However location of the assessment was important for one participant:

Yes, but it would be easier if it was brought to our house, I think. 5(inpatient)

Several people commented that the assessment could be an opportunity to try to improve their health:

Yes, yes, I would want to know if I was getting weaker…. Well I would try to do more exercise and try and live a healthier lifestyle, I guess. 14(PD)

However two participants did not think there would be much scope for improvement:

I don't know. When you get older, I don't know, do you? I mean you don't get your same strength back when you get older, do you? 21(community physiotherapy)

Two participants commented that they would know that they were getting weaker, but another felt that this may not be the case:

I think you would probably realise it yourself but you would probably want confirmation of what you think. 9(PD)

Two participants felt that there could be therapeutic aspects to the grip strength assessment itself, and two people commented on the use of serial measurements for comparison:

Yes, quite happy, yes. Because it would be good to get a comparison I expect. 12(PD)

Negative aspects of routine grip strength measurement

Only two people (both with a chronic progressive condition) commented specifically on aspects of routine screening that might worry them:

To be told whether they are getting stronger or not. Well it would be encouraging if they were told they were fairly strong I suppose. But whether it would be helpful to be told that you were a lot weaker than last time, I don't know. 12(PD)

Passive acceptance of medical assessments

Six participants expressed their views on medical assessments, and all were accepting of them even if they did not understand exactly why or what was being done:

No idea. I've long ago given up wondering why. I just do it and that's that. No idea. Like going around to the surgery, I only go around there if I'm summoned, not otherwise. 2(inpatient)

Ah, doctors, they test your blood all the time, it's a sort of addiction. 19(nursing home)

Acceptability of grip strength assessment overall

Ten participants commented that this was an easy test to do:

No hardship to test it, only takes a few minutes. 19(nursing home)

The only potential problems envisaged were local issues with participant's hand:

I think most people would be good at it, don't you? Unless they had arthritis in their wrist or something like that. 21(community physiotherapy)

Discussion

This is the first study to demonstrate in detail that grip strength measurement is acceptable to older people undergoing rehabilitation, living with a chronic neurological condition or resident in care homes. The vast majority of participants did not find the measurement painful or tiring, and were prepared to repeat the assessment. The instructions were easily understood and the Jamar dynamometer suited most people, although several people commented that it was bulky and would have been heavy if not supported by the researcher. Participants variably felt that their first or third attempts were strongest, or that their grip strength was constant; most felt that their dominant hand was the stronger and some commented that the lack of compressibility of the handle prevented feedback on their performance.

Only one person associated low grip strength with general muscle weakness, and most people felt that grip measurement was specifically related to hand muscle strength or functional tasks involving their hands. Participants felt that this could be a useful and acceptable routine assessment, which some thought could be an opportunity to improve their health, although two people with a chronic progressive condition were uncertain whether it would be helpful to be told that they were becoming weaker. The participants were generally accepting of medical assessments and felt that grip strength measurement was easy, unless there was a problem with an individual's hand.

This study had some limitations. Firstly, practical constraints dictated that the interview group was partly dictated by interviewer availability; however, analyses demonstrated that this sub-group were broadly representative of the whole study group in terms of age, grip strength, and physical and cognitive function. A second limitation was that most interview participants were interviewed several days after the grip strength measurement but the PD participants were interviewed straight away. This may have produced a bias in participants' clarity of recall but saturation of the data was achieved with this number of interviews.

This study also had many strengths. Firstly, the study sample included hospital inpatients undergoing rehabilitation and nursing home residents who are likely to have lower grip strength than community dwelling older people and may find it more difficult to participate in research studies concerning grip strength. Secondly, in-depth interviews were conducted which allowed a greater understanding of the participants' views than a selection of closed response quantitative questions. Thirdly, the study was conducted by an experienced research team with expertise in interviewing older people in different health and social care settings. Finally, grip strength was measured according to a standard protocol and inter- and intra-observer variation studies were conducted to ensure reliability and comparability of measurement between and within observers.

It is important to establish the acceptability of measurements prior to their introduction to routine clinical practice. Acceptability may be gauged in different ways. For example, a study of cognitive screening of older veterans used their consent to be screened as a measure of acceptability (23) while another study validating an outcome scale in PD patients used the degree of completeness of the questionnaire as an indicator of acceptability (24). A study of preference between two handheld indirect calorimeters used four questions with responses provided on a 5-point Likert scale to assess acceptability (25). The experience and views of participants are crucial to demonstration of acceptability yet a systematic review of non-pharmacological interventions to reduce wandering in dementia identified 11 studies where none of the acceptability papers reported the patients' views (26).

Demonstration of the reproducibility, feasibility and acceptability of grip strength measurement is essential if it is to be used in clinical practice. The high level of acceptability found among older people in different healthcare settings in this study supports the use of grip strength measurement in routine clinical practice.'

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REVIEW

A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach

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Abstract

Background: the European Working Group on Sarcopenia in Older People has developed a clinical definition of sarcopenia based on low muscle mass and reduced muscle function (strength or performance). Grip strength is recommended as a good simple measure of muscle strength when 'measured in standard conditions'. However, standard conditions remain to be defined.
Methods: a literature search was conducted to review articles describing the measurement of grip strength listed in Medline, Web of Science and Cochrane Library databases up to 31 December 2009.
Results: there is wide variability in the choice of equipment and protocol for measuring grip strength. The Jamar hand dynamometer is the most widely used instrument with established test–retest, inter-rater and intra-rater reliability. However, there is considerable variation in how it is used and studies often provide insufficient information on the protocol followed making comparisons difficult. There is evidence that variation in approach can affect the values recorded. Furthermore, reported summary measures of grip strength vary widely including maximum or mean value, from one, two or three attempts, with either hand or the dominant hand alone.
Conclusions: there is considerable variation in current methods of assessing grip strength which makes comparison between studies difficult. A standardised method would enable more consistent measurement of grip strength and better assessment of sarcopenia. Our approach is described.

Keywords: *grip strength, measurement, protocol, sarcopenia, elderly*

Introduction

The European Working Party on Sarcopenia in Older People (EWGSOP) has recently reported a consensus approach to the definition and diagnosis of sarcopenia [1]. The diagnosis of sarcopenia requires low muscle mass and low muscle function (strength or physical performance) and a wide range of tools were reviewed. Grip strength was the only assessment technique recommended for the measurement of muscle strength, and was the simplest method for assessment of muscle function in clinical practice. Longitudinal studies confirm that grip strength declines after midlife, with loss accelerating with increasing age [2] and through old age [3]. As an assessment measure grip strength has been shown to have predictive validity and low values are associated with falls [4], disability, impaired health-related quality of life [5] and prolonged length of stay in hospital [6] as well as increased mortality [7, 8].

Grip strength can be measured quantitatively using a hand dynamometer. However, the methods used to characterise grip strength varies considerably, for example with regard to the choice of dynamometer or the measurement protocol used. This has the potential to introduce measurement error. The EWGSOP report recognised the challenge of determining how best to measure variables such as grip strength.We therefore conducted a literature review to evaluate the extent of variation in the method of assessment of grip strength, and the potential effect on values reported.

Methods

A literature search of Medline, Web of Science and Cochrane Library databases was conducted by two researchers independently and then combined. The search terms used were (i) grip strength and frail/elder/protocol/measurement/methods/jamar, (ii) hand grip and frail/elder/protocol/measurement/methods/jamar, (iii) dynamometer and (iv) jamar. The full texts of all potentially relevant papers were obtained. Papers were included in the review if they described measurement of hand grip strength of human subjects aged 16 years or more and were written in English. The search included papers, conference proceedings and e-publications registered with the databases up to 31 December 2009, and the bibliographies of these articles were checked for additional relevant papers. The search terms were used until no further papers were identified. Findings on the measurement of grip strength are presented with regard to the equipment used, variation in measurement protocol and clinimetric properties of the value reported.

Results

Search results

A total of 11,604 papers were identified by the searches. The titles and abstracts of these papers were screened. In all, 189 were found to be possibly relevant and retrieved in full for detailed evaluation. One hundred and forty-seven were excluded, either because they were from a population aged 15 years or younger, or focussed on detection of insincerity of effort or grip endurance, rather than maximal strength testing. When several papers were identified that covered the same research question, the most recent paper was chosen for clarity and brevity, except once when the results were conflicting. Forty-two studies were included in the final review.

Equipment

Choice of dynamometer

Table 1 indicates the main features of the different types of dynamometer. The Jamar hand dynamometer (Lafayette Instrument Company, USA) is the most widely cited in the literature and accepted as the gold standard by which other dynamometers are evaluated [9,10]. It has the most extensive normative data [11], although data are available for other instruments such as the BTE Work Simulator [12] and the Martin Vigorimeter [13]. Excellent concurrent validity of the Jamar with known weights is reported ($r = 0.9998$ [14]; $r > 0.96$ [15]).

A review [14] of the reliability and validity of the Jamar in comparison with other grip strength measurement devices concluded that excellent inter-instrument reliability exists between the Jamar, Dexter and Baseline dynamometers, which all measure grip strength in pounds and kilograms and could be used interchangeably. There was also similar evidence between the Jamar and Rolyan hydraulic dynamometers.

Moderate to excellent reliability was found between the Jamar, the Baltimore Therapeutic Equipment (BTE) work

Table 1. Key features of hand dynamometers

Instrument type	Hydraulic	Pneumatic	Mechanical	Strain
Measures	Grip strength	Grip pressure	Grip strength	Grip strength
Based on	A sealed hydraulic system that enables grip strength to be read off a gauge dial	The compression of an air-filled compartment, e.g. a bag or bulb	The amount of tension produced in a spring	The variation in electrical resistance of a length of wire due to the strain applied to it
Example of instrument	Jamar	Martin Vigorimeter	Harpenden dynamometer	Isometric Strength Testing Unit
Units	Kilograms (kg) or pounds of force (lbf)	Milimeters of mercury (mmHg) or pounds per square inch (psi) (lb/in^2)	Kilograms (kg) or pounds of force (lbf)	Newtons of force (N)
Advantages	Portable, economical, large amount of normative data available	Gentler on weak or painful joints	No evidence for superiority presented in the literature	Are not subject to leaks (of oil/water/air), which can compromise accuracy
Limitations	Can cause stress on weak joints. Can develop slow leaks and hysteresis	These instruments measure grip pressure, which is dependent on the surface area over which the force is applied. Hand size can therefore influence the measurement	Reproducibility of the grip force measurements is limited due to difficulties in exactly replicating the grip position and in calibrating the device	Can be expensive and heavy

Information in the table is taken from [11, 61–63].

simulator and the BTE Primus and the Martin Vigorimeter, but they use different units of measurement and the BTE is not a portable machine. Similar reliability was found between the Jamar and the MicroFET 4 [16] and DynEX [17] dynamometers. Low inter-instrument reliability scores were reported between the Jamar, the sphygmomanometer and the Vigorimeter. It is unclear whether the electronic Grippit dynamometer and the Jamar can be used interchangeably [18]. Since it is the most widely used this review will now focus on the Jamar dynamometer.

Jamar dynamometer

The Jamar is small and portable but relatively heavy at 1.5 lb. The dial reads force in both kilograms and pounds, with markings at intervals of 2 kg or 5 lb, allowing assessment to the nearest 1 kg or 2.5 lb. It requires 3–4 pounds of force to make the indicator needle move, which may be inappropriate when measuring grip strength in very weak patients [19] and the reading error is reported to be greater at lower loadings. The calibration accuracy should be checked on new machines [20] and the manufacturers recommend annual or more frequent calibration if used on a daily basis.

Measurement protocol

Hand size and nail length

The Jamar is a variable hand span dynamometer with five handle positions. As shown in Table 2, most studies have used the second position for all participants. This has been assumed to be the most reliable and consistent position [10] and is the position advocated for routine use. However, hand size is important and only 60% of 214 volunteers demonstrated maximal grip strength at position two [21] and 56 healthy volunteers self-selected position two or three for maximal grip strength [22]. Handle positions one [23] and five [24] have been found to be significantly less reliable than the other positions, but for people with very small hands position one may be required [25]. Grip strength measured using the second handle position has been shown to be reduced in women with fingernails extending 1 cm or more beyond the fingertip, and for those using handle position one, grip was reduced even with finger nails projecting just 0.5 cm [26].

Hand dominance

The 10% rule used by therapists treating patients with injured hands states that the dominant hand has a 10% stronger grip than the non-dominant hand [27]. Among American and Greek volunteers this was true for right-handed people but for left-handed people grip strength was equal in both hands [21, 28], which may influence the final value where only one hand is assessed. Similarly, a review

Table 2. Examples of grip strength measurement protocols employed in studies using a Jamar dynamometer

Author and year of publication	Population (*n*)	Handle setting	Body position	Encouragement/instructions	Hands tested	Measure used
Bohannon and Schaubert 2005 [48]	Community-dwelling elders, USA (21)	2nd	ASHT recommendations	Not stated	Both	Single trial
Desrosiers *et al.* 1995 [13]	Community-dwelling elders, Canada (360)	2nd	ASHT recommendations	Standardised instructions according to Mathiowetz *et al.* (1984)	Both	Highest of three
Fried *et al.* 2001 [64]	Community-dwelling elders from the Cardiovascular Health Study (5,317)	Not stated	Not stated	Not stated	Dominant	Mean of three
Massy-Westropp *et al.* 2004 [65]	Healthy adults, Australia (419)	2nd	ASHT recommendations	Not stated	Both	Single trial
Mathiowetz *et al.* 1985 [66]	Healthy adults, USA (628)	2nd	ASHT recommendations	Standardised instructions according to Mathiowetz *et al.* (1984)	Both	Mean of three
Sayer *et al.* 2007 [67]	Community-dwelling elders from the Hertfordshire Cohort Study, UK (2,677)	Most comfortable	Subjects seated, forearms rested on the arms of the chair, wrist just over the end of the arm of the chair in a neutral position, thumb facing upwards, feet flat on the floor	Standardised encouragement given	Both	Highest of three
Werle *et al.* 2009 [68]	Community-dwelling adults, Switzerland (1,023)	2nd	ASHT recommendations	Standard instructions at a constant volume	Both	Mean of three

of 10 studies found that right dominant subjects were stronger with their right hand, whereas among left dominant subjects the results were equivocal [29].

Body position

Wrist and forearm

Richards *et al.* [30] found that varying the position of the forearm between neutral, supinated and pronated altered the grip strength. The supinated position produced the strongest force, whereas the force was weakest in the pronated position.

Elbow

Higher grip strength has been reported sitting with the elbow in 90° flexion rather than fully extended [31], and a significant difference has been reported between 45° and 90° of elbow flexion [10]. However, Su *et al.* [32] found significantly higher grip strength in 160 Chinese subjects with the elbow fully extended rather than flexed regardless of shoulder position. A Canadian study of 49 healthy right-handed Canadian men aged 60–84 years found significantly higher grip strength in the non-dominant hand with the elbow flexed to 90° rather than fully extended, but no such difference was found for the dominant hand [33].

Shoulder

Su *et al.* [34] evaluated grip strength with the elbow fully extended and 0°, 90°and 180° of shoulder flexion, and also with the elbow flexed to 90° and 0° of shoulder flexion. The highest mean grip strength was found with the shoulder in 180° of flexion, and the lowest was found with the shoulder in 0° flexion and the elbow flexed to 90°.

Posture

One study reported no significant difference in grip strength with subjects in either sitting or standing positions [35], but Balogun *et al.* [36] showed higher grip strength with college students standing rather than sitting. Hillman [37] found that readings with subjects' elbows unsupported were significantly higher than when they were supported.

The American Society of Hand Therapists (ASHT) recommends standardised positioning: subject seated, shoulders adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral and wrist between 0 and 30° of dorsiflexion [38]. The need for a standard protocol to improve the validity of assessment is illustrated by Spijkerman *et al.* [39], who found that allowing subjects to assume a comfortable position produced significantly different readings from the ASHT protocol. Table 2 summarises some of the variation in measurement protocol between studies using a Jamar hand dynamometer to measure grip strength.

Effort and encouragement

Most studies either do not report how much encouragement they give or report differing amounts (Table 2). Different methods of instruction and/or verbal encouragement can affect the performance [40] and thus introduce measurement error, as may the volume of instruction [41]. Mathiowetz *et al.* [42] have a set of standardised instructions: 'I want you to hold the handle like this and squeeze as hard as you can'. The examiner demonstrates and then gives the dynamometer to the subject. After the subject is positioned appropriately, the examiner says, 'Are you ready? Squeeze as hard as you can'. As the subject begins to squeeze, the examiner says, 'Harder!… Harder!… Relax'.

Interval between measurements

Watanabe *et al.* [43] compared the mean of two readings for each hand, measured repeatedly without rest or taken at 1 min intervals in 100 participants. During repeated measurement grip strength decreased gradually, whereas there was no change during interval measurement for either gender or hand.

Time of the day

Young *et al.* [44] reported similar values on testing grip strength in the morning and afternoon but Jasper *et al.* [45] showed a circadian rhythm in grip strength, with a minimum around 06:00 h and a maximum around 18.00 h.

Training of assessors

There is little literature on training individuals to measure grip strength, but there is evidence that assessment of grip strength by different hand therapists can be considered interchangeable, if they follow the same protocol [46]. Currently, research staff are trained prior to measuring grip strength [47] but this is typically poorly documented and not standardised across studies.

Clinimetric properties

Reliability and reproducibility

Measurements of grip strength taken with the Jamar dynamometer have evidence for good to excellent ($r > 0.80$) test–retest reproducibility [42] and excellent ($r = 0.98$) inter-rater reliability [46]. High test–retest reproducibility has been shown among older American community-dwelling volunteers (mean age 75 years) tested repeatedly over a 12-week period [48].

Number of assessments and summary measures reported

The ASHT protocol uses the mean of three trials of grip strength in each hand [38], which had higher test–retest reliability among female students than either one trial alone

Table 3. Comparison of ASHT and Southampton grip-strength measurement protocols

	ASHT	Southampton protocol
Posture	Subject seated	Subject seated, same chair for every measurement
Arm position	Shoulders adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral	Forearms rested on the arms of the chair
Wrist position	Wrist between 0 and 30° of dorsiflexion	Wrist just over the end of the arm of the chair, in a neutral position, thumb facing upwards
Lower extremity position		Feet flat on the floor
Encouragement		'I want you to squeeze as hard as you can for as long as you can until I say stop. squeeze, squeeze, squeeze, stop' (when the needle stops rising)
Number of trials		Three trials on each side, alternating sides
Score to use		Maximal grip score from all six trials used

or the maximum of three trials [42]. However, Hamilton *et al.* [23] found similar test–retest reliability with one trial alone, the mean of two or three trials and the maximum of three trials. A recent UK study found that one trial was as reliable and less tiring than three trials [49].

Responsiveness

Nitschke *et al.* [50] evaluated test–retest reliability in the maximum grip strength of 32 healthy women and pain-free grip in 10 disabled women. The measurement variation between tests was ±5.7 and ±5.9 kg for the healthy and disabled women, respectively. They proposed a minimal significant change of 6 kg. Similarly, studies identifying recovery after stroke estimate the difference in repeat measures of hand grip strength to be between 4.7 kg [51] and 6.2 kg [52].

However, significant clinical change may be obscured by measurement variation. The clinical meaning of change in grip strength over time has been evaluated using the standardised mean response, calculated as the mean change in score/standard deviation of that change [53]. Other authors have similarly used the effect size, calculated as the difference between the mean (median) values of grip strength 'after' and 'before', divided by the standard deviation (inter-quartile range) of the 'before' measurement [54]. For both measures a value of 0.2–0.5 is considered a low responsiveness, 0.51–0.8 is moderate and >0.8 shows a high level of responsiveness.

Discussion

This review consisted of a wide search using many terms, conducted by two independent researchers. The search included original articles as well as reviews, reports and conference proceedings, though these were restricted to articles written in English language. It demonstrated that the choice of equipment and measurement protocol for assessing grip strength varies widely between studies. The Jamar hand dynamometer is the most widely cited instrument in the literature, appears to be generally accepted as the gold standard by which other dynamometers are evaluated, and has the most normative data.

The absolute values and precision of grip strength measurements can be influenced by aspects of the protocol such as allowance for hand size and dominance, posture, joint position, effort and encouragement, frequency of testing and time of day, and training of the assessor. In addition, inconsistencies in the number of assessments and variable use of the maximum or mean grip strength as a summary measure limit comparison of results between epidemiological studies. For example, with multiple attempts, the maximum grip strength will be greater than the mean value.

Differences in protocol and summary measures used in different studies may affect not only the precision and reproducibility of the measurements but also the ability to compare absolute values reported for grip strength between different study populations. A recent systematic review published in this journal highlights the problems of drawing conclusions from studies where physical capability measures and outcomes have been assessed and categorised in different ways [55].

Grip strength testing is likely to be increasingly used in clinical settings, for example in the assessment of sarcopenia [1, 56], frailty and undernutrition [15] in hospitalised older people. A study by Puig-Domingo *et al.* [57], evaluating muscle strength and successful ageing, found it to be a helpful clinical evaluation tool and a Japanese study investigating the optimal physical or cognitive test to screen for falls risk in frail older people found that the most practical physical test was grip strength [58]. However, the use of differing protocols in research studies can lead to confusion among clinicians regarding what constitutes best practice, and the feasibility and acceptability of measuring grip strength in different healthcare settings is not established [59]. The development of accurate and standardised reference values is essential as clinicians aim to identify individuals at increased risk of adverse outcomes within a given population [60].

We suggest that a standardised method is needed to enable more consistent measurement of grip strength and better assessment of sarcopenia. This has been previously proposed by the American Society of Hand Therapists [38]

Figure 1. Southampton protocol for adult grip strength measurement.

(1) Sit the participant comfortably in a standard chair with legs, back support and fixed arms. Use the same chair for every measurement. (2) Ask them to rest their forearms on the arms of the chair with their wrist just over the end of the arm of the chair—wrist in a neutral position, thumb facing upwards. (3) Demonstrate how to use the Jamar handgrip dynamometer to show that gripping very tightly registers the best score. (4) Start with the right hand. (5) Position the hand so that the thumb is round one side of the handle and the four fingers are around the other side. The instrument should feel comfortable in the hand. Alter the position of the handle if necessary. (6) The observer should rest the base of the dynamometer on the palm of their hand as the subject holds the dynamometer. The aim of this is to support the weight of the dynamometer (to negate the effect of gravity on peak strength), but care should be taken not to restrict its movement. (7) Encourage the participant to squeeze as long and as tightly as possible or until the needle stops rising. Once the needle stops rising the participant can be instructed to stop squeezing. (8) Read grip strength in kilograms from the outside dial and record the result to the nearest 1 kg on the data entry form. (9) Repeat measurement in the left hand. (10) Do two further measurements for each hand alternating sides to give three readings in total for each side. (11) The best of the six grip strength measurements is used in statistical analyses so as to encourage the subjects to get as high a score as possible. (12) Also record hand dominance, i.e. right, left or ambidextrous (people who can genuinely write with both hands). Equipment: Model J00105 JAMAR Hydraulic Hand Dynamometer.

but not universally adopted, as can be seen from Table 2. A standardised protocol could improve the measurement of grip strength by not only increasing the precision of measurements within any given study (thereby increasing statistical power to detect associations between grip strength and clinical characteristics), but also enabling the generalisability of results across study populations.

We have a well-established protocol for measurement of grip strength in large epidemiological studies of older people which is based on the ASHT protocol. Our protocol additionally standardises for leg and forearm position, encouragement and assessor training and clearly states the summary measures used (Table 3, Figure 1). We share this protocol to stimulate discussion towards a consensus for the measurement of grip strength.

Key points

- A consensus approach to the definition and diagnosis of sarcopenia has recently been proposed and includes the measurement of grip strength.
- There is considerable variation in current methods of assessing grip strength, which makes comparison between studies difficult.
- A standardised method would enable more consistent measurement of grip strength and better assessment of sarcopenia. Our approach is described.

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Conflict of interests

None declared.

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Supplementary data

Supplementary data mentioned in the text is available to subscribers in *Age and Ageing* online.

References

The very long list of references supporting this review has meant that only the most important are listed here and are represented by bold type throughout the text. The full list of references is available as a supplementary data on the journal website http://www.ageing.oxfordjournals.org/ as Appendix 1.

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Finding the right outcome measures for care home research

SIR—Hoppitt, Sackley and Wright (*Age and Ageing* January 2010) report the results of their trial of therapy for UK care home residents, concluding that there is a lack of appropriate outcomes available for the care home population, and a need for validation of existing measures and development of alternatives in this population.

These conclusions were based on the response rates at three time intervals for measurements of hand grip strength, the Timed Up and Go test, the Falls Efficacy Scale and calcaneal ultrasound densitometry. These measures all had lower response rates than those for the Barthel Index and Rivermead Mobility Index, both of which were completed by proxy where required. Response rates for handgrip varied from 60% (intervention group) and 66% (control group) initially, reducing to 46% and 51% for each group at the third time interval. The authors state that cognitive impairments made it impossible to follow the instructions, while physical impairments meant that some participants were unable to attempt the hand grip.

We recently evaluated the feasibility and acceptability of hand grip strength measurement using a Jamar handheld dynamometer among residents of care homes in Hampshire (BUPA and privately owned). A total of 64/133 (48%) residents from three nursing homes and one dementia registered residential care home participated [mean age 86 years (range 70–98); 18 men, 46 women]. Sixty-two (47%) potential participants were excluded because severe dementia precluded informed consent for the trial, but those with mild to moderate dementia were able to participate (mean Mini-Mental State Examination score 19/30 points, range 6–30). Three (2%) participants were excluded for physical reasons: total deafness (two) and advanced motor neurone disease (one).

Sixty-three of 64 (99%) participants were able to have grip strength measured and hold the dynamometer with both hands; the remaining participant had a fractured arm. Sixty participants answered questions on the acceptability of hand grip assessment, of which 56 (92%) were definitely prepared to repeat, although four (7%) found it painful and 10 (17%) tiring. Additional in-depth interviews with four residents revealed that they found the test straightforward to carry out and had squeezed the dynamometer as hard as they could.

We agree with the authors' conclusions that researchers should select outcome measures that are appropriate for use in the intended population, but our research suggests that assessment of hand grip strength is acceptable and feasible in care home populations. Further research is required to fully evaluate the utility of this measurement.

Conflict of interest

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Reply to Roberts *et al*'s response

SIR—We are writing in response to Roberts *et al.*'s (*Age and Ageing* E-letter 2010) reaction to our article 'Finding the right outcome measures for care home research'. Our original article concluded that outcome measures should be selected that have been validated in the population being studied, and that there is a lack of appropriate outcome measures for use with care home populations. Although Roberts *et al.* concurred that measures appropriate to the population should be selected, based on their findings and contrary to our research, they argued that the assessment of handgrip is acceptable and feasible in care home populations. They reported response rates of 99% being able to complete grip strength measurements with both hands. Furthermore, they reported that whilst 7 and 17% found the measure painful and tiring, respectively, 92% were prepared to repeat the measure. Roberts *et al.* suggest that their results show grip strength assessment is acceptable and feasible in care home populations. However, we suggest that in reality, the response rates reported in their research are comparable to those observed in our study. Our study achieved completion rates ranging from 45 to 70% across all assessment time points taking into account both hands assessed. These rates were reported from the total sample size randomised. Unlike Roberts *et al.*, we did not exclude anyone from attempting to complete this measure based on cognitive or physical impairment. Informed assent was gained for those unable to provide consent. Roberts *et al.* excluded 47% of potential participants due to severe dementia precluding informed consent, and a further 2% as a result of physical limitations. The response rate based on their total sample size was 64/133 (48%), which is comparable to the completion rates we found at follow-up assessment. We conclude that whilst Roberts *et al.*'s suggestion, that hand grip is feasible in care home populations, is accurate for those residents without major cognitive or physical impairments, it does not enable assessment of the general care home population due to the high prevalence of such impairments in this setting.

Conflict of interest

None declared.

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age and ageing

MEASURING GRIP STRENGTH IN DIFFERENT COMMUNITY HEALTH AND SOCIAL CARE SETTINGS: WHAT ARE MEDIAN VALUES AND INTER-QUARTILE RANGES AMONG PATIENTS UNDERGOING IN-PATIENT AND OUT-PATIENT REHABILITATION, ATTENDING A PARKINSON'S DISEASE CLINIC, AND NURSING HOME RESIDENTS?

H C Roberts[1,2], J Ritchie[2], J Butchart[2], J Sparkes[2], K A Jameson[2], A A Sayer[1,2,3]

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Introduction

Normative values are established for general populations of community dwelling older people where low grip strength predicts poor outcomes. They are not known for people presenting to health or social care services where identification of those with low grip strength, who might be at most risk of adverse outcomes, could allow delivery of individualised programmes to maximise patients' potential with optimum use of resources.

Methods

Consent to measure grip strength using handheld dynamometry was obtained from patients in four health and social care settings: in-patient rehabilitation, out-patient rehabilitation, Parkinson's disease clinic and nursing home. All participants lived in the same town. Additional information was collected using the Strawbridge frailty questionnaire, the Barthel score and the Mini Mental State Examination.

Results

The numbers of patients recruited, age, grip strength and functional scores results are shown for each setting in the table below:

	In-patient rehabilitation n=101	Out-patient rehabilitation n=47	PD clinic n=57	N Home residents n=100	p-value
Age (years) Mean (SD)	84.1 (6.1)	79.3 (5.6)	71.8 (7.8)	86.7 (6.9)	<0.001
Grip strength (kg) - Men Median (IQR)	22 (17,27)	32 (27,36)	39 (31,44)	14 (8,20)	<0.001
Grip strength (kg) - Women Median (IQR)	14 (11,16)	20 (15,24)	25 (14,28)	6 (4,9)	<0.001
Frail N (%)	50 (53%)	29 (66%)	32 (56%)	84 (84%)	<0.001
Barthel Score (100 points) Median (IQR)	66 (43,80)	99 (95,100)	98 (93,100)	45 (31,62)	<0.001
MMSE Score (30 points) Median (IQR)	25 (20,27)	28 (25,30)	29 (28,30)	16 (13,24)	<0.001

Conclusions

Grip strength varied significantly between patients in these four distinct health and social care settings, indicating the need for normative ranges of grip strength for different patient groups. Further research is needed to explore the association of grip strength with clinical outcomes within each setting.

THE ACCEPTABILITY OF GRIP STRENGTH ASSESSMENT IN FOUR HEALTH AND SOCIAL CARE SETTINGS

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Introduction
Grip strength has been used to characterise sarcopaenia in community dwelling older people participating in research. It is not used in routine clinical practice in the

Methods
Grip strength was assessed three times in each hand on participants in a series of clinical settings as follows: in-patient rehabilitation (n=100), out-patient rehabilitation (n=47), Parkinson's disease (PD) clinic (n=57), three local care homes (n=44). Within one week of assessment, a purposive sample of 20 participants consented to a semi-structured interview about their experience of grip testing. The interview was recorded, transcribed and analysed on a thematic basis.

Results
20 participants with a Mini Mental State Examination of >20 were interviewed as shown below.

Setting	Number of interviewees (M:F)	Median Age (Range)
In-patient	6 (4:2)	89 (83 - 92)
Out-patient	2 (0:2)	83 (79 – 86)
Parkinson's	8 (5:3)	74 (63 – 79)
Nursing Home	4 (1:3)	85 (81 – 91)

Participants found grip strength testing straightforward. All squeezed their hardest and were prepared to have the test repeated. Six participants (inpatients, PD) felt the dynamometer would be heavy if unsupported. No-one reported grip strength testing to be painful or uncomfortable. Two participants (inpatient & PD) thought it would become tiring after multiple attempts.
Participants variously felt their first or last attempts were better and all except two felt their dominant hand was stronger. Only one participant (inpatient) associated grip strength with general muscle strength. Most welcomed routine assessment as an opportunity to improve their health but two (with PD) commented that confirming increasing weakness might be worrying.

Conclusions
Participants from a range of settings found grip strength assessment acceptable. This supports the use of grip strength testing in clinical practice.

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IS THE ASSESSMENT OF GRIP STRENGTH FEASIBLE AND ACCEPTABLE IN A COMMUNITY HOSPITAL?

HC Roberts[1,3], J Ritchie[3], J Butchart[3], J Sparkes[3], D Padiarchy[3], H Syddall[2], K Jameson[2], A A Sayer[1,2,3]

Academic Geriatric Medicine[1], MRC Epidemiology Resource Centre[2], University of Southampton; Medicine for Older People, Southampton University Hospitals NHS Trust[3], UK

Introduction

Grip strength has been identified as a single marker of physical frailty and biological ageing.
Low grip is associated with adverse outcomes – falls, admission to hospital, poor health related quality of life and death.
Grip strength is measured in research studies but is not routinely assessed in clinical practice, where it might be useful to stratify patients and allow appropriate focus of resources.

Figure 1. Assessment of grip strength

Research Question

Is the assessment of older people's grip strength feasible and acceptable in patients undergoing in-patient rehabilitation in a community hospital?

Methods

Patients aged 70 years and over admitted to a community hospital from acute hospitals or their own homes for rehabilitation were prospectively recruited to the study within 1 week of admission.
Patients admitted for terminal care or who were unable to give written informed consent or grip the dynamometer were excluded.
Maximal grip strength was assessed three times with each hand one minute apart using a Jamar dynamometer.
A Mini Mental State Examination (MMSE) and a questionnaire on pain / tiredness associated with using the dynamometer were administered.
Descriptive statistics were used to describe the study population and analyse the results.
Full ethical approval was obtained.

Results: Participants

100 / 160 eligible patients participated in the study (63%): 37 men, 63 women: median age 83.6 years (range 70 – 99).
Median grip strength was 16.6 Kg (range 2 – 39).

Results: Feasibility of routine grip assessment

1. Number of potential participants excluded

60 patients (37%) were excluded: 28 (17%) for patient reasons (12 too unwell, 12 very confused, 4 refused)
32 (20%) for organisational reasons (11 discharged/transferred before review, 21 could not be seen by single assessor within 1 week).

2. Difficulties using the dynamometer

Only one patient with advanced peripheral neuropathy of the hands could not grip the Jamar dynamometer.
Patients with hemi-paresis / arm fractures and arthritis could all grip with at least one hand.
Patients with lower MMSE scores (median 23.0, range 7 – 30) could participate with clear instruction and demonstration.

3. Equipment issues

The dynamometer is robust but needs accuracy checking at least annually.
Test-retest reliability was high for ten people with low grip (< 15Kg) with a mean variation of 0.4Kg between two assessments a few days apart.
The assessment took a few minutes and could be undertaken in a chair or in bed.

Results: Acceptability of routine grip assessment

Only 3 / 100 patients did not want to repeat the grip assessment.
It did not cause pain or tiredness in 90% of patients, but was uncomfortable for some patients with arthritic hands.

Conclusions

Assessment of grip strength was feasible and acceptable in this study of community hospital in-patients.
Further research is required to establish normal ranges and quintiles for his group, and whether low grip strength is associated with poor outcomes as has been found with community dwelling older people.

Acknowledgements: we are grateful to the participants and staff who helped with this study

Appendix 2 Study Protocol

(REC ref: 07/H0504/176)
TITLE: Study to evaluate the clinical use of hand grip strength to identify frail and "pre-frail" elderly people in different healthcare settings.

Principal Investigator: Dr Helen Roberts
Co-investigators: Prof A Aihie Sayer, Prof C Cooper, Dr H Syddall, Dr N Chambers, Mrs A Horsman,Prof J Powell

Background

Frailty is recognised as a multidimensional syndrome of impaired physical, cognitive, psychological and social functioning (1). Methods of assessment include self-report, clinical judgement and the use of objective performance measures such as grip strength and gait speed. A more statistical approach has also been developed which involves the summation of total impairments (2). All of these methodologies have a high predictive value for adverse outcomes such as disability, hospitalisation and mortality (3).

Sarcopaenia (reduction of skeletal muscle mass and function with age) is central to the development of frailty. There is an increasing recognition of the serious health consequences of loss of muscle strength both in terms of disability (4), morbidity (5) and mortality (6) and in terms of significant healthcare costs (7). It is one of the major risk factors for falls (8), and one study has reported an association between low muscle mass and lower general health score (9). Grip strength is a useful clinical marker of sarcopaenia, and recent work has demonstrated that grip strength is more strongly associated with age and is a better predictor of poor mobility than other potential markers of sarcopaenia such as calf muscle area (10).

Grip strength has been proposed by our group as a useful single marker of generalised frailty and biological ageing (11). It is associated with ageing in a wide range of body systems and may be a good marker of underlying ageing processes because of the rarity of muscle-specific diseases contributing to change in muscle function. Epidemiological studies have shown that grip strength in mid-life (4, 6) and later years (12) can predict functional decline and disability as well as mortality. Longitudinal studies confirm that grip strength in men and women declines across all age groups, with the loss accelerating with increasing age (13,14). Grip strength is known to be related to height and weight loss, gender, nationality (15), serum levels of albumin, 25-hydroxyvitamin D and PTH (16,17) as well as age. Lower grip strength is associated with falls (18), all-cause mortality (19), and with reduced health related quality of life in older men and women (20). Lower grip strength has been shown to be associated with longer lengths of hospital stay among elderly medical in-patients (21).

Despite this body of evidence grip strength is not yet measured in clinical practice. The feasibility of translating this research tool to clinical settings is unknown. Normative data is available for hospital in-patients in the UK (21) and for healthy community dwelling adults (20), but none are available for older people undergoing rehabilitation, who are most likely to be on the threshold of frailty, and for whom intervention to avert further deterioration is crucial.The availability of a single measure that could be used by primary care staff, district nurses etc as well as trained rehabilitation staff would be invaluable. Recognition of frailty and pre-frailty in clinical practice would allow the current provision of appropriate care and enhance the planning for future care including interventions such as the single assessment process, focussed rehabilitation and exercise programmes, specific medication etc.

Aims

1. To evaluate the feasibility, acceptability and clinimetric properties of grip strength measurement in different healthcare settings.
2. To describe typical values for grip strength in different healthcare settings.
3. To describe the clinical correlates of grip strength in different healthcare settings.
4. To evaluate grip strength as a predictor of clinical outcomes among the inpatient group.

Research plan and methodology

Study Design (1)
Descriptive epidemiological study

Study Population
Inclusion criteria
People aged 70 years and over living in Romsey and receiving care in the following healthcare settings will be invited to participate in this study:

2 In-patient rehabilitation care at Romsey Hospital
3 Community rehabilitation care from the Romsey Community Rehabilitation Team
4 Community chronic disease care from the Romsey Parkinson's Disease clinic
5 Community personal and nursing care in care homes

Exclusion criteria

6) Participants unable to give written informed consent
7) Participants unable to use the dynamometer eg arthritis, hemiplegia etc

The number of participants fulfilling these criteria will be documented as screening failures and form part of the feasibility study.

Sample size
The study is descriptive and therefore formal power calculations are not possible. However a recent study investigating the link between admission grip strength and length of hospital stay involved 100 participants (21) and we estimate that recruiting up to 100 people in each setting would be feasible and informative in this study.

Consent
Potential participants will be approached initially by their care staff, and then the researcher will explain the study and give an information sheet to those expressing an interest. An interval of at least 24 hours will be allowed to enable the people approached to come to a decision about taking part in the study and during this time any further questions will be answered.

Study setting
The in-patient and out-patient rehabilitation settings will be at Romsey community hospital in a small town with a stable population. Romsey community hospital has 20 beds and admits patients from home and from two acute hospitals (Southampton and Winchester). There is a community rehabilitation team (therapy-centred) and a community rapid response service (nursing care centred) based in the hospital. A Parkinson's disease clinic is held monthly in the hospital and there is an active Parkinson's disease society in the locality. Parkinson's disease is chosen as a long-term condition associated with increasing frailty. Care homes in the Romsey area will be approached.

Data collection
Grip strength will be measured using a standardised methodology and additional demographic and clinical information as listed below will be collected to identify potential important influences on grip strength.

Case record review
In each setting the case records (hospital notes/community notes/care home records) will be reviewed by the researcher and the following data abstracted:

5) demographic details including date of birth, gender, hospital record number
6) co-morbidities (active medical problems impacting on function)
7) current medications

Clinical assessment
In each setting the following assessments will be made directly by the researcher:

8) Grip strength will be measured three times on each side, alternating between right and left hands, using a Jamar handgrip dynamometer (Promedics, Blackburn, UK). Participants will be given standardised encouragement to squeeze the dynamometer as hard as possible. The repeat measures will allow both practice and tiring effects to be apparent for an individual. The dynamometers will be calibrated at the start of the study and annually thereafter. The best of the six grip measurements will be used to characterise maximum muscle strength.
9) Forearm length will also be measured as a proxy for height to allow adjustment of grip strength for size (22).
10) Strawbridge frailty score (23)
11) 100 point Barthel Score to assess physical function (24)
12) Number of self-reported falls in the previous 12 months
13) MUST nutritional score (25)
14) Mini-mental state examination to assess mental function (26)

Participants will be assigned a study identification number, and neither name nor hospital number will be entered onto the study database.

Feasibility of grip strength assessment
In each setting the number of potential participants fulfilling the exclusion criteria will be documented, as will difficulties in using the dynamometer e.g. understanding the instructions, holding the dynamometer, tiring etc, as well as equipment failure, issues with calibration etc.

Data analysis
A database will be created by double entry data followed by data cleaning, and prepared for use with the STATA version 9 statistical package. Descriptive analysis (summation, percentages, means, medians and ranges) will be used to summarise grip strength, demographic data and the characteristics of participants in each setting. The feasibility of grip strength assessment within each setting will be analysed using descriptive statistics (summation, percentages) as well as the qualitative data derived from study 2 below.

Study Design (2)
Qualitative study

Data Collection

Individual interviews will be conducted with a purposive sample of patients from each setting, selected to represent a range of age, gender, and grip strengths. They will be interviewed in private, with a family member/carer to support them if they wish. In a conversational manner the interviewer will aim to capture their experiences and views, as indicated in the semi-structured interview schedule.

Data analysis

The patient interviews will be audio-taped with express consent from the participants and the audiotapes will be transcribed verbatim. Using grounded theory techniques the tapes will be evaluated for themes, looking for commonality and differences within and between the health care settings. Themes that emerge from early interviews will be explored in subsequent ones for validity in those settings.

Dissemination
The study findings will be disseminated locally through presentations to primary and secondary healthcare staff and managers. The findings will be published in peer reviewed scientific journals and presented at regional and national scientific meetings. The study findings will also be presented to local branches of the Parkinson’s disease society and Help the Aged, and to the care homes assisting with the study.

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Appendix 3 Patient Information Sheet

PATIENT INFORMATION SHEET

Study to evaluate the clinical use of hand grip strength in different healthcare settings.
LREC number: 07/H0504/176

We would like to invite you to take part in a research study. Before you decide we would like you to read the following information in order for you to understand why the research is being done and what it will involve.
Part 1 tells you the purpose of this study and what will happen to you if you take part.
Part 2 gives you more detailed information about the conduct of the study.
Take time to decide whether or not you wish to take part.

PART ONE

What is the purpose of the study?

The purpose of the study is to find out about the grip strength of people over 70 years of age. We want to know if it is possible to measure peoples' grip strength in different care settings, and what training healthcare staff require to be able to measure grip strength properly. We will also find out participants' views on whether measuring grip strength could improve the healthcare of older people.

'Grip strength' means how hard you can squeeze with each hand. Low grip strength may predict an increased risk of future illness and so might allow interventions to avoid this. Grip strength is not currently measured in routine practice and we do not know if this would be a practical thing to do. We also do not know what training is needed for the staff that would be testing people's grip strength. This study would involve one visit by a researcher to measure your grip strength and ask you some questions about yourself. A few people would also be approached to take part in an additional discussion about the measurement process.

Why have I been chosen?

You are being asked to take part in this study because you are either in hospital at the moment, receiving therapy at the moment, attending the Parkinson's Disease clinic at Romsey Hospital, or are living in a care home. We will be recruiting 100 people from each of these categories.

Do I have to take part?

No, it is up to you to decide whether or not to take part. If you do, you will be asked to sign a consent form. You are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

What will happen to me if I take part?

If you decide to take part, you will have one interview with a researcher. Your grip strength will be measured using a piece of equipment called a dynamometer. We will record three squeezes with each hand. It is not painful to perform the test. We will also record some information about you such as your date of birth, hospital number, medications you are taking, any recent falls and any medical conditions you have. We would also like to measure the length of your forearm so that we can account for tall and small people having different grip strengths. We will also ask you to complete a few questionnaires to assess your mental function, level of nutrition and physical function.
A few people will be approached to have an additional interview to ask about their opinions on the grip strength test.

Are there any risks associated with taking part?

There are no risks in taking part in this research.

What are the possible benefits of taking part?

The results of the grip strength test will be made available to the care staff looking after you. The main benefit however is that the information we get may help us to treat future patients better.

Will my taking part in the study be kept confidential?

Yes, all the information about your participation in this study will be kept confidential. The details are included in Part 2.

Contact details: **Dr Helen Roberts telephone 023 8079 4354**
Southampton General Hospital

This completes Part 1 of the Information Sheet.

If the information in Part 1 has interested you and you are considering participation, please continue to read the additional information in Part 2 before making any decision.

PART TWO

What will happen if I don't want to carry on with the study?

You can let us know at any time if you do not wish to participate in the study and your data will be removed from our records.

What if there is a problem?

If you have any cause for concern regarding your participation in the trial, please contact one of the researchers in the first instance (see contact details Part 1). If this is unsatisfactory, they will be able to direct you to an alternative person who will be able to help.
If you have a complaint which cannot be resolved by these measures, you may wish to complain formally. You can do this through the NHS Complaints Procedure. Details can be obtained from the hospital.

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. The researchers carrying out this study will have access to your information which will be stored on a password protected anonymised database.
Any information about you will have your name and address removed so that you cannot be recognised from it. In the analysis of results, your data will be used anonymously. Our procedures for handling, processing, storing and destroying data relating to your participation in the study are compliant with the Data Protection Act 1998.

Your GP (or your hospital consultant if you are in hospital) will be told that you are taking part in the research.

What will happen to the results of the research study?

The results of the research will be published in medical scientific journals. Research staff may also present the results at conferences and local meetings. You will not be identified in any report produced.

Who is organising and funding the research?

The study is organised by the Healthy Ageing Group at the Medical Research Council Epidemiology Resource centre in the University of Southampton, based at Southampton General Hospital. The study is the basis of a higher degree for the researcher, and so is funded by the University of Southampton.

Who has reviewed the study?

This study was given a favourable ethical opinion for conduct in the NHS by the Southampton and Southwest Hampshire Research Ethics Committee, and has been reviewed by the research and development team at Southampton University Hospitals NHS Trust.

This information sheet is for you to keep.

If you decide to take part you will be given a copy of the consent form which you sign when you agree to participate in the study.

Thank you very much for reading this information and considering taking part in the study.

Appendix 4 Letter of invitation

Date…………

Dear …………….

Re: Study to evaluate the clinical use of hand grip strength in different healthcare settings. REC ref: 07/H0504/176

I would like to invite you to take part in this study. The attached information sheet tells you in detail why we are doing this study and what we would ask you to do. Feel free to discuss this with your family/friends/colleagues, or to contact me on the telephone number at the bottom of the letter if you have any questions. I will in any case be in touch in the next few days to answer any questions and to see if you wish to take part.

Thank you for taking the time to read this.

with best wishes

Yours sincerely

Dr Helen Roberts
Senior Lecturer / Hon Consultant in Geriatric Medicine
Medicine for Older People
G level West Wing
Southampton General Hospital

Tel: 023 8079 4354

Appendix 5 Consent Form

Study to evaluate the clinical use of hand grip strength in different healthcare settings.

LREC number: 07/H0504/176
Patient identification number:
Name of Researcher: Dr H Roberts

1	I confirm that I have read and understand the information sheet dated 26 September 2007 (version 1) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.	☐
3	I understand that relevant sections of any of my medical notes and data collected during the study, may be looked at by responsible individuals from Southampton General Hospital, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.	☐
4	I agree to my GP being informed of my participation in the study.	☐
5.	I agree to the audio-taping of any interview with the researcher	☐
6	I agree to take part in the above study.	☐

……………………………………	……………………	…………………………
Name of patient	Date	Signature
……………………………………	……………………	…………………………
Name of person taking consent (if different from researcher)	Date	Signature
……………………………………	…………………….	…………………………
Researcher	Date	Signature

1 copy for patient, 1 for researcher, 1 for medical notes

Appendix 6 Data collection Sheet

Participant ID number

1			

Date of admission (dd/mm/yyyy)
Date of Interview (dd/mm/yyyy)
Date of birth (dd/mm/yyyy)
Participant gender (m=1, f=2)

Active co-morbidities (PRINT)

…………………………………………
…………………………………………
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Current medications including OTC (PRINT NAME ONLY)

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Participant ID number

1			

No. of self reported falls last 12 months ☐☐☐

Forearm length (cm) ☐☐☐ • ☐

Height (cm) ☐☐☐

Grip strength (kg)
3 X both sides alternately
(record to nearest 1kg)
RIGHT *(always start with R hand)* ☐☐

☐☐

☐☐

LEFT ☐☐

☐☐

☐☐

Hand dominance (L=1, R=2, both=3) ☐

Strawbridge Frailty Questionnaire

Q1. Have you had a problem with the following in the last 12 months?

1 = Rarely or never **2 = Sometimes** **3 = Often** **4 = Very often**

i) Sudden loss of balance? ☐

ii) Weakness in the arms? ☐

iii) Weakness in the legs? ☐

iv) Dizziness when standing up quickly? ☐

Participant ID number

1			

Q2. Have you had a problem with the following in the last 12 months?

1 = Rarely or never 2 = Sometimes 3 = Often 4 = Very often

i) Loss of appetite? ☐

ii) Unexplained weight loss? ☐

Q3. Have you had a problem with the following in the last 12 months?

1 = Rarely or never 2 = Sometimes 3 = Often 4 = Very often

i) Paying attention? ☐

ii) Finding the right word? ☐

iii) Remembering things? ☐

iv) Remembering where you put something? ☐

Q4. Have you had difficulty with the following in the last 12 months?

1 = No difficulty 2 = A little difficulty 3 = Some difficulty 4 = A great deal of difficulty

i) Reading a newspaper? ☐

ii) Recognizing a friend across the street? ☐

iii) Reading signs at night? ☐

iv) Hearing over the phone? ☐

v) Hearing a normal conversation? ☐

iv) Hearing conversation in a noisy room? ☐

☐

Participant ID number

1			

Barthel ADL Questionnaire

Q5 Hygiene (washing & grooming)
0 = dependent in all aspects
1 = assistance required in all steps
3 = some assistance required in one or more steps
4 = able to conduct own hygiene but needs min assistance before/after
5 = able to wash hands, face, comb hair, teeth and shave

☐

Q6 Bathing (bath or shower)
0 = Total dependence
1 = assistance required in all aspects
3 = assistance requires with transfer or washing/drying
4 = supervision for safety in adjusting water temp/transfer
5 = able to take all steps without anyone present

☐

Q7 Feeding

0 = dependent in all aspects and needs to be fed
2 = someone must provide active assistance, patient may hold cutlery/cup
5 = able to feed self with supervision. Requires help with adding sugar etc
8 = independence in feeding with prepared tray, may need meat cutting
10 = able to feed self, cut food, spread butter etc

☐☐

Q8 Toilet

0 = dependent in all aspects of toileting
2 = assistance required in all aspects (a lot of physical help)
5 = assistance required with clothing/transferring/washing hands
8 = supervision may be required for safety. ? night commode, needs help emptying
10 = able to get on & off toilet/manage clothing/use paper without help. Empty and clean commode if used

☐☐

Q9 Stairs

0 = unable to climb stairs
2 = assistance required in all aspects (needs physical help)
5 = able to ascend & descend, unable to carry aids & needs supervision
8 = generally no assistance requires, ? supervision at times for safety
10 = able to go up & down without supervision, carrying aids if needed

☐☐

Participant ID number

1			

Q10 Dressing

0 = dependent in all aspects, unable to participate
2 = able to participate to some degree but dependent in all aspects
5 = assistance needed for putting on/removing any clothing
8 = minimal assistance required eg for buttons, zips, bras, shoes etc
10 = independent in all aspects

Q11 Bowels

0 = incontinent (all the time)
2 = needs help to sit on toilet/commode
5 = cannot clean self, accidents (3+/week), needs help with pads
8 = may require supervision with suppositories/enemas, accidents 1-2/week
10 = independent

Q12 Bladder

0 = dependent. Incontinent/indwelling catheter which can't manage
2 = incontinent but able to assist with catheter bag/convene, pads etc
5 = generally dry by day but not night. Needs assistance with devices
8 = generally dry by day & night. Occasional accident. Min help with devices
10 = able to control bladder day & night. Independent

Q13 Transfer

0 = unable to participate in transfer. Requires 2 people with/without aid
3 = maximum assistance of 1 person in all aspects (lot of physical help)
8 = assistance of 1 person in some aspect (little physical help)
12 = presence of 1 person for confidence/supervision
15 = independent in all aspects

Q14 Walking

0 = dependent in walking (unable)
3 = constant presence of 1+ persons required (lot of physical help)
8 = 1 person to offer assistance (little physical help)
12 = independent in walking but **unable** to walk 50m without help/supervision
15 = independent in all aspects and **able** to walk 50m alone

Participant ID number

1			

Q15 Wheelchair (only use this section if patient rated 0 in walking & trained in wheelchair management)
0 = dependent in wheelchair ambulation
1 = can self propel short distances on flat surface. Assistance required for all other steps
3 = presence of 1 person, constant assistance required to manipulate chair
4 = can propel for reasonable duration. Min assistance with 'tight corners'
5 = able to self propel independently 50m, manoeuvre round corners

MUST Nutritional Score
Reported usual weight (Kg)

Reported current weight (Kg)

BMI (Kg/m^2)

BMI score: (>20 = 0, 18.5-20 = 1, <18.5 = 2)

Weight loss score (unplanned last 3-6 months:<5%= 0, 5-10%= 1, >10%= 2)

Acute disease score (add 2 if been/likely no intake for > 5days)

MUST Score (add BMI score, wt loss score & acute disease score)

Participant ID number

1			

<u>**Mini-Mental State Examination (MMSE)**</u>

Orientation (5 points each question)

1. Ask the patient: “What is the year, month, day, date, time of day?”

2. Ask: “What country, town, district, hospital, ward are you in?”

Memory Registration (3 points)

3. Name 3 objects. Ask the patients to repeat the 3 objects. (score 3 points if correct first time, 2 if correct second time and 1 if correct third time). Ask the patient to remember the 3 objects

Attention and calculation (5 points)

4. Ask the patient to subtract 7 from 100, then repeat from the result, etc. Stop after five -100. 93, 86, 79, 72, 65. Score 1 point for each correct answer

(Alternatively :ask the patient to spell ‘world’ backwards. DLROW. Score 1 point for each correct answer)

Recall (3 points)

5. Ask the patient to recall the three objects learnt earlier

Language (2 points)

6. Show the patient 2 familiar items (pen & watch) and ask to name them, 1 point each

7. Ask the patient to repeat ‘No ifs, ands or buts’ (1 point)

Participant ID number

1			

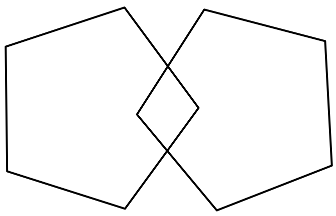
8. Ask the patient to follow a three-stage command. Score 1 point for each stage (eg. 'Place index finger of right/left hand on your nose, and then on your left/right ear') 3 points

9. Ask the patient to read and obey a written command on a piece of paper : 'Close your eyes'- 1 point

10. Ask the patient to write a simple sentence. Score if it is sensible and has a subject and a verb(1 point)

Copying

11 Ask patient to copy a pair of intersecting pentagons (1 point)



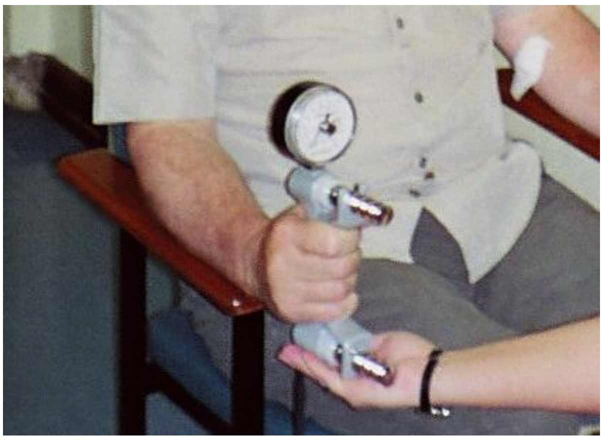
CLOSE YOUR EYES

Total MMSE Score (out of 30)

Would you do this test again (yes=1, no = 2, maybe = 3)	
Were you in pain (yes=1, no=2)	
Did it tire you (yes=1, no=2)	

Appendix 7. Protocol for grip strength measurement in adults

1. Sit the participant comfortably in the chair with their forearms on the arms of the chair and their wrist just over the end of the arm of the chair – wrist in a neutral position, thumb facing upwards. Feet flat on the floor.
2. Demonstrate how to use the dynamometer to show that gripping very tightly registers the best score.
3. Starting with the right hand position the thumb around one side of the handle in position 2 and the four fingers are around the other side. The instrument should feel comfortable in the hand: alter the position of the handle if necessary.
4. Rest the base of the dynamometer on the palm of the observer's hand as the participant holds the dynamometer. The aim of this is to support the weight of the dynamometer, but be careful not to restrict the "movement" of the machine.
5. Encourage the participant to squeeze as long and as tightly as possible or until the needle stops rising. Use a standard encouragement "and squeeze as tightly as you can". Once the needle stops raising you can instruct the participant to stop squeezing as they have achieved their peak.
6. The observer should read from the outside dial which gives grip strength in kilograms. Record the result to the nearest 1kg on the data entry form.
7. Repeat measurement in the left hand
8. Do 2 further measurements at least I minute apart in each hand alternating sides to give 3 readings in total for each side.
9. For analysis use the maximum grip score from each hand.
10. Record hand dominance i.e right, left or ambidextrous (only people who can genuinely write with both hands).



Appendix 8 Participant interview schedule

Thank you for agreeing to talk to me about the handgrip testing that was performed χ days ago. This interview is to discover how you found the testing of your hand strength but is not about the other questions you were asked. All the interviews will be anonymised but please say if you do not want anything recorded.

- Can you tell me a little about what the research project involved.
- Did you understand the instructions given to you?
- How did you find using the grip tester?
- Was it comfortable? Did you find it tiring?
- Did it get easier after the first attempt?
- Do you think you could have done any better?
- Would you be prepared to perform this test regularly at the clinic or general practice?
    - If not, why not?
- What did you think the grip tester was testing? Why?

Thank you for your help. Do you have any questions about the research or what we spoken about today? Are you happy for me to use our conversation in the research?

Appendix 9 Assessment of Jamar accuracy against known weights

Table 1. 25th April 2008

Calibration weight (N)	Calibration weight (kg)	Jamar 1 (kg) (difference)	Jamar 2 (kg) (difference)	Jamar 3 (kg) (difference)
50	5.1	4.0 (-1.1)	5.0 (0.1)	6.0 (0.9)
100	10.2	9.5 (-0.7)	10.5 (0.3)	11.5 (1.3)
150	15.3	14.5 (-0.8)	16.0 (0.7)	16.0 (0.7)
200	20.4	20.0 (-0.4)	21.0 (0.6)	22.0 (1.6)
250	25.5	25.0 (-0.5)	26.5 (1.0)	27.0 (1.5)
Mean difference		-0.7	0.5	1.2

N: Newtons; kg: kilograms

Table 2. 5th January 2009

Calibration weight (N)	Calibration weight (kg)	Jamar 1 (kg) (difference)	Jamar 2 (kg) (difference)
50	5.1	5.5 (0.4)	4.0 (-1.1)
100	10.2	10.7 (0.5)	10.0 (-0.2)
150	15.3	15.5 (0.2)	15.0 (-0.3)
200	20.4	21.0 (0.6)	20.0 (-0.4)
250	25.5	26.0 (0.5)	26.0 (0.5)
Mean difference		0.4	-0.3

N: Newtons; kg: kilograms

Table 3. 22nd April 2009

Calibration weight (N)	Calibration weight (kg)	Jamar 3 (kg) (difference)	Jamar 5 (kg) (difference)
50	5.1	6.0 (0.9)	4.0 (-1.1)
100	10.2	11.0 (0.8)	9.0 (-1.2)
150	15.3	17.0 (1.7)	15.0 (-0.3)
200	20.4	22.0 (1.6)	20.0 (-0.4)
250	25.5	27.0 (1.5)	21 (-4.5)
Mean difference		1.3	1.5

N: Newtons; kg: kilograms

Appendix 10. Research Ethics Committee application, approvals and amendments

1. Research Ethics Committee application form October 2007
2. Correspondence regarding original application
3. Approval confirmation December 2007
4. Letter confirming approval of substantial amendment May 2008
5. Letter confirming approval of substantial amendment February 2009

WELCOME TO THE NHS RESEARCH ETHICS COMMITTEE APPLICATION FORM

An application form specific to your project will be created from the answers you give to the following questions.

1. Is your project an audit or service evaluation?

○ Yes ◉ No

2. Select one research category from the list below:

○ Clinical trials of investigational medicinal products
○ Clinical investigations or other studies of medical devices
○ Other clinical trial or clinical investigation
◉ Research administering questionnaires/interviews for quantitative analysis, or using mixed quantitative/qualitative methodology
○ Research involving qualitative methods only
○ Research limited to working with human tissue samples and/or data
○ Research tissue bank

If your work does not fit any of these categories, select the option below:

○ Other research

2a . Please answer the following questions:

a) Does the study involve the use of any ionising radiation?	○ Yes	◉ No
b) Will you be taking new human tissue samples?	○ Yes	◉ No
c) Will you be using existing human tissue samples?	○ Yes	◉ No

3. Is your research confined to one site?

◉ Yes ○ No

4. Does your research involve work with prisoners?

○ Yes ◉ No

5. Do you plan to include in this research adults unable to consent for themselves through physical or mental incapacity?

○ Yes ◉ No

6. Is the study, or any part of the study, being undertaken as an educational project?

◉ Yes ○ No

6a. Is the project being undertaken in part fulfilment of a PhD or other doctorate?

(•) Yes ( ) No

NHS Research Ethics Committee NHS
Application form for research administering questionnaires/interviews for quantitative analysis or mixed methodology study

This form should be completed by the Chief Investigator, after reading the guidance notes. See glossary for clarification of different terms in the application form.

Short title and version number: (maximum 70 characters – this will be inserted as header on all forms)
Hand grip strength to identify frail elderly people version 1

Name of NHS Research Ethics Committee to which application for ethical review is being made:
Southampton and South West Hants REC 'B'

Project reference number from above REC: 07/H0504/176
Submission date: 22/10/2007

PART A: Introduction

A1. Title of the research

Full title:	Study to evaluate the clinical use of hand grip strength to identify frail and "pre–frail" elderly people in different healthcare settings.
Key words:	Grip strength, elderly people, frail, pre–frail, community

A2. Chief Investigator

Title:	Dr
Forename/Initials:	Helen
Surname:	Roberts
Post:	Senior Lecturer/Honorary Consultant
Qualifications:	BSc, MBChB, MRCP, FRCP
Organisation:	University of Southampton
Work Address:	University Geriatric Medicine Level E, Southampton General Hospital Southampton
Post Code:	SO16 6YD
E–mail:	hcr@soton.ac.uk
Telephone:	02380796130/4
Fax:	02380796134
Mobile:	

A copy of a current CV (maximum 2 pages of A4) for the Chief Investigator must be submitted with the application

A3. Proposed study dates and duration

Start date:	01/12/2007
End date:	30/11/2011
Duration:	Years: 4 ; Months: 0

A4. Primary purpose of the research: *(Tick as appropriate)*

- [ ] Commercial product development and/or licensing
- [ ] Publicly funded trial or scientific investigation
- [x] Educational qualification
- [ ] Establishing a database/data storage facility
- [ ] Other

Question(s) 5 disabled.

A6. Does this research require site-specific assessment (SSA)? (Advice can be found in the guidance notes on this topic.)

○ Yes ◉ No

If No, please justify:

If Yes, an application for SSA should be made for each research site on the Site-Specific Information Form and submitted to the relevant local Research Ethics Committee. Do not apply for SSA at sites other than the lead site until the main application has been booked for review and validated by the main Research Ethics Committee.

Management approval to proceed with the research will be required from the R&D office for each NHS care organisation in which research procedures are undertaken. This applies whether or not the research is exempt from SSA. R&D applications in England, Wales and Scotland should be made using the Site-Specific Information Form.

PART A: Section 1

A7. What is the principal research question/objective? *(Must be in language comprehensible to a lay person.)*

The main objective is to describe normative values of grip strength in older people in several healthcare settings.

A8. What are the secondary research questions/objectives? *(If applicable, must be in language comprehensible to a lay person.)*

1. To find out if it is feasible to measure grip strength in these settings.
2. To establish the training needs of healthcare professionals.
3. To identify participants's views on grip strength assessment.

A9. What is the scientific justification for the research? What is the background? Why is this an area of importance?*(Must be in language comprehensible to a lay person.)*

Grip strength is associated with ageing in a range of body systems and may be a marker of underlying ageing processes. Studies have shown that grip strength can predict functional decline and disability. Lower grip strength is associated with falls and with reduced health-related quality of life in older men and women. Lower grip strength has been shown to be associated with longer lengths of hospital stay in elderly in-patients. Grip strength is not at present measured in clinical practice, and normative values for older people in many health settings are unknown.

A10-1. Give a full summary of the purpose, design and methodology of the planned research, including a brief explanation of the theoretical framework that informs it. It should be clear exactly what will happen to the research participant, how many times and in what order.

This section must be completed in language comprehensible to the lay person. It must also be self-standing as it will be replicated in any applications for site-specific assessment on the Site-Specific Information Form. Do not simply reproduce or refer to the protocol. Further guidance is available in the guidance notes.

Background

Frailty is recognised as a multidimensional syndrome of impaired physical, cognitive, psychological and social functioning (1). Methods of assessment include self-report, clinical judgement and the use of objective performance measures such as grip strength and gait speed. A more statistical approach has also been developed which involves the summation of total impairments (2). All of these methodologies have a high predictive value for adverse outcomes such as disability, hospitalisation and mortality (3).

Sarcopaenia (reduction of skeletal muscle mass and function with age) is central to the development of frailty. There is an increasing recognition of the serious health consequences of loss of muscle strength both in terms of disability (4), morbidity (5) and mortality (6) and in terms of significant healthcare costs (7). It is one of the major risk factors for falls (8), and one study has reported an association between low muscle mass and lower general health score (9). Grip strength is a useful clinical marker of sarcopaenia, and recent work has demonstrated that grip strength is more strongly associated with age and is a better predictor of poor mobility than other potential markers of sarcopaenia such as calf muscle area (10).

Grip strength has been proposed by our group as a useful single marker of generalised frailty and biological ageing (11). It is associated with ageing in a wide range of body systems and may be a good marker of underlying ageing processes because of the rarity of muscle-specific diseases contributing to change in muscle function. Epidemiological studies have shown that grip strength in mid-life (4, 6) and later years (12) can predict functional decline and disability as well as mortality. Longitudinal studies confirm that grip strength in men and women declines across all age groups, with the loss accelerating with increasing age (13,14). Grip strength is known to be related to height and weight loss, gender, nationality (15), serum levels of albumin, 25-hydroxyvitamin D and PTH (16,17) as well as age. Lower grip strength is associated with falls (18), all-cause mortality (19), and with reduced health related quality of life in older men and women (20). Lower grip strength has been shown to be associated with longer lengths of hospital stay among elderly medical in–patients (21).

Despite this body of evidence grip strength is not yet measured in clinical practice. The feasibility of translating this research tool to clinical settings is unknown, as are the training needs of clinical staff. Normative data is available for hospital in–patients in the UK (21) and for healthy community dwelling adults (20), but none are available for older people undergoing rehabilitation, who are most likely to be on the threshold of frailty, and for whom intervention to avert further deterioration is crucial.The availability of a single measure that could be used by primary care staff, district nurses etc as well as trained rehabilitation staff would be invaluable. Recognition of frailty and pre–frailty in clinical practice would allow the current provision of appropriate care and enhance the planning for future care including interventions such as the single assessment process, focussed rehabilitation and exercise programmes, specific medication etc.

Aims

The aim of this study is to translate the measurement of grip strength in a research setting to use in a clinical setting. There are four specific objectives:
1) to describe normative data for grip strength in older people in different healthcare settings
2) to evaluate the feasibility of assessing grip strength in diverse healthcare settings
3) to establish the training needs of different healthcare professionals in each setting to use the tool correctly and produce training guidance for the assessment of grip strength in clinical settings
4) to identify patient's and healthcare professionals' views on how clinical assessment of grip strength could improve the healthcare of older people

Research Question
1. How do the normative values for grip strength in elderly people within rehabilitation, and care settings compare to those in acute settings?
2. Is assessment of grip strength feasible and acceptable in different healthcare settings?
3. What are the training needs of different healthcare professionals for the assessment of grip strength?

Research plan and methodology

Study Design (1)
Descriptive epidemiological study

Study Population
Inclusion criteria
People aged 70 years and over living in Romsey and receiving care in the following healthcare settings will be invited to participate in this study:
1. In–patient rehabilitation care at Romsey Hospital
2. Community rehabilitation care from the Romsey Community Rehabilitation Team
3. Community chronic disease care from the Romsey Parkinson's Disease clinic
4. Community personal and nursing care in care homes
5. In–patient acute medical care in Southampton General Hospital

Additionally people aged over 70 years and receiving in–patient acute multi–disciplinary care from the Older People Outreach Support Team in Southampton General Hospital will be invited to participate.

Exclusion criteria
1) Participants unable to give written informed consent
2) Participants unable to use the dynamometer
The number of participants fulfilling these criteria will be documented as screening failures and form part of the feasibility study.

Sample size
The study is descriptive and therefore formal power calculations are not possible. However a recent study investigating the link between admission grip strength and length of hospital stay involved 100 participants (21) and we estimate that recruiting up to 100 people in each setting would be feasible and informative in this study.

Consent
Potential participants will be approached initially by their care staff, and then the researcher will explain the study and give an information sheet to those expressing an interest. An interval of at least 24 hours will be

allowed to enable the people approached to come to a decision about taking part in the study and during this time any further questions will be answered.

Study setting
The in−patient and out−patient rehabilitation settings will be at Romsey community hospital in a small town with a stable population. Romsey community hospital has 20 beds and admits patients from home and from two acute hospitals (Southampton and Winchester). There is a community rehabilitation team (therapy−centred) and a community rapid response service (nursing care centred) based in the hospital. A Parkinson's disease clinic is held monthly in the hospital and there is an active Parkinson's disease society in the locality. Parkinson's disease is chosen as a long−term condition associated with increasing frailty. Care homes in the Romsey area will be approached.

Data collection
Grip strength will be measured using a standardised methodology and additional demographic and clinical information as listed below will be collected to identify potential important influences on grip strength.

Case record review
In each setting the case records (hospital notes/community notes/care home records) will be reviewed by the researcher and the following data abstracted:
1) demographic details including date of birth, gender, hospital record number
2) co−morbidities (active medical problems impacting on function)
3) current medications

Clinical assessment
In each setting the following assessments will be made directly by the researcher:
4) Grip strength will be measured three times on each side, alternating between right and left hands, using a Jamar handgrip dynamometer (Promedics, Blackburn, UK). Participants will be given standardised encouragement to squeeze the dynamometer as hard as possible. The repeat measures will allow both practice and tiring effects to be apparent for an individual. The dynamometers will be calibrated at the start of the study and annually thereafter. The best of the six grip measurements will be used to characterise maximum muscle strength.
5) Forearm length will also be measured as a proxy for height to allow adjustment of grip strength for size (22).
6) Strawbridge frailty score (23)
7) 100 point Barthel Score to assess physical function (24)
8) Number of self−reported falls in the previous 12 months
9) MUST nutritional score (25)
10) Mini−mental state examination to assess mental function (26)
11) UPDRS and Hoehn and Yahr scores to assess disease severity of Parkinson's disease patients only

Participants will be assigned a study identification number, and neither name nor hospital number will be entered onto the study database.

Feasibility of grip strength assessment
In each setting the number of potential participants fulfilling the exclusion criteria will be documented, as will difficulties in using the dynamometer e.g. understanding the instructions, holding the dynamometer, tiring etc, as well as equipment failure, issues with calibration etc.

Data analysis
A database will be created by double entry data followed by data cleaning, and prepared for use with the STATA version 9 statistical package. Descriptive analysis (summation, percentages, means, medians and ranges) will be used to summarise grip strength, demographic data and the characteristics of participants in each setting. The feasibility of grip strength assessment within each setting will be analysed using descriptive statistics (summation, percentages) as well as the qualitative data derived from study 2 below.

Study Design (2)
Qualitative study

Study population

The care staff of participants in the study in the different healthcare settings will be invited to participate. They will be given an information sheet detailing the study and written informed consent will be obtained from those willing. A purposive sample of 6–8 staff will be sought, to include a broad range of clinical professions, seniority and experience within each setting, for example nurses, health care assistants, therapists and therapy assistants.
Exclusion criteria:
1) Unable to give written consent
2) No clinical component to current role

Data Collection
Health care staff in each setting will be trained in the use of the dynamometer in accordance with the manufacturer's guidelines. The training will be on a one–to–one basis and tailored to each individual in the first instance. The training programme will be further developed as the learning needs of health care staff become apparent. The training will include explanation of the aims and objectives of grip strength assessment and demonstration of the correct technique on other staff members and then patients, when the trainee becomes proficient.

Separate focus groups will be held with care staff in each setting to obtain their experiences and their views on the training process, e.g. how it might be improved and how useful they found it and also what role they see for the routine use of grip strength assessment in their clinical practice. The discussion will be led by an experienced qualitative researcher, who will ask open questions and aim to include all participants' in the discussion. An interview schedule (appendix two), derived from a pilot study conducted by the Older Persons Outreach and Support team will be used to facilitate the discussions and individual interviews.

Individual interviews will be conducted with a purposive sample of patients from each setting, selected to represent a range of age, gender, and grip strengths. They will be interviewed in private, with a family member/carer to support them if they wish. In a conversational manner the interviewer will aim to capture their experiences and views, as indicated in the semi–structured interview schedule (appendix one).

Data analysis

The focus groups and patient interviews will be audio–taped with express consent from the participants and the audiotapes will be transcribed verbatim. Using grounded theory techniques the tapes will be evaluated for themes, looking for commonality and differences within and between the health care settings. Themes that emerge from early focus groups will be explored in subsequent groups for validity in those settings. These themes will allow the research team to compile recommendations for the use of grip strength in the assessment of older people in these health care settings, and for the training of different health care staff in its use. A training guidance pack will be produced for use by health staff in these clinical settings.

Dissemination
The study findings will be disseminated locally through presentations to primary and secondary healthcare staff and managers. The findings will be published in peer reviewed scientific journals and presented at regional and national scientific meetings. The study findings will also be presented to local branches of the Parkinson's disease society and Help the Aged, and to the care homes assisting with the study.

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A10–2. In which parts of the research have patients, members of the public or service users been involved?

- ☐ As user–researchers
- ☐ As members of a research project group
- ☐ As advisor to a project
- ☐ As members of a departmental or other wider research strategy group
- ☑ None of the above

Please provide brief details if applicable:

A10–3. Could the research lead to the development of a new product/process or the generation of intellectual property?

○ Yes ⊙ No ○ Not sure

Question(s) 11–12 disabled.

A13. Give details of any non–clinical research–related intervention(s) or procedure(s).*(These include interviews, non–clinical observations and use of questionnaires.)*

Additional Intervention	**Average number per participant**	**Average time taken** (mins/hours/days)	**Details of additional intervention or procedure, who will undertake it, and what training they have received.**
Face to Face Interview	1	1 hour	Participants grip strength will be measured three times in each hand by a trained researcher. Forearm length will be measured and short questionnaires (to assess physical and mental function, frailty, falls and nutrition) will be administered. This will take place in a private room,where available, if not at a screened bedside.
Face to Face Interview	1	40 mins	Individual interviews will be conducted with a purposive sample of patients from each setting (n=10), selected to represent a range of age, gender, and grip strengths. They will be interviewed in private, with a family member/carer if they wish. In a conversational manner the experienced interviewer will aim to capture their experiences and views, using a semi–structured interview schedule.
Other	1	30 mins	Health care staff in each setting will be trained in a private room in the use of the dynamometer in accordance with the manufacturer's guidelines. The training will be on a one–to–one basis, by an experienced trainer and tailored to each individual in the first instance. The training programme will be developed as the learning needs of health care staff become apparent. The training will include explanation of the aims and objectives of grip strength assessment and demonstration of the correct technique on other staff members and then patients, when the trainee becomes proficient.
Focus Group	1	1 hour	Separate focus groups will be held with care staff in a private room in each setting to obtain their experiences and their views on the training process, e.g. how it might be improved and how useful they found it and also what role they see for the routine use of grip strength assessment in their clinical practice. The discussion will be led by an experienced qualitative researcher, who will ask open questions and aim to include all participants' in the discussion. An interview schedule derived from a pilot study conducted by the Older Persons Outreach and Support team will be used to facilitate the discussions and individual interviews.

A14. Will individual or group interviews/questionnaires discuss any topics or issues that might be sensitive, embarrassing or upsetting, or is it possible that criminal or other disclosures requiring action could take place during the study (e.g. during interviews/group discussions, or use of screening tests for drugs)?

○ Yes ⊙ No

The Information Sheet should make it clear under what circumstances action may be taken

A15. What is the expected total duration of participation in the study for each participant?

The expected interval between clincal assessment and face to face interview for patients will be no more than 3 months.

The expected interval between staff training and focus groups will be no more than 12 months, during which period staff will be using the technique.

Question(s) 16–17 disabled.

A18. What is the potential for benefit to research participants?

The potential benefit is that participants' level of frailty will be assessed, and it is expected that their care teams will use this information to inform their clinical care.

Benefits to the staff are the acquisition of skills in assessing frailty which should be transferable to other client populations.

A19. What is the potential for adverse effects, risks or hazards, pain, discomfort, distress, or inconvenience to the researchers themselves? *(if any)*

The University of Southampton has a lone researcher policy which researchers will be expected to follow. Mobile telephones are provided for the researchers.

A20. How will potential participants in the study be (i) identified, (ii) approached and (iii) recruited?
Give details for cases and controls separately if appropriate:

(i). The following patients will be identified:
Inclusion criteria
People aged 70 years and over living in Romsey and receiving care in the following healthcare settings will be invited to participate in this study:
1. In–patient rehabilitation care at Romsey Hospital
2. Community rehabilitation care from the Romsey Community Rehabilitation Team
3. Community chronic disease care from the Romsey Parkinson's Disease clinic
4. Community personal and nursing care in care homes
5. In–patient acute medical care in Southampton General Hospital

Additionally people aged over 70 years and receiving in–patient acute multi–disciplinary care from the Older People Outreach Support Team in Southampton General Hospital will be invited to participate.

Exclusion criteria
1) Participants unable to give written informed consent
2) Participants unable to use the dynamometer

(ii). Potential participants will be approached initially by their care staff, and asked if they wish to participate in the study.

(iii). The researcher will then explain the study and give an information sheet to those expressing an interest. An interval of at least 24 hours will be allowed to enable the people approached to come to a decision about taking part in the study and during this time any further questions will be answered.

A21. Where research participants will be recruited via advertisement, give specific details.

☑ Not Applicable

If applicable, enclose a copy of the advertisement/radio script/website/video for television (with a version number and date).

A22. What are the principal inclusion criteria? *(Please justify)*

People aged 70 years and over living in Romsey and receiving care in the following healthcare settings will be invited to participate in this study:
1. In–patient rehabilitation care at Romsey Hospital
2. Community rehabilitation care from the Romsey Community Rehabilitation Team
3. Community chronic disease care from the Romsey Parkinson's Disease clinic
4. Community personal and nursing care in care homes
5. In–patient acute medical care in Southampton General Hospital

Additionally people aged over 70 years and receiving in–patient acute multi–disciplinary care from the Older People Outreach Support Team in Southampton General Hospital will be invited to participate

A23. What are the principal exclusion criteria? *(Please justify)*

1) Participants unable to give written informed consent
2) Participants unable to use the dynamometer eg because of arthritis, weakness of the arms etc

These patients would thus be included in the 'frail' group in clinical practice

A24. Will the participants be from any of the following groups? *(Tick as appropriate)*

☐ Children under 16
☐ Adults with learning disabilities
☐ Adults who are unconscious or very severely ill
☐ Adults who have a terminal illness
☐ Adults in emergency situations
☐ Adults with mental illness (particularly if detained under Mental Health Legislation)
☐ Adults with dementia
☐ Prisoners
☐ Young Offenders
☐ Adults in Scotland who are unable to consent for themselves
☐ Healthy Volunteers
☑ Those who could be considered to have a particularly dependent relationship with the investigator, e.g. those in care homes, medical students
☐ Other vulnerable groups

Justify their inclusion.

Care home residents need their health assessment too, and so the question of dependency will be handled sensitively by the care staff and myself, with reassurance that care will not be affected by declining to participate.

PCT staff will similarly be offered a true choice of whether to participate or not, and those individual decisions will not be discussed with higher PCT management.

☐ No participants from any of the above groups

A26. Will informed consent be obtained from the research participants?

(•) Yes ( ) No

If Yes, give details of who will take consent and how it will be done. Give details of any particular steps to provide information (in addition to a written information sheet) e.g. videos, interactive material.

If participants are to be recruited from any of the potentially vulnerable groups listed in A24, give details of extra steps taken to assure their protection. Describe any arrangements to be made for obtaining consent from a legal representative.

If consent is not to be obtained, please explain why not.

Potential participants will be approached initially by their care staff, and then the researcher will explain the study and give a written information sheet to those expressing an interest. An interval of at least 24 hours will be allowed to enable the people approached to come to a decision about taking part in the study and during this time any further questions will be answered.

At this point written, informed consent will be obtained by a researcher who has received training in obtaining informed consent.

Staff participants will be identified from the staff list and given a written information sheet about the study. If willing they will be approached by the researcher who will answer any questions before obtaining written, informed consent from those wishing to particiapate.

Copies of the written information and all other explanatory material should accompany this application.

A27. Will a signed record of consent be obtained?

(•) Yes ( ) No

If Yes, attach a copy of the information sheet to be used, with a version number and date.

A28. How long will the participant have to decide whether to take part in the research?

At least 24 hours.

A29. What arrangements have been made for participants who might not adequately understand verbal explanations or written information given in English, or who have special communication needs? *(e.g. translation, use of interpreters etc.)*

We will be unable to include participants whose first language is not english, or those who cannot understand a verbal explanation of how to assess grip strength.

Question(s) 30 disabled.

A30-1. What steps would you take if a participant, who has given informed consent, loses capacity to consent during the study? *Tick one option only.*

( ) The participant would be withdrawn from the study. Data or tissue which is not identifiable to the research team may be retained. Any identifiable data or tissue would be anonymised or disposed of.

(•) The participant would be withdrawn from the study. Identifiable data or tissue already collected with consent would be retained and used in the study.

( ) The participant would continue to be included in the study.

( ) Not applicable – informed consent will not be sought from any participants in this research.

Further details:

Participants should be informed when seeking initial consent if it is planned to retain and make further use of identifiable data/tissue in the event of loss of capacity.

Question(s) 31–32b disabled.

A33. Will individual research participants receive any payments for taking part in this research?

○ Yes ◉ No

A34. Will individual research participants receive *reimbursement of expenses* or any other *incentives or benefits* for taking part in this research?

○ Yes ◉ No

A35. Insurance/indemnity to meet potential legal liabilities

Note: References in this question to NHS indemnity schemes include equivalent schemes provided by Health and Personal Social Services (HPSS) in Northern Ireland.

A35–1. What arrangements will be made for insurance and/or indemnity to meet the potential legal liability of the *sponsor(s)* for harm to participants arising from the *management of the research*?

Note: Where a NHS organisation has agreed to act as the sponsor, indemnity is provided through NHS schemes. Indicate if this applies (there is no need to provide documentary evidence). For all other sponsors, describe the arrangements and provide evidence.

◉ NHS indemnity scheme will apply
○ Other insurance or indemnity arrangements will apply (give details below)

Please enclose a copy of relevant documents.

A35–2. What arrangements will be made for insurance and/or indemnity to meet the potential legal liability of the *sponsor(s) or employer(s)* for harm to participants arising from the *design of the research*?

Note: Where researchers with substantive NHS employment contracts have designed the research, indemnity is provided through NHS schemes. Indicate if this applies (there is no need to provide documentary evidence). For other protocol authors (e.g. company employees, university members), describe the arrangements and provide evidence.

○ NHS indemnity scheme will apply to all protocol authors
◉ Other insurance or indemnity arrangements will apply (give details below)

University of Southampton insurance will apply

Please enclose a copy of relevant documents.

A35-3. What arrangements will be made for insurance and/or indemnity to meet the potential legal liability of *investigators/collaborators* and, where applicable, *Site Management Organisations*, arising from harm to participants in the *conduct of the research*?

Note: Where the participants are NHS patients, indemnity is provided through NHS schemes or through professional indemnity. Indicate if this applies to the whole of the study (there is no need to provide documentary evidence). Where non-NHS sites are to be included in the research, including private practices, describe the arrangements which will be made at these sites and provide evidence.

- ○ All participants will be recruited at NHS sites and NHS indemnity scheme or professional indemnity will apply
- ◉ Research includes non-NHS sites (give details of insurance/indemnity arrangements for these sites below)

University of Southampton insurance will apply

Please enclose a copy of relevant documents.

Question(s) 36 disabled.

A37. How is it intended the results of the study will be reported and disseminated? *(Tick as appropriate)*

- [x] Peer reviewed scientific journals
- [ ] Internal report
- [x] Conference presentation
- [ ] Other publication
- [ ] Submission to regulatory authorities
- [ ] Access to raw data and right to publish freely by all investigators in study or by Independent Steering Committee on behalf of all investigators
- [ ] Written feedback to research participants
- [x] Presentation to participants or relevant community groups
- [ ] Other/none e.g. Cochrane Review, University Library

A38. How will the results of research be made available to research participants and communities from which they are drawn?

Presentation to staff participants, care homes and relevant community groups.

A39. Will the research involve any of the following activities at any stage (including identification of potential research participants)? *(Tick as appropriate)*

- [ ] Examination of medical records by those outside the NHS, or within the NHS by those who would not normally have access
- [ ] Electronic transfer by magnetic or optical media, e-mail or computer networks
- [ ] Sharing of data with other organisations
- [ ] Export of data outside the European Union
- [ ] Use of personal addresses, postcodes, faxes, e-mails or telephone numbers
- [x] Publication of direct quotations from respondents
- [ ] Publication of data that might allow identification of individuals
- [x] Use of audio/visual recording devices
- [x] Storage of personal data on any of the following:
  - [ ] Manual files including X-rays
  - [ ] NHS computers

- [ ] Home or other personal computers
- [x] University computers
- [ ] Private company computers
- [ ] Laptop computers

Further details:

Direct quotations will be anonymised and non–attributable to any individual. The interviews with a sample of patient participants will be audio–taped as will the staff focus groups and specific consent for this will be obtained. All clinical information will be coded and participants will be only identifiable by a study number on a University computer.

A40. What measures have been put in place to ensure confidentiality of personal data? Give details of whether any encryption or other anonymisation procedures have been used and at what stage:

Direct quotations will be anonymised and non–attributable to any individual. The interviews with a sample of patient participants will be audio–taped as will the staff focus groups and specific consent for this will be obtained. All clinical information will be coded and patients will only be identifiable by a study number on a password–protected University computer. Patient's names and hospital number will not be held on any computer. All study data will be retained for 5 years. Storage will be in a locked, fire–proof storage facility.

A41. Where will the analysis of the data from the study take place and by whom will it be undertaken?

Analysis will be undertaken within the School of Medicine, University of Southampton. It will be undertaken by the applicants.

A42. Who will have control of and act as the custodian for the data generated by the study?

The Caldicott Guardian for the Southampton University Hospitals Trust (SUHT) will be custodian for the data. The data will be controlled by the applicants.

A43. Who will have access to research participants' or potential research participants' health records or other personal information? *Where access is by individuals outside the normal clinical team, justify and say whether consent will be sought.*

The research team only.

A44. For how long will data from the study be stored?

5 Years **0** Months

Give details of where they will be stored, who will have access and the custodial arrangements for the data:

All study material will be retained for 5 years, in an archive in University Geriatric Medicine, within the School of Medicine at Southampton General Hospital. Storage will be in a locked, fire–proof storage facility. The research team only with have access to the data.

A45–1. How has the scientific quality of the research been assessed? *(Tick as appropriate)*

- ☐ Independent external review
- ☐ Review within a company
- ☐ Review within a multi–centre research group
- ☑ Review within the Chief Investigator's institution or host organisation
- ☑ Review within the research team
- ☐ Review by educational supervisor
- ☐ Other

Justify and describe the review process and outcome. If the review has been undertaken but not seen by the researcher, give details of the body which has undertaken the review:

Divisional Scientific Peer Review within SUHT

A45–2. How have the statistical aspects of the research been reviewed? *(Tick as appropriate)*

- ☐ Review by independent statistician commissioned by funder or sponsor
- ☐ Other review by independent statistician
- ☐ Review by company statistician
- ☐ Review by a statistician within the Chief Investigator's institution
- ☑ Review by a statistician within the research team or multi–centre group
- ☐ Review by educational supervisor
- ☐ Other review by individual with relevant statistical expertise

In all cases give details below of the individual responsible for reviewing the statistical aspects. If advice has been provided in confidence, give details of the department and institution concerned.

Title:	Forename/Initials:	Surname:
Ms	Holly	Syddall

Department:	MRC Epidemiology Resource Unit
Institution:	School of Medicine, University of Southampton
Work Address:	MRC Epidemiology Resource Unit Southampton General Hospital Southampton
Postcode:	SO16 6YD
Telephone:	023 80704021
Fax:	
Mobile:	
E–mail:	hes@mrc.soton.ac.uk

Please enclose a copy of any available comments or reports from a statistician.

Question(s) 46–47 disabled.

A48. What is the primary outcome measure for the study?

1) to describe normative data for grip strength in older people in different healthcare settings

A49. What are the secondary outcome measures? *(if any)*

2) to evaluate the feasibility of assessing grip strength in diverse healthcare settings
3) to establish the training needs of different healthcare professionals in each setting to use the tool correctly and produce training guidance for the assessment of grip strength in clinical settings
4) to identify patient's and healthcare professionals' views on how clinical assessment of grip strength could improve the healthcare of older people

A50. How many participants will be recruited?
If there is more than one group, state how many participants will be recruited in each group. For international studies, say how many participants will be recruited in the UK and in total.

100 in each of 6 healthcare settings (Total 600).

A51. How was the number of participants decided upon?

The study is descriptive and therefore formal power calculations are not possible. However a recent study investigating the link between admission grip strength and length of hospital stay involved 100 participants and we estimate that recruiting up to 100 people in each setting would be feasible and informative in this study.

If a formal sample size calculation was used, indicate how this was done, giving sufficient information to justify and reproduce the calculation.

A52. Will participants be allocated to groups at random?

○ Yes ◉ No

A53. Describe the methods of analysis (statistical or other appropriate methods, e.g. for qualitative research) by which the data will be evaluated to meet the study objectives.

A database will be created by double entry followed by data cleaning, and prepared for use with the STATA version 9 statistical package. Descriptive analysis (summation, percentages, means, medians and ranges) will be used to summarise grip strength, demographic data and the characteristics of participants in each setting. The feasibility of grip strength assessment within each setting will be analysed using descriptive statistics (summation, percentages) for quantitative data, and the qualitative data will be analysed as outlined below:
The focus groups and patient interviews will be audio-taped with express consent from the participants and the audiotapes will be transcribed verbatim. Using grounded theory techniques the tapes will be evaluated for themes, looking for commonality and differences within and between the health care settings. Themes that emerge from early focus groups will be explored in subsequent groups for validity in those settings. These themes will allow the research team to compile recommendations for the use of grip strength in the assessment of older people in these health care settings, and for the training of different health care staff in its use. A training guidance pack will be produced for use by health staff in these clinical settings.

A54. Where will the research take place?*(Tick as appropriate)*

- ☑ UK
- ☐ Other states in European Union
- ☐ Other countries in European Economic Area
- ☐ Other

If Other, give details:

A55. Has this or a similar application been previously rejected by a Research Ethics Committee in the UK, the European Union or the European Economic Area?

○ Yes ◉ No

A56. In how many and what type of host organisations (NHS or other) in the UK is it intended the proposed study will take place?

Indicate the type of organisation by ticking the box and give approximate numbers if known:

	Number of organisations
☑ Acute teaching NHS Trusts	1
☐ Acute NHS Trusts	
☑ NHS Primary Care Trusts or Local Health Boards in Wales	1
☐ NHS Trusts providing mental healthcare	
☐ NHS Health Boards in Scotland	
☐ HPSS Trusts in Northern Ireland	
☐ GP Practices	
☐ NHS Care Trusts	
☑ Social care organisations	4
☐ Prisons	
☐ Independent hospitals	
☐ Educational establishments	
☐ Independent research units	
☐ Other (give details)	

Other:

4 Local care homes.

A57. What arrangements are in place for monitoring and auditing the conduct of the research?

The project is registered with the Research and Development Department of SUHT. There is a robust governance process for monitoring and auditing research conduct.

Question(s) 57a disabled.

A58. Has external funding for the research been secured?

○ Yes ◉ No

If No, what arrangements are being made to cover any costs of the research? If no external funding is being sought, please say so:

This study has a large educational component and so the researchers' time will be funded by the University of Southampton.

A59. Has the funder of the research agreed to act as sponsor as set out in the Research Governance Framework?

○ Yes ⦿ No

Has the employer of the Chief Investigator agreed to act as sponsor of the research?

○ Yes ⦿ No

Lead sponsor *(must be completed in all cases)*

Name of organisation which will act as the lead sponsor for the research:

Southampton University Hospitals NHS Trust

Status:

⦿ NHS or HPSS care organisation ○ Academic ○ Pharmaceutical industry ○ Medical device industry ○ Other

If Other, please specify:

Address:	Tremona Road, Southampton
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Telephone:	023 8079 4752
Fax:	023 8079 8678
Mobile:	
E-mail:	christine.mcgrath@suht.swest.nhs.uk

Sponsor's UK contact point for correspondence with the main REC *(must be completed in all cases)*

Title: Ms Forename/Initials: Christine Surname: McGrath

Work Address:	Southampton University Hospitals NHS Trust, MP 18, TMO, Tremona Road, Southampton
Post Code:	SO16 6YD
Telephone:	023 8079 4752
Fax:	023 8079 8678
Mobile:	
E-mail:	christine.mcgrath@suht.swest.nhs.uk

Co-sponsors

Are there any co-sponsors for this research?

○ Yes ⦿ No

A60. Has any responsibility for the research been delegated to a subcontractor?

○ Yes ⦿ No

A61. Will individual *researchers* receive any personal payment over and above normal salary for undertaking this research?

○ Yes ⦿ No

A62. Will individual *researchers* receive any other benefits or incentives for taking part in this research?

○ Yes ⦿ No

A63. Will the host organisation or the researcher's department(s) or institution(s) receive any payment or benefits in excess of the costs of undertaking the research?

○ Yes ⦿ No

A64. Does the Chief Investigator or any other investigator/collaborator have any direct personal involvement (e.g. financial, share-holding, personal relationship etc.) in the organisations sponsoring or funding the research that may give rise to a possible conflict of interest?

○ Yes ⦿ No

A65. Research reference numbers: *(give any relevant references for your study):*

Applicant's/organisation's own reference number, e.g. R&D (if available):	RHM MED 0789
Sponsor's/protocol number:	N/A
Funder's reference number:	N/A

Project website: N/A

A66. Other key investigators/collaborators *(all grant co-applicants or protocol co-authors should be listed)*

Title: Prof Forename/Initials: Avan Surname: Aihie Sayer

Post:	MRC Clinical Scientist/Honorary Consultant
Qualifications:	BSc; MBBS; MRCP (UK); PhD; FRCP(UK)
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Title: Prof Forename/Initials: Cyrus Surname: Cooper

Post:	Director MRC Epidemiology Resource Centre
Qualifications:	BA; MA; MBBS; MRCP(UK); DM; FRCP(UK); FMedSci; FFPH

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Title: Dr Forename/Initials: Nadia Surname: Chambers

Post:	Consultant Nurse
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Title: Mrs Forename/Initials: Amanda Surname: Horsman

Post:	Head of adults and older peoples services
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Title: Prof Forename/Initials: Jacqueline Surname: Powell

Post:	Professor Social Sciences
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Title: Mrs Forename/Initials: Holly Surname: Syddall

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Question(s) 67 disabled.

PART A: Summary of Ethical Issues

A68. What are the main ethical issues with the research?

Summarise the main issues from the participant's point of view, and say how you propose to address them.

This is a simple study from the patient participants point of view with no invasive procedures.

Staff participants will be given a free choice as to whether to participate in the study.

Indicate any issues on which you would welcome advice from the ethics committee.

No specific issues forseen

Question(s) 69 disabled.

PART A: Student Page

A70. Give details of the educational course or degree for which this research is being undertaken:

Name of student:

Dr Helen Roberts

Name and level of course/degree:

DM

Name of educational establishment:

School of Medicine, University of Southampton

Name and contact details of educational supervisor:

Prof Avan Aihie Sayer
MRC Epidemiology Resource Unit
University of Southampton

email: aas@mrc.soton.ac.uk

A71. Declaration of educational supervisor

I have read and approved both the research proposal and this application for the ethical review. I am satisfied that the scientific content of the research is satisfactory for an educational qualification at this level. I undertake to fulfil the responsibilities of a supervisor as set out in the Research Governance Framework for Health and Social Care.

Signature: ....

Print Name: Professor Avan Aihie Sayer

Date: (dd/mm/yyyy)

A one–page summary of the supervisor's CV should be submitted with the application

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05 December 2007

Dr Helen Roberts
Senior Lecturer/Honorary Consultant
University of Southampton
University Geriatric Medicine
Level E, Southampton General Hospital
Southampton
SO16 6YD

Dear Dr Roberts

Full title of study: **Study to evaluate the clinical use of hand grip strength to identify frail and "pre-frail" elderly people in different healthcare settings.**

REC reference number: **07/H0504/176**

The Research Ethics Committee reviewed the above application at the meeting held on 28 November 2007. Thank you for attending to discuss the study.

Documents reviewed

The documents reviewed at the meeting were:

Document	*Version*	*Date*
Application		05 October 2007
Investigator CV: Dr Helen Roberts		27 September 2007
Protocol	1	12 September 2007
Covering Letter		12 October 2007
Letter from Sponsor		17 September 2007
Peer Review		11 September 2007
Compensation Arrangements		15 October 2007
Interview Schedules/Topic Guides: Older People	1	27 September 2000
Interview Schedules/Topic Guides: Focus Group - Health Care Staff	1	27 September 2007
Questionnaire: Modified Hoehn and Yhr Staging		
Questionnaire: Unified Parkinson's Disease Rating Scale		
Questionnaire: Mini Mental State Examination		
Questionnaire: Malnutrition Universal Screening Tool		
Questionnaire: The Barthel ADL Index		
Letter of invitation to participant	1	12 October 2007
GP/Consultant Information Sheets: GP	1	05 July 2007
GP/Consultant Information Sheets: Consultant	1	05 July 2007
Participant Information Sheet: Staff	1	26 September 2007
Participant Information Sheet: Patient	1	26 September 2007

Participant Consent Form: Staff	1	26 September 2007
Participant Consent Form: Patient	1	26 September 2007
Investigator CV: Professor A A Sayer		28 September 2007
Letter from Funder		31 August 2007
Letter from Karen Cubbon		08 October 2007
Letter from Amanda Horsman		03 May 2007
Protocol for Strawbridge Frailty Score		
Protocol for Grip Strength Measurement in Adults		13 November 2006

Provisional opinion

The Committee would be content to give a favourable ethical opinion of the research, subject to receiving a complete response to the request for further information set out below.

Authority to consider your response and to confirm the Committee's final opinion has been delegated to the Chair / Vice-Chair.

Further information or clarification required

1. **Information Sheet - Patients**
   1.1. **The phrase 'could improve the healthcare of older people.' should be reworded to 'is a convenient and acceptable test.'**
   1.2. **Should indicate that length of time the test and questionnaire will take to complete. It should also make it clear that the 'additional discussion' will involve an individual interview and the length of time that this is likely to take.**
   1.3. **The phrase 'tall and small' should be changed to either 'tall and short' or 'large and small'.**
   1.4. **The Committee would suggest moving the contact details for the researcher to the end of the document, to enable them to be located more easily.**
   1.5. **Make it clear that those participants in the additional interview will be audiotaped.**
   1.6. **The phrase 'A few people would also be approached to' should be reworded to 'You may be asked to'.**
   1.7. **The phrase 'low grip strength' should be reworded.**
   1.8. **Further explanation of why grip strength is being measured, how this will indicate illness or frailty should be included.**
2. **Information Sheet - Staff**
   2.1. **Under 'What is the purpose of the study? the word 'staff' should be inserted in to the sentence 'We will also find out participants' views.'**
   2.2. **Under 'Do I have to take part' include the phrase 'this is not part of your normal duties, but your employer has agreed that you may take the time to participate during normal working hours, if you choose to do so'.**
   2.3. **The Committee would suggest moving the contact details for the researcher to the end of the document, to enable them to be located more easily.**
3. **Consent Form - Staff**
   3.1. **Should insert the word 'Staff' prior to 'Consent Form'.**
   3.2. **Point 2 - should insert 'my employment' between 'without' and 'legal'.**
4. **The Committee felt it was not necessary to inform each participant's GP individually, they would suggest leaving an information sheet at the care homes for any visiting GPs to read. A copy of the information to be left out for GP's should be submitted for review.**
5. **The investigator must justify the answer to A44 in writing and provide confirmation that this complies with the Trust's current policy relating to data storage.**

6. **The Committee would suggest the use of a reply slip which both patients and staff can return if they are interested in taking part in the study. A copy of the reply slip should be provided for review. It should also be made clear in both information sheets how participants are to indicate that they are interested in taking part and who this should be directed to.**

When submitting your response to the Committee, please send revised documentation where appropriate underlining or otherwise highlighting the changes you have made and giving revised version numbers and dates.

The Committee will confirm the final ethical opinion within a maximum of 60 days from the date of initial receipt of the application, excluding the time taken by you to respond fully to the above points. A response should be submitted by no later than 03 April 2008.

Ethical review of research sites

The Committee agreed that all sites in this study should be exempt from site-specific assessment (SSA). There is no need to submit the Site-Specific Information Form to any Research Ethics Committee. However, all researchers and local research collaborators who intend to participate in this study at NHS sites should seek approval from the R&D office for the relevant care organisation.

Membership of the Committee

The members of the Committee who were present at the meeting are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

07/H0504/176	**Please quote this number on all correspondence**

Yours sincerely

Dr Raj Patel
Chair

Email: scsha.SWHRECB@nhs.net

Enclosures: *List of names and professions of members who were present at the meeting and those who submitted written comments.*

Copy to: *Mrs Christine McGrath, Southampton University Hospitals NHS Trust*

NHS

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19 December 2007

Dr Helen Roberts
Senior Lecturer/Honorary Consultant
University of Southampton
University Geriatric Medicine
Level E, Southampton General Hospital
Southampton
SO16 6YD

Dear Dr Roberts

Full title of study: **Study to evaluate the clinical use of hand grip strength to identify frail and "pre-frail" elderly people in different healthcare settings.**

REC reference number: **07/H0504/176**

Thank you for your letter of 14 December 2007, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Vice-Chair.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

Ethical review of research sites

The Committee has designated this study as exempt from site-specific assessment (SSA. There is no requirement for [other] Local Research Ethics Committees to be informed or for site-specific assessment to be carried out at each site.

Conditions of approval

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Application		05 October 2007
Investigator CV: Dr Helen Roberts		27 September 2007
Protocol	1	12 September 2007
Covering Letter		12 October 2007
Letter from Sponsor		17 September 2007
Peer Review		11 September 2007

Compensation Arrangements		15 October 2007
Interview Schedules/Topic Guides: Older People	1	27 September 2000
Interview Schedules/Topic Guides: Focus Group - Health Care Staff	1	27 September 2007
Questionnaire: Modified Hoehn and Yhr Staging		
Questionnaire: Unified Parkinson's Disease Rating Scale		
Questionnaire: Mini Mental State Examination		
Questionnaire: Malnutrition Universal Screening Tool		
Questionnaire: The Barthel ADL Index		
Letter of invitation to participant	1	12 October 2007
GP/Consultant Information Sheets: GP	1	05 July 2007
GP/Consultant Information Sheets:Consultant	1	05 July 2007
GP/Consultant Information Sheets	2	14 December 2007
Participant Information Sheet: Staff	2	14 December 2007
Participant Information Sheet: Patient	2	14 December 2007
Participant Consent Form: Staff	2	14 December 2007
Participant Consent Form: Patient	2	14 December 2007
Response to Request for Further Information		14 December 2007
E-mail from R&D		26 September 2007
Investigator CV: Professor A A Sayer		28 September 2007
Letter from Funder		31 August 2007
Letter from Karen Cubbon		08 October 2007
Letter from Amanda Horsman		03 May 2007
Protocol for Strawbridge Frailty Score		
Protocol for Grip Strength Measurement in Adults		13 November 2006

R&D approval

All researchers and research collaborators who will be participating in the research at NHS sites should apply for R&D approval from the relevant care organisation, if they have not yet done so. R&D approval is required, whether or not the study is exempt from SSA. You should advise researchers and local collaborators accordingly.

Guidance on applying for R&D approval is available from http://www.rdforum.nhs.uk/rdform.htm.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Now that you have completed the application process please visit the National Research Ethics Website > After Review

Here you will find links to the following

a) Providing feedback. You are invited to give your view of the service that you have received from the National Research Ethics Service on the application procedure. If you wish to make your views known please use the feedback form available on the website.

b) Progress Reports. Please refer to the attached Standard conditions of approval by Research Ethics Committees.
c) Safety Reports. Please refer to the attached Standard conditions of approval by Research Ethics Committees.
d) Amendments. Please refer to the attached Standard conditions of approval by Research Ethics Committees.
e) End of Study/Project. Please refer to the attached Standard conditions of approval by Research Ethics Committees.

We would also like to inform you that we consult regularly with stakeholders to improve our service. If you would like to join our Reference Group please email referencegroup@nationalres.org.uk .

07/H0504/176	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project

Yours sincerely

pp **Mr. Peter Wilson**
Vice-Chair

Email: scsha.SWHRECB@nhs.net

Enclosures:	*Standard approval conditions*
Copy to:	Mrs Christine McGrath Southampton University Hospitals NHS Trust

STA/hph

03 June 2008

NHS

National Research Ethics Service

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Dr Helen Roberts
Senior Lecturer/Honorary Consultant
University Geriatric Medicine
Level E, Southampton General Hospital
Southampton
SO16 6YD

Dear Dr Roberts

Study title:	**Study to evaluate the clinical use of hand grip strength to identify frail and "pre-frail" elderly people in different healthcare settings.**
REC reference:	**07/H0504/176**
Amendment number:	**Version 1**
Amendment date:	**19 May 2008**

The above amendment was reviewed at the meeting of the Sub-Committee of the REC held on 28 May 2008.

Ethical opinion

The members of the Committee present gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Questionnaire	version 1	19 May 2008
Protocol	Version 2	19 May 2008
Notice of Substantial Amendment (non-CTIMPs)	Version 1	19 May 2008
Covering Letter		19 May 2008

Membership of the Committee

The members of the Committee who were present at the meeting are listed on the attached sheet.

R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

07/H0504/176:	Please quote this number on all correspondence

Yours sincerely

Mrs Sharon Atwill
Committee Co-ordinator

E-mail: scsha.SWHRECA@nhs.net

Enclosures	List of names and professions of members who were present at the meeting and those who submitted written comments
Copy to:	Mrs Christine McGrath Southampton University Hospitals NHS Trust

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26 February 2009

Dr Helen Roberts
Senior Lecturer/Honorary Consultant
University of Southampton
University Geriatric Medicine
Level G, West Wing
Southampton General Hospital
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SO16 6YD

Dear Dr Roberts,

Study title:	**Study to evaluate the clinical use of hand grip strength to identify frail and "pre-frail" elderly people in different healthcare settings.**
REC reference:	**07/H0504/176**
Amendment number:	**Amendment 2 dated 17 October 2008 (Modified)**
Amendment date:	**17 October 2008**

Thank you for submitting the above amendment, which was received on 19 February 2009. It is noted that this is a modification of an amendment previously rejected by the Committee (our letter of 07 November 2008 refers).

The modified amendment has been considered on behalf of the Committee by the Alternate Vice-Chair.

Ethical opinion

I am pleased to confirm that the Committee has given a favourable ethical opinion of the modified amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved are:

Document	Version	Date
Protocol	4	17 February 2009
Participant Information Sheet	4	17 February 2009
Participant Consent Form: For Photographs / Videos	2	17 February 2009
Participant Consent Form	4	17 February 2009
Physician Letter	2	17 February 2009
Discharge Data Collection Sheet	1	17 October 2008
Modified Amendment	Amendment 2 dated 17 October 2008 (Modified)	17 October 2008
Covering Letter		17 February 2009

R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

07/H0504/176:	Please quote this number on all correspondence

Yours sincerely

Mrs Sharon Atwill
Committee Co-ordinator

E-mail: scsha.SWHRECB@nhs.net

Copy to: Mrs Christine McGrath
Southampton University Hospitals NHS Trust

Appendix 11. Test-retest reproducibility of maximum grip strength measurement where initial grip strength is 15kg or less: results of both readings on 10 participants

	Maximum grip strength (kg)	
Participant	**1st reading**	**2nd reading**
1	14	14
2	12	12
3	7	10
4	14	15
5	14	14
6	7	4
7	9	11
8	11	12
9	14	14
10	14	13

Appendix 12. Maximum grip strength and Barthel score on admission and discharge in a sub-sample of 20 rehabilitation inpatients

	ID	Maximum grip strength on admission	Maximum grip strength on discharge	Barthel score on admission	Barthel score on discharge
1	037	6	4	39	32
2	042	19	19	31	39
3	049	6	6	12	17
4	057	6	5	65	52
5	058	14	16	100	95
6	059	31	30	45	40
7	060	17	25	95	95
8	064	20	20	43	90
9	066	16	18	82	81
10	067	26	26	23	33
11	070	18	17	90	81
12	098	14	8	64	75
13	114	16	15	77	80
14	120	18	15	72	86
15	123	10	9	51	80
16	131	12	11	72	75
17	138	7	11	88	82
18	149	14	16	74	80
19	124	14	18	41	67
20	148	18	19	21	77

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