UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL AND HUMAN SCIENCES

Centre for Research on Ageing

Social inequalities in musculoskeletal ageing among community dwelling older men and women in the United Kingdom

by

Holly Emma Syddall

Thesis for the degree of Doctor of Philosophy

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ABSTRACT

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SOCIAL INEQUALITIES IN MUSCULOSKELETAL AGEING AMONG COMMUNITY DWELLING OLDER MEN AND WOMEN IN THE UNITED KINGDOM

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The population of the United Kingdom (UK) is ageing; the already substantial burden of musculoskeletal disorders on health and social care systems will increase over time as the population ages. Social inequalities in health are well documented for the UK in general but little is known about social inequalities in musculoskeletal ageing.

Using data from the 3,225 'young-old' (age 59 to 73 years) community dwelling men and women who participated in the Hertfordshire Cohort Study, this thesis has explored social inequalities in musculoskeletal ageing: specifically, loss of muscle strength and physical function (PF); falls; Fried frailty; and osteoporosis. Socioeconomic position was characterised by age left full-time education, parental social class at birth and own social class in adulthood, and current material deprivation by housing tenure and car availability.

Not owning one's home was associated with lower grip strength and increased frailty prevalence among men and women and with poorer self-reported short-form 36 (SF-36) PF among men. Reduced car availability was associated with lower grip strength and poorer SF-36 PF among men and women and with increased falls and frailty prevalence among men. There was no convincing evidence for social inequalities in fracture, dual-energy x-ray absorptiometry (DXA) total femoral bone mineral density (BMD) and bone loss rate, or peripheral quantitative computed tomography (pQCT) strength strain indices for the radius or tibia.

This thesis has argued that social variations in height, fat mass, diet and physical activity are likely to have mediated these results. Moreover, evidence for a social gradient in grip strength but not BMD is consistent with ageing skeletal muscle remaining highly responsive to physical activity in later life in a way that ageing bone does not; the impact of lifecourse customary and occupational physical activity on social inequalities in musculoskeletal ageing merits further research.

The results presented in this thesis suggest that any clinical interventions designed to reduce the loss of muscle mass and function with age should be targeted proportionately across the social gradient; strategies to reduce fracture and osteoporosis should continue to have a universal population focus.

Finally, this thesis suggests that there exists a subgroup of older men and women in the UK who face the multiple jeopardy of increased levels of material deprivation combined with greater loss of muscle strength and physical function; these men and women urgently need the government to commit to reform of the funding system for adult care and support.

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Academic Thesis: Declaration of Authorship

I, Holly Emma Syddall, declare that this thesis entitled "Social inequalities in musculoskeletal ageing among community dwelling older men and women in the United Kingdom" and the work presented in it 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:

Syddall, H., Evandrou, M., Cooper, C., & Sayer, A.A. 2009. Social inequalities in grip strength, physical function, and falls among community dwelling older men and women: findings from the Hertfordshire Cohort Study. *Journal of Aging and Health*, 21, (6) 913-939

Syddall, H., Roberts, H.C., Evandrou, M., Cooper, C., Bergman, H., & Sayer, A.A. 2010. Prevalence and correlates of frailty among community-dwelling older men and women: findings from the Hertfordshire Cohort Study. *Age and Ageing,* 39, (2) 197-203

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I have worked at the MRC Lifecourse Epidemiology Unit long enough to know full well that epidemiology is a team sport. It is therefore important to acknowledge the hard work that my fellow members of the Hertfordshire Cohort Study Research Group have put in across the years to create a cohort study of which we can be proud. I particularly thank Vanessa Cox, Shirley Simmonds, Sian Robinson, Hayley Denison, Helen Martin, Karen Jameson, Clare Statham, Sue Batelaan and Alex Ward.

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Abbreviations

A&E	Accident and Emergency
ALSPAC	Avon Longitudinal Study of Parents and Children
ANOVA	Analysis of variance
APHO	Association of Public Health Observatories
BMD	Bone mineral density
BNF	British National Formulary
CCG	Clinical Commissioning Group
CI	Confidence interval
CM	Centimetres
DFLE	Disability free life expectancy
DH	Department of
DM	Diabetes mellitus
DRA	Default retirement age
DXA	Dual-energy x-ray absorptiometry
ECG	Electrocardiogram
EWGSOP	European Working Group on Sarcopenia in Older People
FHSA	Family health services authority
FRAX	Fracture risk assessment tool
FSA	Food Standards Agency
FT	Full-time
GP	General practitioner
HALCyon	Healthy Ageing across the Life Course
HCS	Hertfordshire Cohort Study
HPA	Hypothalamic pituitary adrenal
HSE	Health Survey for England
IHD	Ischemic heart disease
IL-6	Inflammatory cytokine interleukin-6
IMD	Index of multiple deprivation
IQR	Inter-quartile range
KG	Kilogrammes
LIDNS	Low Income Diet and Nutrition Survey
LCPUFA	Long-chain polyunsaturated fatty acids
MMT	Manual muscle testing
MRC	Medical Research Council
MRC EEU	MRC Environmental Epidemiology Unit
MRC LEU	MRC Lifecourse Epidemiology Unit
NHS	National Health Service

NDNS	National Diet and Nutrition Surveys
NHSCB	NHS Commissioning Board
NHSCR	National Health Service Central Register
NSF	National Service Framework
NSHD	National Survey of Health and Development
NSSEC	UK National Statistics socioeconomic classification
OGTT	Oral glucose tolerance test
OPCS	Office of Population Censuses and Surveys
OR	Odds ratio
OA	Osteoarthritis
PF	Physical functioning
pQCT	Peripheral quantitative computed tomography
PSA	Public Service Agreement
PSS	Personal social services
QDR	Quantitative digital radiography
SD	Standard deviation
SACN	Scientific Advisory Committee on Nutrition
SEP	Socioeconomic position
SF-36	Short form 36 health questionnaire
SOC	Standard Occupational Classification
TIA	Transient ischemic attack
UK	United Kingdom
WHO	World Health Organisation

Chapter 1. Introduction

1.1 Rationale

The population of the United Kingdom (UK) is ageing; the already substantial burden of musculoskeletal disorders on health and social care systems will only increase over time as the population ages. Social inequalities in health are well documented for the UK in general but little is known about social inequalities in musculoskeletal ageing.

1.2 Objective

The objective of this thesis is to address this gap in knowledge by examining the evidence for social inequalities in musculoskeletal ageing (specifically loss of muscle strength, loss of physical function, falls, frailty, and osteoporosis) among the 3,225 'young-old' men and women who participated in the internationally renowned Hertfordshire Cohort Study (HCS) (Syddall et al. 2005a). The social circumstances of the HCS participants will be characterised by occupationally based social class at birth and in adulthood and age left full-time education as markers of socioeconomic position, and housing tenure and household car availability as markers of material deprivation.

This thesis will extend existing knowledge by comparing and contrasting the evidence for social inequalities in aspects of musculoskeletal ageing which are predominantly underpinned by ageing muscle as opposed to ageing bone. Consideration of the potential mediating role of lifestyle choices and health behaviours (specifically anthropometry, physical activity, diet, smoking and alcohol consumption) in the specific pattern of results presented in this thesis will suggest potential mechanisms which may underpin social inequalities in musculoskeletal ageing. This thesis will be placed in its policy context and its relevance for current health and social care policy will be discussed.

1.3 Population and individual ageing

The UK has an ageing population. Ageing of the population refers to both the increase in the median age and the increase in the proportion of older people in the population. Over the 25 year period 1985 to 2010, the median age of the UK population increased from 35.4 years to 39.7 years (Office for National Statistics 2012b). In terms of increases in the number and proportion of older people in the UK, the percentage of the population aged 65 years and over increased from 15% in 1985 to 17% in 2010, an increase of 1.7 million people. By 2035 it is projected that those aged 65 and over will account for 23% of the total UK population (Office for National Statistics 2012b). The fastest increases have been in the 'oldest old'; between 1985 and 2010 the proportion of the UK population aged 85 and over increased from 1% (0.7 million people) to 2%

(1.4 million people) and is projected to increase to 5% (3.5 million people) in 2035 (Office for National Statistics 2012b). This reflects the ageing of the large birth cohorts of the 1940s and 1960s and the smaller subsequent cohorts due to lower fertility in the 1970s and 1980s, as well as rising life expectancy.

This demographic change has wide ranging social and economic implications for society (UNFPA and HelpAge International 2012); issues such as changes to work and retirement patterns, pension provision, and reform of the health and social care system are central to the current political agenda in the UK (HM Government 2012c) and also regularly permeate the UK popular press. For example, the issue of how best to reform the UK funding system for social care (Commission on Funding of Care and Support 2011) arises as a consequence of an ageing population and is an issue which has been the subject of extensive, ongoing political debate (HM Government 2012a) and which also receives wide coverage in the popular press (Cassidy 2012;Jackson 2012;Ramesh 2012).

At an individual level, longer lifespan is an achievement of public health and medicine which should be celebrated (UNFPA and HelpAge International 2012); healthy ageing offers individuals extended opportunity to work, volunteer, pursue leisure interests, and play an active role in society, community and family (Age UK 2010). However, many chronic diseases and conditions are associated with ageing (e.g. musculoskeletal disorders, mobility disability, dementia, cardiovascular and respiratory disease and sensory impairment) and, within the context of an ageing population, the numbers of older people suffering from these conditions will inevitably increase over time; health and social care systems need to plan effectively for the capability to care for the increasing numbers of people with these problems (Holmes 2008;Khaw 1999). In addition to providing high quality, integrated, patient centred treatment of ill-health when it arises (Darzi of Denham 2008), the UK government recognises that the National Health Service (NHS) must also play an important role in the prevention of ill health and the promotion of health and wellbeing across the lifecourse (Department of Health 2012b). Improved understanding of the patterns and mechanisms of successful, healthy, individual ageing is therefore relevant to the focus of current UK health and social care policy.

1.4 The ageing musculoskeletal system

A healthy musculoskeletal system is vital for physical functioning (Cooper et al. 2012) and consequently for healthy ageing during which an individual is able to maintain function, mobility and independence (Age UK 2010). However, musculoskeletal conditions are the most frequent cause of physical disability in the developed world (WHO Scientific Group 2003) and are prevalent among older people (Fejer and Ruhe 2012). Currently in the UK it is estimated that 70% of people in their seventies and 83% of eighty year olds have mobility problems, and it is estimated that by 2018 there will be in the UK: nearly 7 million older people who cannot walk up one flight of stairs without resting; over one million people aged 75 years and over who find it very difficult to get to their local hospital; and a third of a million who have difficulty bathing (Holmes 2008). Musculoskeletal disorders constitute a major public health problem; their societal costs in western populations approach 3% of gross national product (WHO Scientific Group 2003).

This thesis will focus on five specific aspects of musculoskeletal ageing: (i) loss of muscle strength; (ii) loss of physical function; (iii) falls; (iv) frailty, and (v) osteoporosis. Sections 1.4.1 to 1.4.5 will briefly outline the prevalence, aetiology and impact of these aspects of musculoskeletal ageing at the individual and population level.

1.4.1 Muscle strength

Sarcopenia, the loss of skeletal muscle mass and function with age (American Geriatrics Society et al. 2001;Cruz-Jentoft et al. 2010), is common among older people (Cruz-Jentoft et al. 2010). Prevalence estimates for sarcopenia among community dwelling men and women aged 60 years and older range from 7% to 59% according to study population, method of ascertainment and definition of sarcopenia (Doherty 2003;Iannuzzi-Sucich et al. 2002;Janssen et al. 2002). Determinants of sarcopenia include age, gender, size, levels of physical activity, diet (Robinson et al. 2008), heritability and also early life developmental influences (Sayer et al. 2008). Sarcopenia has important consequences in terms of functional impairment and disability (Bohannon 2008;Janssen et al. 2002), morbidity (Sayer et al. 2005;Sayer et al. 2007) and mortality (Bohannon 2008;Cooper et al. 2010;Rantanen et al. 2000). For example, Rantanen (Rantanen et al. 2000) prospectively followed up a cohort of 6,040 initially healthy Hawaiian men aged 45 to 68 years for 30 years and showed that, independent of age, education, occupation, smoking, physical activity and body height, all cause mortality rates per 1,000 person years ranged from 24.8 in the lowest third of grip strength (a measure of muscle strength and a marker of sarcopenia), to 18.5 in the middle third, and 14.0 in the highest third of grip strength.

Sarcopenia also confers significant healthcare costs: Janssen (Janssen et al. 2004) estimated the healthcare costs of sarcopenia in the US by considering the effect of moderate or severe sarcopenia (defined as skeletal muscle index <10.76kg/m^2 among older men and <6.76kg/m^2 among older women) on increasing physical disability risk in older persons. The direct healthcare cost attributable to sarcopenia in the United States in 2000 was estimated at $18.5 billion, which represented approximately 1.5% of total healthcare expenditures for that year. Janssen estimated that a 10% reduction in the prevalence of sarcopenia would result in savings of $1.1 billion per year in US healthcare costs.

Although recognised as conferring huge personal and financial costs, sarcopenia has only recently achieved a broadly accepted clinical definition in the form of the European Working Group on Sarcopenia in Older People (EWGSOP) case-finding algorithm for sarcopenia which is based on a combination of loss of muscle mass, muscle strength and physical performance (Cruz-Jentoft et al. 2010). However, this algorithm may not be feasible to implement in all clinical and research settings. Grip strength is a simple measure of muscle strength (Roberts et al. 2011) which is widely used as a marker of sarcopenia in epidemiological studies; lower grip strength has been shown to be associated with premature mortality, the development of disability, and an increased risk of complications or prolonged length of stay after hospitalisation or surgery (Bohannon 2008).

1.4.2 Physical function

Loss of physical function and difficulty in performing activities of daily living increase with age and are prevalent among older people (Cooper et al. 2011a;Ebrahim et al. 2000;Evandrou 2005). Among 5717 men (mean age 63 years) who participated in a follow-up component of the British Regional Heart Study in 1992, the prevalence of mobility disability (defined as having difficulty independently doing any of the following: walking up or down stairs; bending down; straightening up; keeping balance; leaving the house; walking 400 yards) was 25.0% (Ebrahim et al. 2000). Using data from the General Household Survey 2001-2002, Evandrou (Evandrou 2005) demonstrated that 21% of women and 12% of men aged 65 years and over living in private households were unable to carry out at least one of the following activities of daily living: managing stairs; going outdoors and walking down the road; using the toilet; getting around the house; getting in and out of bed. The percentage of older people aged 65-69 who could not manage steps or stairs unaided was 3%; this rose to 13% among those aged 85 and over (Evandrou 2005). Cooper et al. harmonised data from men and women aged 50 to 90 plus years of age who participated in the eight UK cohorts which have contributed to the Healthy Ageing across the Life Course (HALCyon) research programme; older participants tended to have lower levels of physical capability as reflected by weaker grip strength, longer chair rise times, slower walking and timed up and go speeds and greater odds of being unable to balance for 5 seconds than younger participants (Cooper et al. 2011a).

Loss of physical function and loss of independence in the ability to perform activities of daily living are risk factors for subsequent development of arthritis, diabetes, hip fracture, cancer, heart disease, obesity, stroke, institutionalisation, premature death (Ostir et al. 1998) and mobility disability (Guralnik et al. 2000;Ostir et al. 1998).

1.4.3 Falls

Falls are common among community dwelling older men and women: 30% of persons aged 65 and over who live in the community fall each year, a prevalence which increases to 40% among those over the age of 80 years (Tinetti et al. 1988). Falls have serious consequences in terms of disability, morbidity and mortality as well as economic cost. Approximately 40-60% of falls lead to injuries, with 30-50% being minor injuries and 5-6% being fractures (one percent of falls are estimated to result in a hip fracture) (Masud and Morris 2001). The Longitudinal Aging Study Amsterdam considered the consequences of falling among 204 community-dwelling older men and women (aged 65 or over) who had fallen in the year preceding interview: as a consequence of falling, 68% reported physical injury, 6% major injury, 24% health service use, 35% decline in functional status and 17% and 15% declines in social and physical activities respectively (Stel et al. 2004). Injury is the fifth leading cause of death in older adults and most of these fatal injuries are related to falls (Kannus et al. 2005). Scuffham (Scuffham et al. 2003) estimated the number of accident and emergency (A&E) attendances, admissions to hospital, and the associated costs to the National Health Service (NHS) and Personal Social Services (PSS) as a result of unintentional falls among older people (aged 60 and over) in the UK in 1999. Scuffham estimated that there were 647,721 A&E attendances and 204,424 admissions to hospital for fall related injuries in people aged 60 years and over and that these falls cost the UK government £981 million with 59% of these costs being incurred by the NHS: the major costs arose from falls among people aged 75 years or over, or those requiring inpatient admission or long term care as a consequence of their fall (Scuffham et al. 2003).

1.4.4 Frailty

Frailty is a multidimensional geriatric syndrome (Bauer and Sieber 2008); it may be described as a state of increased vulnerability which results from decreased physiological reserves, multi-system dysregulation and limited capacity to maintain homeostasis (Abellan van Kan et al. 2008). Although overlapping, frailty is not synonymous with co-morbidity or disability (Fried et al. 2004;Wong et al. 2010). Rather, co-morbidity may be considered a risk factor for frailty and disability a consequence of frailty (Fried et al. 2001).

The Fried criteria (Fried et al. 2001) are the most widely implemented objective approach to the classification of frailty as a biological functional limitation or impairment (Morley et al. 2006), defining physical frailty as present if a person has at least three of the following criteria: weight loss, weakness, exhaustion, slowness and low activity (Fried et al. 2001). Thus defined, the prevalence of frailty among the 5,317 community dwelling men and women aged 65 years and older who participated in the American Cardiovascular Health Study was 6.9% with a four year incidence of 7.2%; frailty was associated with older age and conferred a high risk for falls, disability, hospitalisation and mortality (Fried et al. 2001). However, the prevalence of Fried frailty varies widely according to study setting and the exact implementation of the Fried criteria in different epidemiological studies.

Although loss of muscle mass and function contribute to both the EWGSOP definition of sarcopenia (Cruz-Jentoft et al. 2010) and the Fried definition of frailty (Fried et al. 2001), Cooper et al. have recently emphasised that physical frailty and sarcopenia are distinct components of musculoskeletal ageing (Cooper et al. 2012).

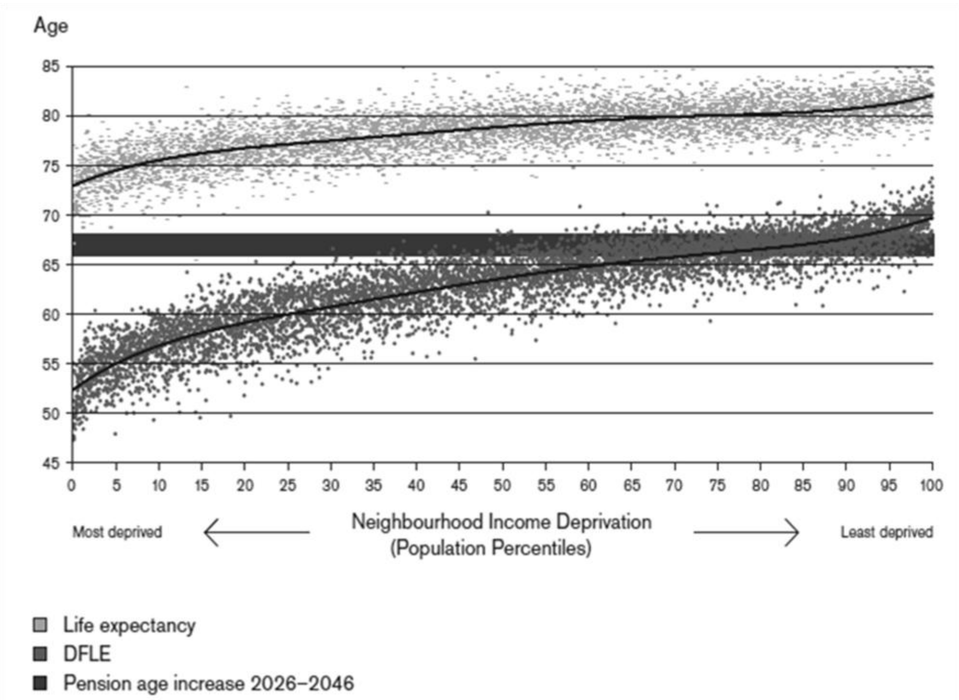
1.4.5 Osteoporosis

Osteoporosis is a skeletal disorder characterised by low bone mass and microarchitectural deterioration of bone tissue which predisposes to fracture (Harvey and Cooper 2003), typically of the hip, spine or wrist. The prevalence of osteoporosis increases rapidly with older age (Sambrook and Cooper 2006) and it has been estimated that the remaining lifetime risk of fracture at the hip, spine or wrist is 40% among white women and 13% among white men at age 50 years (Melton et al. 2005). The annual cost to the NHS of managing osteoporotic fractures is £2.1 billion, with over 80% of this figure attributable to hip fracture (Kanis et al. 2008). These costs demonstrate that osteoporosis is a major public health issue for society, but the burden of osteoporosis for the affected individual is also high; fracture is typically associated with hospitalisation, increased risk of subsequent mortality, long term morbidity and loss of function (Walker-Bone et al. 2001). In the United States, 8% of men and 3% of women aged over 50 years die while hospitalised for their fracture and one year after hip fracture, mortality is 36% for men and 21% for women (Walker-Bone et al. 2001). Approximately 7% of survivors of all types of fragility fracture have some degree of permanent disability and 8% require long-term nursing home care. Hip fracture is a particularly disabling event; one year after hip fracture, 40% of patients are still unable to walk independently and 60% require assistance in at least one essential activity of daily living (e.g. dressing, bathing) (Walker-Bone et al. 2001).

1.5 Social inequalities in health

Social inequalities in health have long been recognised (Marmot 2001) and persist across relative levels of deprivation irrespective of absolute standards of living (Wilkinson 1997). Although the overall health of the UK population has steadily improved over the last century, social inequalities in health widened in the latter part of the 20th century. For example, between 1972 and 1976 the gap in life expectancy at birth between men in social classes I and V was five and a half years but this inequality had widened to seven and a half years by the period 1997 to 1999 (Coulthard et al. 2004). In 2010, the Marmot Review (Marmot 2010) emphasised that the association between social circumstances and health is not restricted to differences between the best-off and worst-off in society; rather there is a graded association between social circumstances and health, referred to as the social gradient in health. In England, people living in the poorest neighbourhoods will, on average, die seven years earlier than people living in the richest neighbourhoods and the average difference in disability-free life expectancy is 17 years (Figure 1).

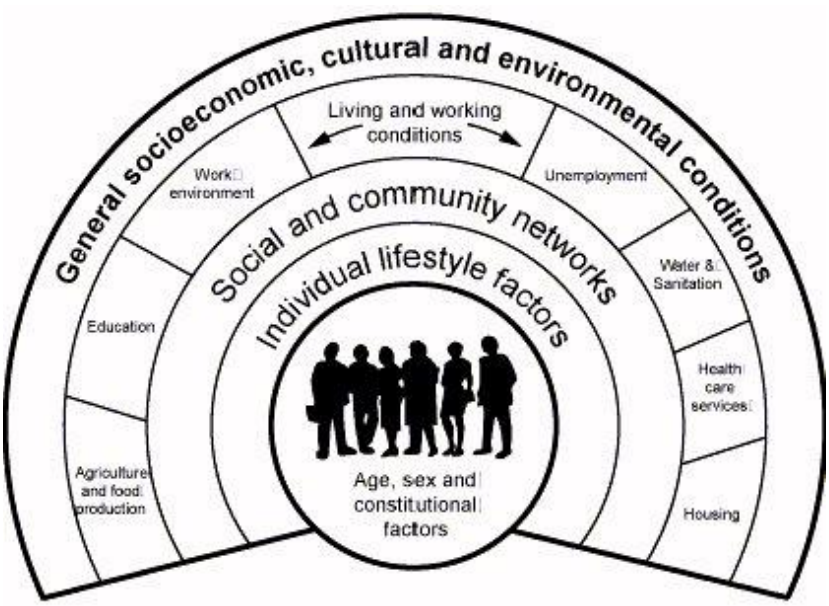
Figure 1 Life expectancy and disability free life expectancy (DFLE) at birth, persons by neighbourhood income level, England, 1999-2003



(reproduced from figure 1.1, page 38 in (Marmot 2010))

Dahlgren and Whitehead's framework for determinants of health (Dahlgren and Whitehead 1991) proposed that all personal behaviours and characteristics which influence health are nested within, and are influenced by, layers of social determinants of health ranging from social and community influences such as friendship patterns and behaviour norms within communities, to the more general socioeconomic conditions in which these sit, including housing, living conditions, access to health care services, work environment and education (Figure 2). In keeping with this framework, the Marmot Review argued that inequalities in health do not arise by chance and cannot be attributed simply to differences in genetic make-up, 'bad' unhealthy behaviours, or difficulties in access to medical care. Rather, social inequalities in health reflect, and are caused by, social and economic inequalities in society i.e. differences in the conditions in which people are born, grow, live, work and age.

Figure 2 Determinants of health

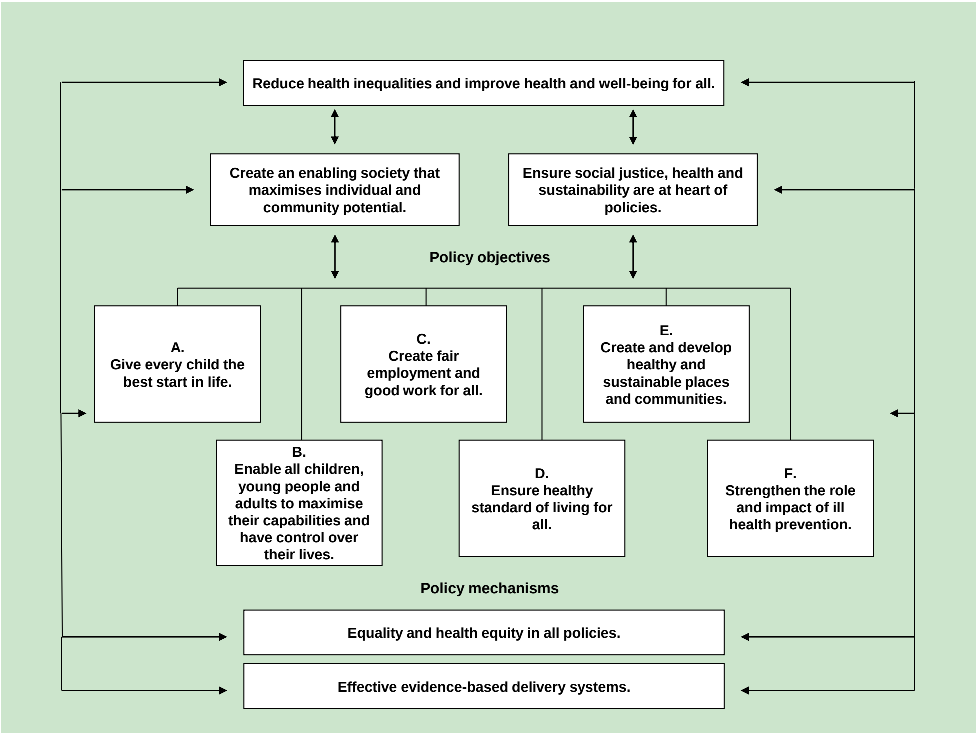


(reproduced from (Dahlgren and Whitehead 1991))

The Marmot Review's framework for action concerned the social determinants of health in their widest sense and emphasised that involvement is required from all central and local government departments as well as the third and private sectors if the social gradient in health is to be reduced; action taken by the Department of Health (DH) and the NHS alone will not be sufficient to reduce health inequalities. The Marmot Review also emphasised that to reduce the steepness of the social gradient in health, actions must be universal, but with a scale and intensity that is proportionate to the level of disadvantage; Marmot called this proportionate universalism.

The Marmot Review's conceptual framework for action had twin overarching aims i.e. to improve health and well-being for all and to reduce health inequalities (Figure 3).

Figure 3 Marmot Review conceptual framework for action



(reproduced from figure 1.3, page 41 in (Marmot 2010))

The review took a lifecourse perspective on social inequalities in health and emphasised that disadvantage starts before birth and accumulates throughout life. The framework therefore proposed action on health inequalities across all stages of the lifecourse with six main policy objectives ranging as follows (Figure 3): give every child the best start in life (policy objective A); enable all children, young people and adults to maximise their capabilities and have control over their lives (policy objective B); create fair employment and good work for all (policy objective C); ensure a healthy standard of living for all (policy objective D); create and develop healthy and sustainable places and communities (policy objective E); and strengthen the role and impact of ill-health prevention (policy objective F). While emphasising that interventions to narrow the social gradient in health should be targeted from birth onwards, the review noted that action on the services which promote the health, well being and independence of older people and which prevent or delay the need for more intensive or institutional care can also make a significant contribution to narrowing health inequalities now and in the future. The Marmot review emphasised that current and future strategies and policies to reduce the social gradient in health must take into account that the UK population is ageing and that the burden of lifelong ill-health and disability on health and social care systems is only going to increase.

Policy objective F of the Marmot review, i.e. to strengthen the role and impact of ill-health prevention, has particular relevance to the focus of this thesis. The priority objectives within policy F were to prioritise prevention and early detection of those conditions and health behaviours most strongly related to health inequalities and to increase availability of long-term and sustainable funding in ill-health prevention across the social gradient. However, the evidence presented in the Marmot Review focused heavily on inequalities in life expectancy, mortality, circulatory disease and cancer, mental health, well-being, limiting long term illness, disability and risk factors such as smoking, alcohol, physical inactivity and obesity and drug use; little attention was given to musculoskeletal ageing and yet, as described above, musculoskeletal disorders have a major impact on both acute and long-term disability and their burden on health and social care systems will only increase as the population ages. The focus of the Marmot Review was of course partly guided by previous reviews of social inequalities in health in the UK (i.e. the Acheson and Black reports (Acheson 1998;Townsend and Davidson 1982)) and the policy objectives on health inequalities in force at the time; the Public Service Agreement (PSA) targets during the period of the Marmot review had been set in 2001 after publication of the Acheson report and had the principal aims of reducing inequalities in health outcomes in infant mortality and life expectancy by 2010. The absence of any main focus on social inequalities in musculoskeletal ageing in the Marmot Review adds to the novelty and relevance of this thesis.

In summary, social inequalities in health are widely recognised but little is known about social inequalities in musculoskeletal ageing.

1.6 Thesis Structure

1.6.1 Overview

This thesis examines the evidence for social inequalities in five specific aspects of musculoskeletal ageing among the community dwelling men and women who participated in the Hertfordshire Cohort Study (HCS): (i) loss of muscle strength; (ii) loss of physical function; (iii) falls; (iv) frailty, and (v) osteoporosis. The thesis follows a 'three-papers' structure.

Chapter 2 comprises a 'data and methods' chapter. Sections 2.1 to 2.3 describe the origin of the Hertfordshire Cohort Study and the wealth of data available for HCS participants. The recruitment of the HCS participants is described in detail and the phasing of the HCS fieldwork by region of the county and over time is explained. The markers of socioeconomic position and material deprivation available in HCS are described in section 2.4.1 and the advantages, disadvantages and caveats for interpretation of analyses based on the various measures are discussed. The particular challenges involved in characterising socioeconomic position among older people are outlined. Section 2.4.2 explains the musculoskeletal ageing phenotypes that are available in HCS; these phenotypes are summarised and the inter-relationships between them are presented. Section 2.4.3 indicates the potential effect mediators and confounders that were available in HCS and which were included in the analysis strategy for papers 1 to 3. Section 2.5 appraises the potential sources of response bias in the various stages of recruitment of the HCS participants and concludes that there is, unsurprisingly, evidence for a healthy participant effect in HCS. Section 2.5.2 compares the characteristics of the HCS participants with those in the nationally representative Health Survey for England and contrasts the distribution of housing tenure and household car availability among HCS participants with that in the county of Hertfordshire, and England as a whole, in the 2001 census. Chapter 2 closes with an overview of the statistical methods utilised throughout the thesis (section 2.6); note that papers 1 to 3 also include their own specifically relevant statistical methods sections.

Chapter 3 comprises paper 1 and describes social inequalities in grip strength, physical function and falls in the HCS; this work has been published in the Journal of Aging and Health (Syddall et al. 2009). Chapter 4 comprises paper 2 and describes the prevalence, and lifestyle and social determinants, of frailty among HCS men and women; this work has been published in Age and Ageing (Syddall et al. 2010). Chapter 5 comprises paper 3 and explores social inequalities in fracture and osteoporosis among HCS men and women; this work has been published in Archives of Osteoporosis (Syddall et al. 2012).

Chapter 6 is the overarching Discussion chapter for the thesis. Section 6.1 recaps, and compares and contrasts, the key results from papers 1 to 3. With reference to both the literature and further analysis of HCS data, section 6.2 considers mechanisms underpinning social inequalities in health and examines the potential role of lifestyle choices and health behaviours (specifically anthropometry, physical activity, diet, smoking and alcohol consumption) in mediating the specific pattern of results presented in papers 1 to 3. Section 6.3 discusses the strengths and limitations of the thesis, section 6.4 outlines possibilities for future research and section 6.5 places the thesis in its policy context and discusses the wider relevance of the thesis for current health and social care policy. Chapter 7 recaps the research presented in the thesis and draws final conclusions.

1.6.2 Chronology of preparation of the thesis

The candidate had worked as a medical statistician for many years prior to registration for a PhD and had experience in the process of preparation of an academic paper but did not have any specific knowledge about social inequalities in health or gerontology; as a consequence, to a degree this thesis was prepared ‘inside-out’. During the first year of PhD registration the candidate conducted relevant literature searches and undertook background reading on social inequalities in health, gerontology and the demography of ageing, and conducted the statistical analyses for papers 1 and 2 and prepared and submitted the manuscripts to the Journal of Ageing and Health and Age and Ageing respectively. The candidate prepared an outline of the Introduction chapter during the first year of PhD registration. Note that the candidate suspended PhD registration for two calendar years between years 1 and 2 owing to maternity leave. During the second year of PhD registration the candidate continued relevant overarching background reading and conducted the specific literature searches, reading and statistical analyses for paper 3; the candidate submitted this paper to Archives of Osteoporosis. The candidate also wrote the majority of Chapter 2 (data and methods) during the second year of PhD registration. In the third and final year of registration the candidate compared and contrasted the specific evidence for social inequalities in musculoskeletal ageing presented in the three papers and considered the potential mediating role of lifestyle choices and health behaviours in generating these results. During this year of registration the candidate also conducted extensive literature searches, wider reading, further analysis of HCS data, completed the Introduction chapter, wrote the Discussion and Conclusions chapters, wrote the Abstract and formatted the thesis.

Chapter 2. Data and methods: the Hertfordshire Cohort Study (HCS)

2.1 Overall objectives of the Hertfordshire Cohort Study

The principal objective of the Hertfordshire Cohort Study is to evaluate interactions between the genome; the intra-uterine and early postnatal environment; and adult diet and lifestyle in the aetiology of chronic disorders in later life (cardiovascular disease, type II diabetes mellitus and obesity; osteoporosis, osteoarthritis and sarcopenia). The study aims to place these interactions within a life-course model for disease pathogenesis, and to characterise the physiological mechanisms underlying the pathways to these chronic disorders e.g. re-setting of hypothalamic-pituitary-adrenal, growth hormone, or insulin-like growth factor-1 axes.

The Hertfordshire Cohort Study was established by Prof. David Barker and members of the Hertfordshire Cohort Study Group based at the MRC Environmental Epidemiology Unit (MRC EEU), University of Southampton. In 2003, direction was passed to Prof. Cyrus Cooper and based in the reconfigured MRC Epidemiology Resource Centre (subsequently renamed the MRC Lifecourse Epidemiology Unit), University of Southampton. The Medical Research Council was the principal source of funding, but this multi-stakeholder study has also received grants from the British Heart Foundation, Arthritis Research Campaign, National Osteoporosis Society, Wellcome Trust, and University of Southampton.

2.2 The origin of the Hertfordshire Cohort Study

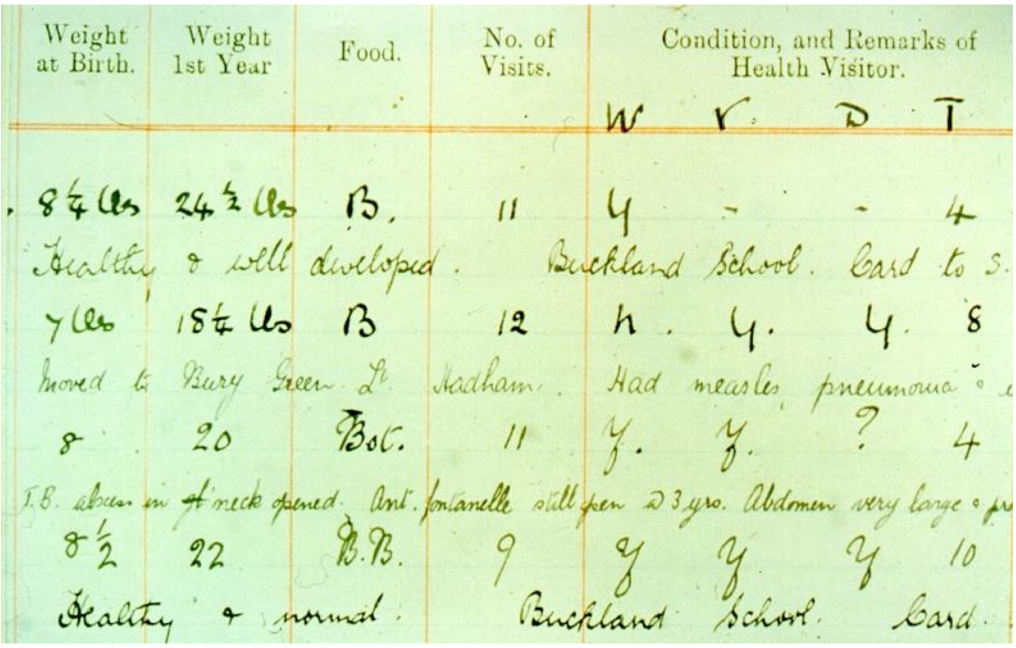
Ecological studies conducted in the 1980’s demonstrated a close geographic correlation between death rates from coronary heart disease during 1968-78 in different parts of England and Wales and the infant mortality rate in those areas sixty years previously (Barker and Osmond 1986;Osmond et al. 1993). These studies suggested that adverse environmental influences acting in utero and during infancy might increase the risk of cardiovascular disease in later life. However, this hypothesis required investigation using more robust epidemiological techniques. To yield results within a relatively short space of time, a cohort study was needed which linked information about the early environment of individuals born at least sixty years previously to their health outcomes in later life. As part of a nationwide search of archives, staff working at the MRC EEU discovered a large set of records maintained in Hertfordshire during the early twentieth century.

2.2.1 The Hertfordshire records

In the early twentieth century there was widespread concern about the physical deterioration of the British people (Barker 2003). In 1911, Ethel Margaret Burnside (Hertfordshire's first "chief health visitor and lady inspector of midwives") assembled a team of midwives and nurses charged with improving the health of children in Hertfordshire.

A midwife attended women during childbirth and recorded the birth weight of their offspring on a card. A health visitor subsequently went to each baby's home throughout its infancy and recorded its illnesses, development and method of infant feeding; the baby was then weighed again at one year of age. This information was transcribed into ledgers at the Hertfordshire county office (Figure 4). The ledgers cover all births in Hertfordshire from 1911 until the NHS was formed in 1948.

Figure 4 An extract from the Hertfordshire ledgers



2.2.2 Studies based on men and women born in Hertfordshire 1911-30

The MRC EEU computerised the Hertfordshire ledgers and used the National Health Service Central Register (NHSCR) to identify mortality outcomes by the end of 1992 for 15,000 men and women born in Hertfordshire between 1911-30. Increased risk of death from cardiovascular disease was found to be related to low birth weight in these men and women, and to low weight at one year among the men (Osmond et al. 1993). This was the first study based on individual (rather than ecological) level data to demonstrate such relationships. Having studied mortality, the next stage was to explore the relationship between the early environment and a range of morbidity outcomes in surviving members of the cohort.

Detailed physiological investigations of men and women born in Hertfordshire between 1920-30 and still living there in the early 1990's were conducted. These studies ranged in size from 224 to 468 men, and 189 to 306 women. Small size at birth and during infancy was shown to be associated with increased risk of developing coronary heart disease and type II diabetes mellitus (Fall et al. 1995;Hales et al. 1991), the metabolic syndrome and insulin resistance (Barker et al. 1993), osteoporosis (Cooper et al. 1997) and sarcopenia (Sayer et al. 1998) in later life. These studies led to the "developmental origins" hypothesis which states that the nourishment a baby receives from its mother during pregnancy, and its nutrition and illnesses in infancy and early childhood, determine its susceptibility to disease in later life.

2.3 Men and women born in Hertfordshire 1931-39: The Hertfordshire Cohort Study

The early Hertfordshire studies described above were important for establishing relationships between the early environment and physiological markers of disease but: they were too small a sample for investigation of the early environment and adult risk factors in the aetiology of clinical outcomes (such as incident or fatal coronary heart disease, cerebrovascular disease or osteoporotic fracture); the sample size was inadequate for research into gene-environment interactions; detailed information on adult anthropometry and diet was unavailable; and the men and women born 1920-30 were becoming too frail to take part in further studies. As a consequence, a younger cohort of 3000 men and women born in Hertfordshire 1931-39, and included in the Hertfordshire records described above, was recruited to a new study referred to as the Hertfordshire Cohort Study (HCS).

2.3.1 Who is in the Hertfordshire Cohort Study sample?

The recruitment process of the HCS participants is shown in Figure 5. The ledgers contained records for 42 974 births in Hertfordshire between 1931 and 1939; 39 764 of these were live born. Multiple births, deaths during childhood, records with missing birth weight or weight at one year, or with insufficient tracing information were excluded and the details of the remaining 24 130 boys and girls were sent for tracing by the National Health Service Central Register (NHSCR) in Southport. 8650 men and women were traced as still alive in Hertfordshire in 1998 and the Hertfordshire Family Health Services Authority (FHSA) confirmed that 7106 of these were currently registered with a Hertfordshire General Practitioner (GP); these men and women comprised the HCS target population. Permission to contact 6099 (86%) men and women by letter was obtained from their GP's and 1684 (54%) men and 1541 (52%) women aged 59-73 years took part in a nurse administered home interview of whom 1579 (94%) men and 1418 (92%) women subsequently attended a clinic for detailed physiological investigations (herein referred to as the HCS baseline interview and clinic, Figure 5).

The HCS fieldwork was conducted between 1998 and 2004 and phased by region of the county for practical reasons; 737 of the men and 675 of the women who participated in the HCS baseline clinic were resident in East Hertfordshire. Bone mineral content (BMC), bone area and bone mineral density (BMD) were measured in a subgroup of 498 (68%) of these men and 468 (69%) of these women by dual-energy X-ray absorptiometry at the proximal femur using a Hologic quantitative digital radiography (QDR) 4500 instrument (Dennison et al. 2005); herein referred to as the HCS baseline DXA scan (
Figure 6). Individuals taking drugs known to alter bone metabolism (such as bisphosphonates) were excluded from this part of the study, although women taking Hormone Replacement Therapy (HRT) were allowed to participate. There were no other exclusion criteria to this part of the study, and subjects were approached for consent as they attended the baseline HCS clinic.

In 2004-5, a follow-up study was performed in East Hertfordshire (Dennison et al. 2010;Oliver et al. 2007); herein referred to as the East Hertfordshire follow-up study (
Figure 6). In brief, of the original 498 men and 468 women who had undergone the HCS baseline DXA scan, 8 had died, 6 had moved away, we were unable to obtain GP permission to approach 4 people, 47 were no longer on family doctor lists, and 17 were unavailable. Consequently, 437 men and 447 women were invited to take part in the follow-up study. Of these, 322 men (74%) and 320 women (72%) agreed to attend a follow-up clinic where frailty was assessed according to the Fried criteria (Fried et al. 2001) and DXA bone mineral measurements of the total femur were repeated, enabling calculation of annualised percentage change in bone mineral density at this site. Peripheral quantitative computed tomography (pQCT) was also performed of the radius and tibia (non-dominant side) using a Stratec 4500 instrument for 313 (97%) of the men, and 318 (99%) of the women (Oliver et al. 2007).

In 2007, a cohort-wide postal questionnaire was used to ascertain clinical outcomes, including fracture, since the baseline HCS clinic; herein referred to as the HCS clinical outcomes study (

Figure 6). Of the original 2997 baseline clinic participants, 157 had died, 48 had moved away and 15 had withdrawn from the study (due to illness or at the participant's request). Hence, the questionnaire was posted to 2777 HCS participants of whom 2299 (83%) replied; 1093 of the men and 1049 of the women provided information on incident fractures since the HCS baseline clinic.

The entire cohort is also being followed up through primary care and hospital records over a 15-year period (1998-2013), for clinical outcomes including incident coronary heart disease, cerebrovascular disease, chronic airflow obstruction and fracture. The cohort members are flagged with the NHS Central Register for notification of deaths.

All interviews and physiological investigations were carried out according to strict protocols and intra- and inter-observer studies were conducted at regular intervals during the fieldwork to ensure comparability of measurements obtained over several years (HCS baseline clinics were completed in late 2004). The study has ethical approval from the Hertfordshire and Bedfordshire Local Research Ethics Committee and all participants have given written informed consent.

Figure 5 Recruitment of the Hertfordshire Cohort Study participants

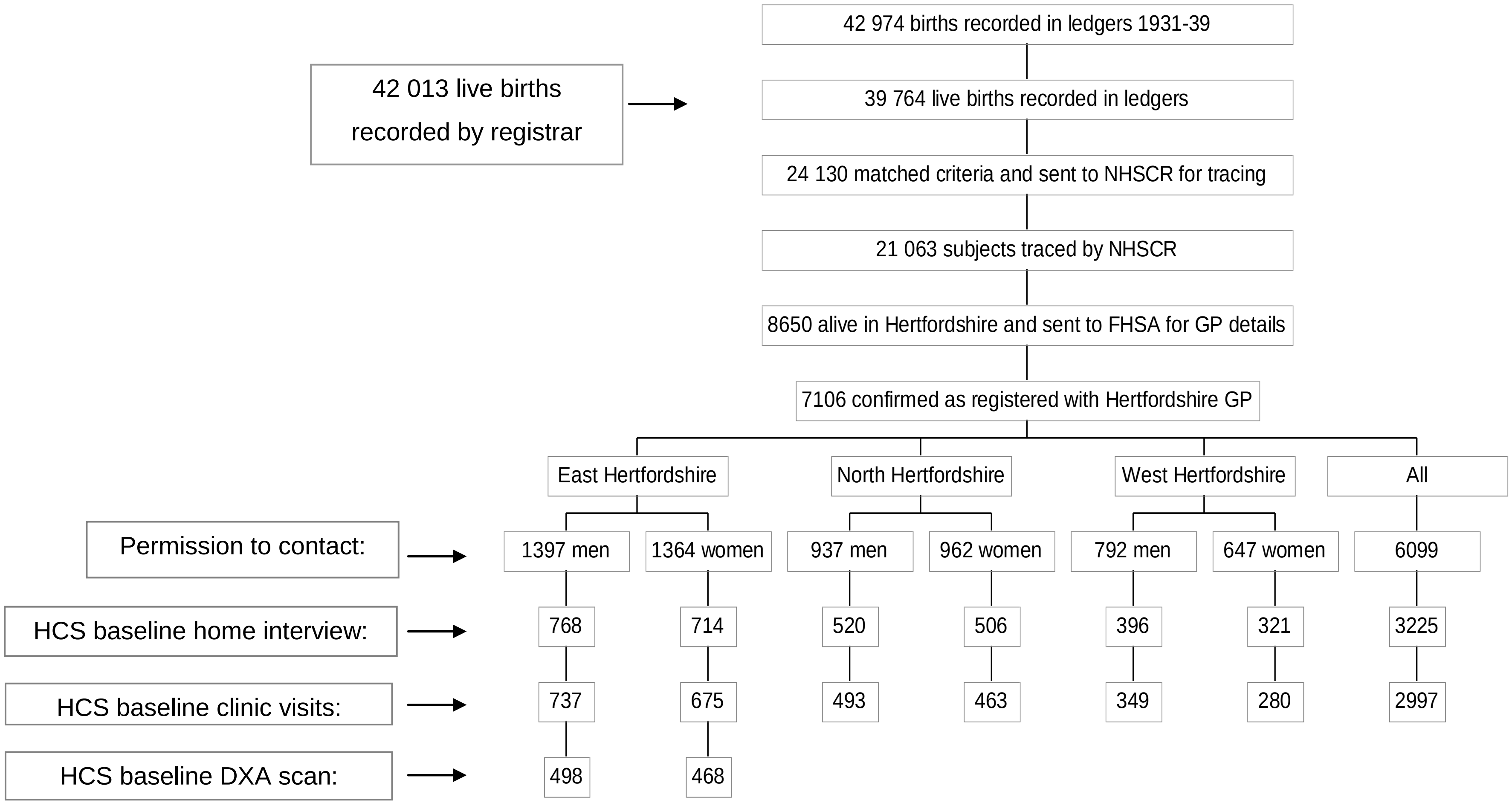
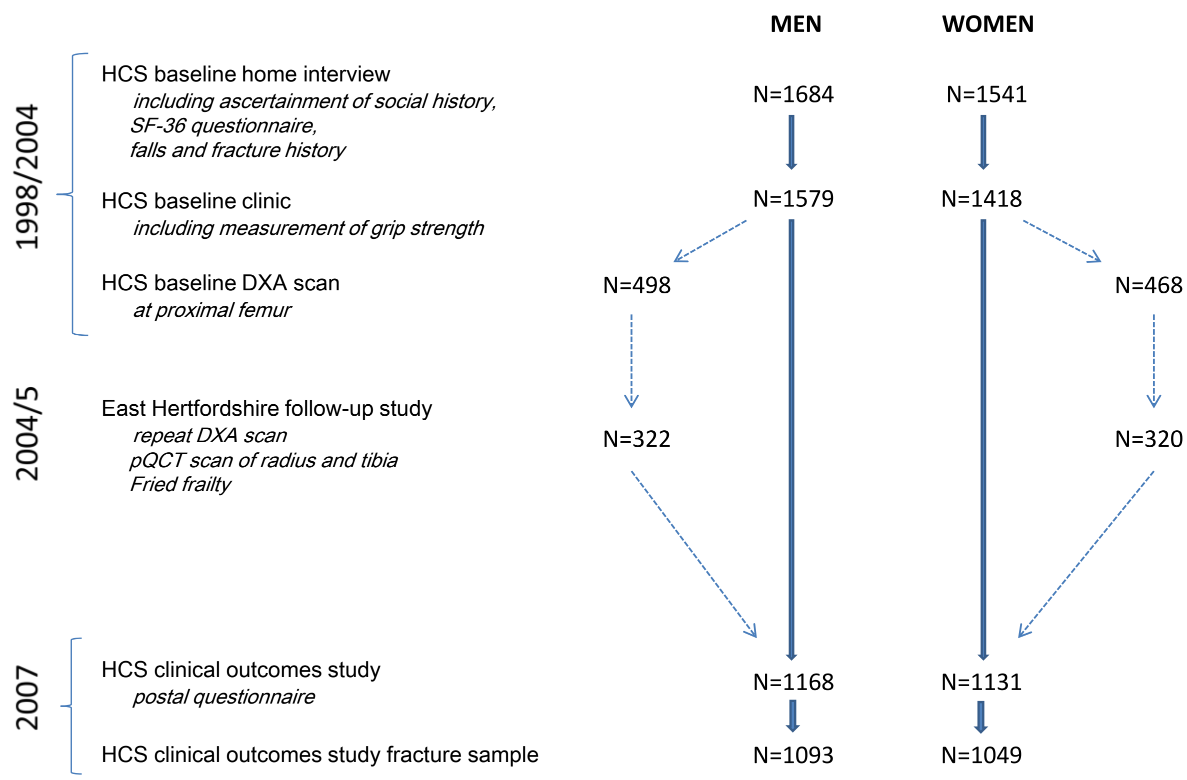


Figure 6 Phases of data collection for the Hertfordshire Cohort Study (HCS)



2.4 What has been measured?

Data collected during the HCS baseline home interviews and clinic visits are outlined in Table 1 and Table 2. The characterisation of socioeconomic position and material deprivation in HCS is described in section 2.4.1; section 2.4.2 outlines the musculoskeletal ageing phenotypes available in HCS; section 2.4.3 details the potential confounders available in HCS which are relevant to the papers presented in this thesis. Full details of the data collection methods for relevant variables are provided in the specific methods sections of papers 1 to 3.

Table 1 Data available from the HCS baseline home interview

HCS Home interview	
	Marital status
	Age left full-time education
	Housing tenure
	Car availability
	Family history including father's social class
	Physical activity
	Cigarette smoking and alcohol consumption
	Obstetric history
	Occupational history and current social class
	Rose/WHO chest pain and leg pain questionnaires
	Severe chest pain and previous coronary surgery
	Respiratory symptoms (MRC questionnaire)
	Fracture history (own and of parents and siblings)
	Lower back pain
	Medical history (including stroke and diabetes)
	Current medications
	Falls
	Self-rated general health
	SF-36 health related quality of life
	Hospital anxiety and depression (HAD) scores
	Current diet assessed using an administered food frequency questionnaire and 24-hour food diary
	Nutrient intake from dietary supplements
	Social support and networks
	Job effort-reward and demand-control

Table 2 Data available from the HCS baseline clinic visit and baseline DXA scan

HCS Baseline Clinic Visit

Height; weight; waist, hip, mid-upper arm and thigh circumferences
Triceps, biceps, subscapular and suprailiac skinfold thicknesses (Harpenden calipers)

Blood pressure and pulse rate (Dinamap recorder)
Lung function (FEV_1 and FVC, Micro Spirometer, Micro Medical)

Standard 12-lead electrocardiography (1982 Minnesota protocol)

Venous blood samples after 12 hour overnight fast:

- Glucose
- Insulin and proinsulin precursors
- Total, HDL and LDL cholesterol
- Triglycerides
- Apolipoprotein A1 and B
- Vitamin C
- Frozen plasma and sera stored for future measurements

Two hour timed 75g oral glucose tolerance test

- Glucose and insulin 30’ and 120’ post load

DNA extracted from whole blood samples

Timed overnight urine collection

Grip strength (Jamar hand-grip dynamometer)
Quadriceps strength (West Hertfordshire only, Lafayette MMT strength system)
Timed 6m up-and-go test and 3m walk
Chair rises
Timed one-legged stand

Clinical hand examination for pain, swelling and tenderness

HCS baseline DXA scan (East Hertfordshire)

Bone mineral density at lumbar spine and proximal femur (Hologic QDR4500)

2.4.1 Socioeconomic position (SEP) and material deprivation

2.4.1.1 Overview of characterisation in HCS

Socioeconomic position and material deprivation among the men and women at HCS baseline home interview were specifically characterised by: social class at birth based on the father’s occupation at the time of the participant’s birth; age of leaving full-time education; current social class; and housing tenure and car availability for household use as markers of material deprivation (Arber and Ginn 1993;Wiggins et al. 2002). The wider relevance of these markers of socioeconomic position and material deprivation and the challenges of characterising socioeconomic position among older people is outlined in sections 2.4.1.2 to 2.4.1.6. No direct measures of income or wealth were ascertained in the Hertfordshire Cohort Study.

Registrar General's social class at birth, and currently, was coded from the 1990 OPCS Standard Occupational Classification (SOC90) unit group for occupation (Office of Population Censuses and Surveys 1990) using computer assisted standard occupational coding (Elias et al. 1993). Current social class was coded from own current or most recent full-time occupation for men and never-married women, and from husband's occupation for ever-married women (Arber and Ginn 1993).

2.4.1.2 Wider relevance of HCS markers of SEP and material deprivation

Socioeconomic position (SEP) refers to the social and economic factors that influence which positions individuals or groups hold within the structure of a society (Galobardes et al. 2006a). SEP is a complex multidimensional concept which reflects the composite of an individual's social class, social status and material circumstances (Blane 2006). Social class refers to the position of an individual's occupation in the structure of employment relations and conditions. Social status, in contrast, refers to a hierarchy of prestige accorded to an individual which is not necessarily dependent on an individual's occupation. For example, an individual may be an employee with no managerial power yet have high status owing to membership of the clergy or, in some cultures, may be perceived to have high status if they are descended from a particular caste or land-owning family, irrespective of their present-day occupation.

There is no single best indicator of SEP (Galobardes et al. 2006a) but the markers ascertained in HCS may be regarded as having the broad strengths and limitations as outlined in the following sections.

2.4.1.3 Registrar General's social class based on occupation

This scale is based on the prestige or social standing that a given occupation has in society and has been widely used in UK official statistics and research. Epidemiological studies have typically used an individual's current, most recent or longest held occupation to characterise adult SEP. Social inequalities in health outcomes have been widely demonstrated using this measure (Galobardes et al. 2006b).

In practice, Registrar General's social class is often interpreted as an indicator of both social standing and material reward and resources. The broad mechanisms that may underpin associations between occupationally based social class and health outcomes include: a direct impact of occupation on income, material resources and consequent health; occupation as a reflection of improved social standing with associated better access to health care, education and quality housing; occupation as a reflection of social networks and work based stressors, control and autonomy which could all impact on health through psychosocial mechanisms (Galobardes et al. 2006b).

Social class based on occupation clearly cannot be identified for people who are not currently employed, although most recent full-time occupation may be brought forward to characterise SEP for retired men and women, and a married woman may be assigned a social class based on her husband's occupation. These approaches may not provide an ideal reflection of the current social circumstances of the individuals involved but assigning a married woman a social class based on her husband's occupation is an approach which has been widely used in epidemiological studies and is reasonable for women of the age range of the HCS participants in whom labour market participation rates were relatively low although is less appropriate for contemporary cohorts of women (Galobardes et al. 2006b). A further limitation of Registrar General's social class is the subjectivity of the ranking of occupations underlying the classification and its inability to reflect recent changes in UK occupational structure such as increases in service jobs, decreases in unskilled occupations and the increasing participation of women in the labour market in recent decades (Galobardes et al. 2006b). The UK National Statistics socioeconomic classification (NSSEC) has replaced the Registrar General's social class as the UK's official occupation classification but this was only introduced and widely adopted during the HCS fieldwork; Registrar General's social class has therefore been coded for HCS participants as the classification in force at the time of the HCS fieldwork.

2.4.1.4 Education

Formal education is normally completed in young adulthood and is strongly determined by parental characteristics; within a lifecourse framework it may therefore be regarded as an individual level indicator which in part measures early life SEP. Education captures the transition from received (parental) to own (adult) SEP and is a determinant of future employment and income. When analysed in relation to health outcomes, it may be regarded as capturing the long-term influences of both early circumstances and the influence of adult resources, through employment status, on health (Galobardes et al. 2006a).

However, the generalisability of epidemiological findings pertaining to education must be considered relative to the context of the birth cohort and geographical setting of the study in question and with due consideration of any temporal changes in educational opportunities which may have arisen, particularly for women (Galobardes et al. 2006a).

2.4.1.5 Housing tenure and car availability

Housing characteristics reflect material aspects of socioeconomic position. Housing is generally the key component of most people's wealth and accounts for a large proportion of household expenditure (Galobardes et al. 2006a).

The most commonly used household level characteristic is housing tenure i.e. whether housing is owner-occupied (owned outright or mortgaged), or rented from a private or social landlord. However, housing tenure does not reflect housing condition; for example, an individual may owner-occupy their residence but it may be in poor condition and lack facilities such as central heating or an inside toilet. Access to household amenities is therefore also used as a marker of material circumstances in epidemiological studies. One amenity which has proven to be a useful marker of SEP in the UK is car availability, although this may not be the best reflection of underlying SEP either in rural areas of the UK where even relatively poor households require a car out of necessity, or in urban areas such as Greater London where good public transport systems render car ownership unnecessary irrespective of levels of income or housing tenure (Galobardes et al. 2006a).

Housing tenure and car availability are extensively used as measures of SEP and have been shown to predict longevity and health in many epidemiological studies (Macintyre et al. 2001). It could be argued that their impact on health principally arises because they reflect broader underlying material assets and circumstances, income or indeed psychological traits such as self esteem. However, in a series of papers based on data from Scotland, Macintyre has suggested that this is not the case. Rather, housing tenure and car availability appear to have some directly health promoting or damaging effects independently of income, social class and self-esteem (Macintyre et al. 1998;Macintyre et al. 2001). Macintyre argues that housing tenure could also have an influence on health by exposing people to different levels of health hazards in the dwelling itself or in the immediate surrounding area (Ellaway and Macintyre 1998;Macintyre et al. 2003).

2.4.1.6 Challenges of characterisation among older people

Research into social inequalities in health requires markers of socioeconomic position which provide a manageable number of classifications while at the same time providing a sensitive, hierarchical classification which facilitates exploration of gradients in health; identification of relevant markers among older people is a particular challenge (Alwan et al. 2007;Bowling 2004). Firstly, many people aged 65 years and over are retired which calls in to question the relevance of occupationally based measures of socioeconomic position for studies of older people who have mainly left the labour market (Hyde and Jones 2007). Secondly, older people may be sensitive about providing information on their sources and amount of income. Thirdly, care must be taken to avoid the use of markers of socioeconomic position which may be a reflection of, possibly declining, health status if problems of reverse causation are to be avoided. For some individuals, poor health in later years may have resulted in early retirement or change to a less demanding job, or both, thereby impacting on the social class identified from that individual's last full-time occupation (Bowling 2004). Fourthly, some widely used markers of socioeconomic position may not provide sufficient discrimination between older people. For example, education is a marker of socioeconomic position which suffers less from the problem of reverse causation than occupationally based social class but many current older members of the UK community, including the HCS participants, will have left school at the minimum age with the consequence that only the most advantaged groups who underwent higher education may be distinguished from others (Bowling 2004).

Housing tenure is a marker of material circumstances which is relevant to all community dwelling older people; the availability of housing wealth as a potential source of income in old age acts to differentiate people at later stages of the lifecourse and reflects an accumulation of advantages or disadvantages across the lifecourse (Arber and Evandrou 1993). However, housing tenure does carry the disadvantage that most members of the UK population fall in to the advantaged group of those who own or mortgage own their home, thereby providing limited opportunity for exploration of variations in health across a wide social gradient. Moreover, use of housing tenure as a marker of material circumstances requires more care amongst the oldest old, many of whom may have had to move to live with relatives as a consequence of increasing frailty; fortunately this is was not a concern for the age range of the Hertfordshire Cohort Study participants (59 to 73 years).

Car availability is a marker of current material circumstances which may provide greater separation between older people than housing tenure but which is likely to be more influenced by reverse causation owing to cessation of driving as a consequence of failing health; again, this is perhaps of limited concern across the age range of the Hertfordshire Cohort Study participants.

In spite of their limitations, housing tenure and car availability have been shown to predict longevity and health in many studies (Macintyre et al. 2001) and a clear social gradient in self-assessed health and functional disability has been demonstrated across levels of housing tenure and car availability, independent of social class, among older men and women who participated in the General Household Survey (Arber and Ginn 1993). These previous studies suggest that housing tenure and car availability, in conjunction with social class and education, comprise an appropriate panel of markers of socioeconomic position for investigation of social inequalities in musculoskeletal ageing among the Hertfordshire Cohort Study participants.

2.4.1.7 Summary characteristics in HCS

Table 3 summarises the markers of socioeconomic position and material deprivation among participants in the HCS baseline home interview.

Table 3 Socioeconomic position and material deprivation among participants in the HCS baseline home interview

n(%)		Men (n=1,684)	Women (n=1,541)
Socioeconomic position at birth			
Social class at birth[+]	I Professional	20 (1.3)	12 (0.8)
	II Management and Technical	111 (7.0)	120 (8.3)
	IIINM Skilled non-manual	118 (7.5)	106 (7.4)
	IIIM Skilled manual	707 (44.7)	692 (48.0)
	IV Partly skilled	440 (27.8)	393 (27.3)
	V Unskilled	185 (11.7)	119 (8.3)
Socioeconomic position in adulthood			
Age left full-time education (years)*		15 (15,16)	15 (15,16)
Left full-time education aged ≤14 years		327 (19.4)	276 (17.9)
Social class in adulthood**	I Professional	107 (6.6)	84 (5.5)
	II Management and Technical	395 (24.2)	347 (22.5)
	IIINM Skilled non-manual	165 (10.1)	209 (13.6)
	IIIM Skilled manual	638 (39.1)	593 (38.5)
	IV Partly skilled	272 (16.7)	253 (16.4)
	V Unskilled	57 (3.5)	54 (3.5)
Material deprivation in adulthood			
Housing tenure	Owned/mortgaged	1357 (80.7)	1185 (76.9)
	Rented/other	325 (19.3)	356 (23.1)
Number of cars available	None	107 (6.4)	273 (17.7)
	1	898 (53.5)	893 (58.0)
	2	552 (32.9)	330 (21.4)
	3	122 (7.3)	45 (2.9)

Registrar General's social class was based on occupation and classified according to the 1990 edition of the standard occupational classification
Missing data: 103 men and 99 women had missing data for social class at birth and 50 men had missing data for social class in adulthood; 2 men had missing data for housing tenure; 5 men had missing data for car availability.
[+]Based on paternal occupation at the time of the participant's birth
*Median and interquartile range
**Based on social class of the husband for ever married women. 21 women did not have a job code of their own (having never worked or having provided insufficient information about their most recent full-time occupation for successful social class coding) but were assigned a social class on the basis of their husband's job code. 1 woman had missing data for her own and her husband's job code class and no social class was therefore assigned. The woman's own job code was used in 110 cases because job code data for their husbands was missing. For 333 women, their own and their husband's social class codes tallied. Use of the husband's social class resulted in 561 women being assigned a higher social class than had their own social class been used and 515 women were assigned a lower social class on this basis.

2.4.1.8 Inter-relationships between markers of socioeconomic position and material deprivation in HCS

Tables 4 to 8 describe the inter-relationships between the HCS markers of socioeconomic position and material deprivation across the lifecourse. Lower social class at birth was associated with younger age of leaving full-time education (p<0.001, Table 4). Younger age of leaving full-time education was associated with lower social class in adulthood (p<0.001, Table 5), reflecting limited levels of social mobility across the lifecourse. For example, only 3.2% of men who left school aged 14 years or younger were in social class I in adulthood in contrast with 23.8% of the men who left school aged 18 or older (corresponding statistics 2.9% and 15.0% for women). Lower social class in adulthood was associated with greater likelihood of not owning or mortgaging one's home, and having no cars available to the household (p<0.001, Tables 6 and 7). For example, the prevalence of not having a car available ranged from 0.9% among men of social class I to 21.1% among men of class V (corresponding statistics 14.3% and 44.4% for women) and the prevalence of not owner-occupying one's home ranged from 10.3% among men of social class I to 54.5% for men of social class V (6.0% to 50.0% for women). Men and women who owner-occupied their homes were more likely to have cars available for their household's use and vice versa (p<0.001,

Table 8). The prevalence of not having a car available ranged from 3.1% among men who owner-occupied their home to 20.1% among those who did not owner-occupy their home (corresponding statistics 10.0% and 43.3% for women).

Appendix 1 presents the mutually adjusted associations between housing tenure at HCS baseline and social class at birth, age left full-time education, social class in adulthood and car availability at HCS baseline among men and women separately. All of the lifecourse markers of socioeconomic position and material deprivation were associated with housing tenure at HCS baseline among men (p≤0.008 for all) but the magnitudes of the estimated odds ratios unsurprisingly showed greater association between housing tenure at HCS baseline and the other most proximal markers of socioeconomic position and material deprivation i.e. social class in adulthood and car availability. Social class at birth was only weakly associated with housing tenure at HCS baseline among women (p=0.06) but the associations between age left full-time education, social class in adulthood and car availability and housing tenure among women were of a similar statistical significance, and magnitude of association, as for men.

Appendix 1 also presents the mutually adjusted associations between car availability at HCS baseline and social class at birth, age left full-time education, social class in adulthood and housing tenure at HCS baseline among men and women separately. All of the lifecourse markers of socioeconomic position and material deprivation were associated with car availability at HCS baseline among men (p≤0.001 for all). However, only social class in adulthood and housing tenure at HCS baseline were associated with car availability at HCS baseline in the mutually adjusted model for women.

Overall, the results presented in Tables 4 to 8 and Appendix 1 demonstrate that socioeconomic position and material deprivation track across the lifecourse among the HCS study participants and that measures of material deprivation in later life reflect an accumulation of social disadvantage across the lifecourse; these results fit well within the Marmot Review's framework for a lifecourse perspective on social inequalities in health (Marmot 2010).

Table 4 Age left full-time education according to father's social class at birth

		Age left full-time education in years n(%)					
		<=14	15	16	17	18+	All
		MEN (n=1580)					
Father's social class at birth	I	3 (15.0)	11 (55.0)	3 (15.0)	3 (15.0)	0 (0.0)	20 (100.0)
	II	12 (10.8)	46 (41.4)	27 (24.3)	14 (12.6)	12 (10.8)	111 (100.0)
	IIINM	12 (10.2)	31 (26.3)	36 (30.5)	16 (13.6)	23 (19.5)	118 (100.0)
	IIIM	129 (18.3)	390 (55.2)	129 (18.3)	26 (3.7)	33 (4.7)	707 (100.0)
	IV	113 (25.7)	240 (54.7)	63 (14.4)	13 (3.0)	10 (2.3)	439 (100.0)
	V	39 (21.1)	112 (60.5)	29 (15.7)	3 (1.6)	2 (1.1)	185 (100.0)
	All	308 (19.5)	830 (52.5)	287 (18.2)	75 (4.8)	80 (5.1)	1580 (100.0)
		WOMEN (n=1442)					
	I	2 (16.7)	2 (16.7)	3 (25.0)	2 (16.7)	3 (25.0)	12 (100.0)
	II	14 (11.7)	50 (41.7)	27 (22.5)	12 (10.0)	17 (14.2)	120 (100.0)
	IIINM	11 (10.4)	42 (39.6)	16 (15.1)	22 (20.8)	15 (14.2)	106 (100.0)
	IIIM	129 (18.6)	350 (50.6)	139 (20.1)	45 (6.5)	29 (4.2)	692 (100.0)
	IV	75 (19.1)	221 (56.2)	71 (18.1)	14 (3.6)	12 (3.1)	393 (100.0)
	V	28 (23.5)	71 (59.7)	15 (12.6)	4 (3.4)	1 (0.8)	119 (100.0)
	All	259 (18.0)	736 (51.0)	271 (18.8)	99 (6.9)	77 (5.3)	1442 (100.0)

p=0.0001 for difference in median age left full-time education by father's social class among both men and women (Kruskall Wallis test).

Table 5 Social class in adulthood according to age left full-time education

		Social class in adulthood n(%)						
		I	II	IINM	IIIM	IV	V	All
		MEN (n=1634)						
	<=14	10 (3.2)	46 (14.5)	34 (10.7)	151 (47.6)	63 (19.9)	13 (4.1)	317 (100.0)
Age left	15	33 (3.9)	159 (18.6)	60 (7.0)	399 (46.6)	166 (19.4)	40 (4.7)	857 (100.0)
full-time	16	27 (9.0)	116 (38.8)	47 (15.7)	71 (23.8)	34 (11.4)	4 (1.3)	299 (100.0)
education	17	18 (22.2)	35 (43.2)	11 (13.6)	13 (16.1)	4 (4.9)	0 (0.0)	81 (100.0)
	18+	19 (23.8)	39 (48.8)	13 (16.3)	4 (5.0)	5 (6.3)	0 (0.0)	80 (100.0)
	All	107 (6.6)	395 (24.2)	165 (10.1)	638 (39.1)	272 (16.7)	57 (3.5)	1634 (100.0)
		WOMEN (n=1540)						
	<=14	8 (2.9)	39 (14.1)	36 (13.0)	128 (46.4)	54 (19.6)	11 (4.0)	276 (100.0)
Age left	15	29 (3.7)	143 (18.0)	99 (12.5)	334 (42.0)	159 (20.0)	31 (3.9)	795 (100.0)
full-time	16	18 (6.4)	86 (30.4)	46 (16.3)	93 (32.9)	29 (10.3)	11 (3.9)	283 (100.0)
education	17	17 (16.0)	36 (34.0)	20 (18.9)	27 (25.5)	6 (5.7)	0 (0.0)	106 (100.0)
	18+	12 (15.0)	43 (53.8)	8 (10.0)	11 (13.8)	5 (6.3)	1 (1.3)	80 (100.0)
	All	84 (5.5)	347 (22.5)	209 (13.6)	593 (38.5)	253 (16.4)	54 (3.5)	1540 (100.0)

p=0.0001 for difference in median age left full-time education by current social class among both men and women (Kruskall Wallis test)

Table 6 Housing tenure at HCS baseline home interview according to social class in adulthood

		Housing tenure n(%)					
		MEN (n=1632)			***WOMEN (n=1540)***		
		Owned/mortgaged	Rented/other	All	Owned/mortgaged	Rented/other	All
Social class in adulthood	I	96 (89.7)	11 (10.3)	107 (100.0)	79 (94.1)	5 (6.0)	84 (100.0)
	II	365 (92.4)	30 (7.6)	395 (100.0)	312 (89.9)	35 (10.1)	347 (100.0)
	IIINM	150 (90.9)	15 (9.1)	165 (100.0)	168 (80.4)	41 (19.6)	209 (100.0)
	IIIM	497 (78.0)	140 (22.0)	637 (100.0)	459 (77.4)	134 (22.6)	593 (100.0)
	IV	181 (66.8)	90 (33.2)	271 (100.0)	140 (55.3)	113 (44.7)	253 (100.0)
	V	26 (45.6)	31 (54.5)	57 (100.0)	27 (50.0)	27 (50.0)	54 (100.0)
	All	1315 (80.6)	317 (19.4)	1632 (100.0)	1185 (77.0)	355 (23.0)	1540 (100.0)

$p<0.001$ for association between social class in adulthood and housing tenure among both men and women (Chi-squared test)

Table 7 Car availability at HCS baseline home interview according to social class in adulthood

		Number of cars available n(%)				
		None	One	Two	Three or more	All
		MEN (n=1630)				
Social class in adulthood	I	1 (0.9)	50 (46.7)	46 (43.0)	10 (9.4)	107 (100.0)
	II	8 (2.0)	194 (49.1)	159 (40.3)	34 (8.6)	395 (100.0)
	IIINM	8 (4.9)	86 (52.4)	62 (37.8)	8 (4.9)	164 (100.0)
	IIIM	36 (5.7)	364 (57.2)	188 (29.6)	48 (7.6)	636 (100.0)
	IV	40 (14.8)	153 (56.5)	65 (24.0)	13 (4.8)	271 (100.0)
	V	12 (21.1)	32 (56.1)	10 (17.5)	3 (5.3)	57 (100.0)
	All	105 (6.4)	879 (53.9)	530 (32.5)	116 (7.1)	1630 (100.0)
		WOMEN (n=1540)				
	I	12 (14.3)	38 (45.2)	31 (36.9)	3 (3.6)	84 (100.0)
	II	27 (7.8)	206 (59.4)	98 (28.2)	16 (4.6)	347 (100.0)
	IIINM	33 (15.8)	132 (63.2)	43 (20.6)	1 (0.5)	209 (100.0)
	IIIM	105 (17.7)	349 (58.9)	119 (20.1)	20 (3.4)	593 (100.0)
	IV	71 (28.1)	143 (56.5)	34 (13.4)	5 (2.0)	253 (100.0)
	V	24 (44.4)	25 (46.3)	5 (9.3)	0 (0.0)	54 (100.0)
	All	272 (17.7)	893 (58.0)	330 (21.4)	45 (2.9)	1540 (100.0)

$p<0.001$ for association between social class in adulthood and car availability among both men and women (Chi-squared test)

Table 8 Car availability according to housing tenure at HCS baseline home interview

		Number of cars available n(%)				
		None	One	Two	Three or more	All
		MEN (n=1679)				
Housing tenure	Owned/mortgaged	42 (3.1)	695 (51.3)	506 (37.3)	112 (8.3)	1355 (100.0)
	Rented/other	65 (20.1)	203 (62.7)	46 (14.2)	10 (3.1)	324 (100.0)
	All	107 (6.4)	898 (53.5)	552 (32.9)	122 (7.3)	1679 (100.0)
		WOMEN (n=1541)				
	Owned/mortgaged	119 (10.0)	728 (61.4)	298 (25.2)	40 (3.4)	1185 (100.0)
	Rented/other	154 (43.3)	165 (46.4)	32 (9.0)	5 (1.4)	356 (100.0)
	All	273 (17.7)	893 (58.0)	330 (21.4)	45 (2.9)	1541 (100.0)

p<0.001 for association between housing tenure and car availability among both men and women (Chi-squared test)

2.4.2 Musculoskeletal ageing

2.4.2.1 Phenotypes available in HCS

This thesis will consider five specific aspects of musculoskeletal ageing: (i) loss of muscle strength; (ii) loss of physical function; (iii) falls; (iv) frailty and (v) osteoporosis. These aspects of musculoskeletal ageing were characterised as follows in HCS.

Grip strength was measured at the HCS baseline clinic as a marker of sarcopenia. Grip strength was measured three times for each hand using a Jamar handgrip dynamometer (Weiner and Lourie 1969) according to the Southampton protocol (Roberts et al. 2011). The best of the six grip measurements was used to characterise maximum muscle strength.

Self-assessed health related quality of life was ascertained at the HCS baseline home interview using the short-form 36 (SF-36) questionnaire; SF-36 data were mapped to eight domain scores, including physical function (PF) (Ware et al. 2000). Each domain score ranged from 0 to 100 with higher values indicating better functional status.

History of falls in the past year was ascertained at the HCS baseline home interview although this was only introduced during the fieldwork and data are therefore only available for 941 men and 1398 women.

The Fried frailty criteria define frailty as the presence of three or more of the following items: unintentional weight loss (greater than 10lb over the past year), weakness, self-reported exhaustion, slow walking speed and low physical activity (Fried et al. 2001). Frailty was characterised for the men and women who participated in the East Hertfordshire follow-up study (Figure 6); see paper 2 for details.

History of fracture since 45 years of age was ascertained at the HCS baseline home interview; minor trauma fractures were identified from the information provided.

Bone mineral density (BMD) at the proximal femur was assessed by dual-energy X-ray absorptiometry using a Hologic QDR 4500 instrument for the 498 (68%) men and 468 (69%) women who underwent the HCS baseline DXA scan (Figure 6) (Dennison et al. 2005).

DXA bone mineral measurements of the total femur were repeated at the East Hertfordshire follow-up study (Figure 6), enabling calculation of annualised percentage change in bone mineral density at this site. Peripheral quantitative computed tomography (pQCT) was also performed of the radius and tibia (non-dominant side) using a Stratec 4500 instrument; see paper 3 for further details.

Incident fracture between the HCS baseline home interview and the HCS clinical outcomes study (Figure 6) was ascertained by self-completed postal questionnaire.

2.4.2.2 Summary characteristics of musculoskeletal ageing phenotypes in HCS

The summary characteristics of the musculoskeletal ageing phenotypes among HCS men and women are shown in Table 9. On average, at HCS baseline home interview men had better (i.e. higher) SF-36 physical functioning scores, and a lower prevalence of history of any, or minor trauma, fractures since 45 years of age, and a lower prevalence of history of falling in the past year than women (p<0.001 for all gender differences). Men also had higher average grip strength at HCS baseline clinic and higher DXA total femoral BMD at the HCS baseline DXA scan than women (p<0.0001 for both gender differences). At East Hertfordshire follow-up, the prevalence of Fried frailty was lower among men than women (p=0.02) and men had decelerated average rates of loss of DXA total femoral BMD and had higher pQCT radius and tibia pQCT strength strain indices than women (p<0.0001 for all gender differences). Finally, the incidence of fracture between the HCS baseline clinic and the HCS clinical outcomes study was lower among men than women (p<0.001).

Table 9 Musculoskeletal ageing phenotypes among HCS participants

n(%)	Men	Women
HCS baseline home interview	*n=1684*	*n=1541*
Age (years)*	65.6 (2.9)	66.6 (2.7)
SF-36 physical functioning (PF) score**	90 (80,95)	85 (65,95)
Any fracture since 45yrs of age	235 (14.0)	333 (21.6)
Minor trauma fracture since 45yrs of age	129 (7.7)	284 (18.4)
Falls history in the past year	140 (14.9)	316 (22.6)
HCS baseline clinic	*n=1579*	*n=1418*
Grip strength (kg)*	44.0 (7.5)	26.5 (5.8)
HCS baseline DXA scan	*n=498*	*n=468*
DXA Total femoral BMD (g/cm^2)*	1.04 (0.13)	0.90 (0.13)
East Hertfordshire follow-up study	*n=322*	*n=320*
Age (years)*	69.2 (2.5)	69.5 (2.6)
Fried frailty	13 (4.1)	27 (8.5)
Follow-up time between DXA scans (years)**	5.2 (4.8,5.6)	3.5 (3.0,4.0)
DXA total femoral change in BMD (%/yr)*,[a]	-0.09 (0.70)	-0.55 (1.20)
pQCT radius strength strain index (SSI)*	397 (82)	226 (51)
pQCT tibia strength strain index (SSI)*	2072 (328)	1400 (227)
HCS clinical outcomes study fracture sample	*n=1093*	*n=1049*
Age (years)*	71.7 (2.5)	71.6 (2.5)
Follow-up time since HCS baseline clinic (years)**	5.8 (5.0,7.3)	4.9 (4.1,6.1)
Incident fracture since HCS baseline clinic	46 (4.2)	113 (10.8)

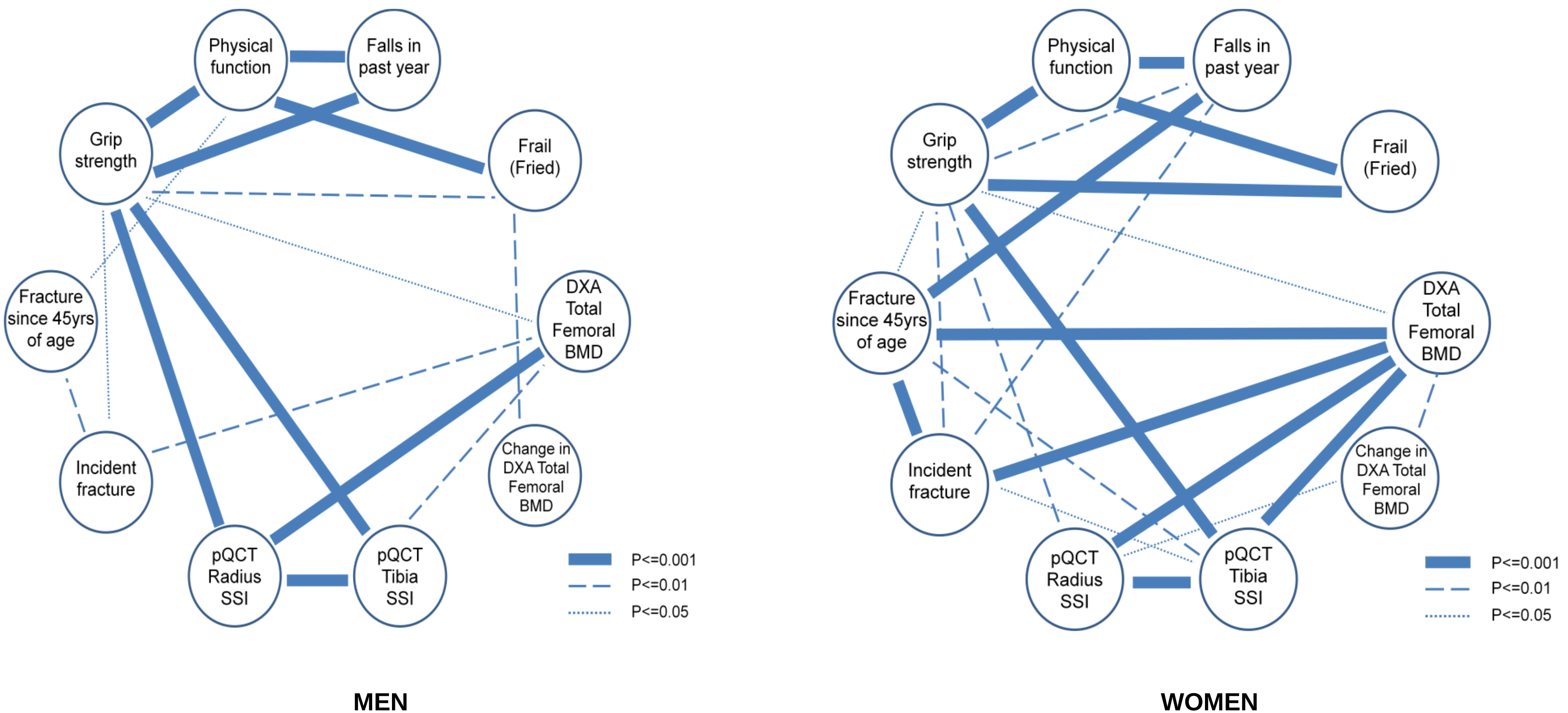
*Mean and standard deviation (SD)
**Median and interquartile range
[a] Change in BMD defined as BMD at the East Hertfordshire follow-up study minus BMD at the HCS baseline DXA scan, divided by BMD at the HCS baseline DXA scan and annualised per year of follow-up to yield a change variable with units of percentage change per year and with positive values indicating an increase in bone over time and negative values a decrease in bone over time.
Non-missing sample sizes where not as indicated in the table were as follows for men: SF-36 PF n=1682; falls history n=941; grip strength n=1572; DXA total femoral BMD n=495; Fried frailty n=320; DXA change in BMD n=276; pQCT radius SSI n=304; pQCT tibia SSI n=295.
Non-missing sample sizes where not as indicated in the table were as follows for women: SF-36 PF n=1540; falls history n=1398; grip strength n=1415; DXA total femoral BMD n=467; Fried frailty n=318; DXA change in BMD n=289; pQCT radius SSI n=316; pQCT tibia SSI n=298.

2.4.2.3 Inter-relationships between musculoskeletal ageing phenotypes

Appendices 2 and 3 describe the inter-relationships between the musculoskeletal ageing phenotypes considered in this thesis in detail. Figure 7 provides a simple schematic overview of these associations.

Lower grip strength, poorer physical function and falls history were strongly inter-related among both men and women. Frailty was strongly associated with lower grip strength and poorer physical function among men and women; this was unsurprising given the structure of the Fried definition of frailty and its implementation in HCS (see paper 2). Frailty was also associated with accelerated total femoral bone loss rate among men. Prevalent and incident fracture, DXA total femoral BMD and pQCT radius and tibia strength strain indices were strongly inter-related among women but less consistently among men. Grip strength was associated with all but one of the markers of fracture and osteoporosis among women but the magnitude and significance of these associations were generally weaker than the associations between grip strength and physical function, falls history and frailty among women. Lower grip strength was associated with lower pQCT strength strain indices among men but only weakly, if at all, with the other markers of fracture and osteoporosis. Physical function and frailty were not strongly associated with the markers of fracture and osteoporosis among men or women. Falls history was associated with prevalent and incident fracture among women but was not associated with DXA or pQCT measures of bone among women. Associations between falls history and DXA and pQCT measures of bone could not be investigated among men owing to insufficient sample size as a consequence of phasing of the HCS fieldwork; however, good sample sizes were available for analysis of the association between falls history and prevalent and incident fracture among men but, in contrast with the results for women, no significant associations were identified.

Figure 7 Overview of inter-relationships between musculoskeletal ageing phenotypes among HCS men and women



Lines on the figures represent the simple, unadjusted pairwise associations between the musculoskeletal ageing phenotypes based on maximum available sample sizes. With the exception of the weak association between change in DXA BMD and pQCT radius SSI among women, all associations were as expected intuitively (see Appendices 2 and 3 for details) e.g. poor physical function was associated with lower grip strength and greater likelihood of falls and frailty. The overlap of data availability for falls, DXA and pQCT measures was limited among men owing to fieldwork phasing. Sophisticated multivariate data analyses techniques e.g. cluster analysis, were not possible because only 3 men and 180 women had data available for all ten phenotypes (and still only 219 men and 231 women had full data for all nine phenotypes with the exception of falls history). Results were substantively unaltered if history of minor trauma fractures was analysed instead of all fractures.

2.4.3 Covariates available in HCS which could mediate or confound the association between socioeconomic position and material deprivation and musculoskeletal ageing

The clinical and lifestyle characteristics of the HCS participants were recorded in detail. Age, marital status, smoking habit, weekly alcohol intake, self-reported walking speed, the Dallosso physical activity score (Dallosso et al. 1988), weekly oily fish consumption, daily calcium intake from foods, details of all currently used prescription and over the counter medications coded to the British National Formulary (BNF), menopausal status and history of HRT use (for women only), history of stroke or transient ischaemic attack (TIA) and symptoms of bronchitis were recorded at the HCS baseline home interview. Height, weight, and current clinical status with regard to ischaemic heart disease, hypertension, type II diabetes mellitus, and hand osteoarthritis were ascertained at the HCS baseline clinic.

These clinical and lifestyle characteristics are variously associated with the range of musculoskeletal phenotypes considered in this thesis and may also be expected to vary according to socioeconomic position; these covariates therefore have the potential to either mediate or confound any associations between socioeconomic position and musculoskeletal ageing. Consideration of the impact of adjustment for these covariates in statistical models enables assessment of the evidence for social inequality in any specific musculoskeletal ageing phenotype, over and above differences in the lifestyles, health behaviours and co-morbidities that may exist between people of different socioeconomic position. Further, if adjustment for specific covariates attenuates the evidence for a social gradient in any given musculoskeletal phenotype this might suggest a mechanism through which that social gradient may have arisen and might suggest potential avenues for intervention. The statistical analysis strategy for this thesis, including adjustment for covariates, is described further in the Statistical Methods section (see section 2.6). Possible mechanisms that may underpin social inequalities in health are discussed in broad terms in section 6.2 of the Discussion and particular mechanisms which may have contributed to the specific pattern of results presented in this thesis are considered in detail in section 6.2.1.

2.5 Sample attrition

Attrition from the HCS ledgers to clinics has been described above (Figure 5); as in any epidemiological study, selection bias is a possibility and the representativeness of the study participants is open to question. This has been examined in three ways. Firstly, response bias between the different stages of the HCS has been examined (see section 2.5.1). Secondly, the socioeconomic, anthropometric, medical and functional characteristics of participants in the East phase of HCS have been contrasted with those in the nationally representative Health Survey for England (HSE) (see section 2.5.2) (Syddall et al. 2005a). Finally, the distributions of housing tenure and car availability (markers of material deprivation) among the HCS participants have been compared with the distributions of these variables for the county of Hertfordshire, and the country of England as a whole, in the 2001 census (see section 2.5.3).

2.5.1 Response bias within HCS

Birth weight and weight at one year of age were similar in men and women in the East HCS target population (i.e. those confirmed as registered with a GP in East Hertfordshire) but who did not participate in the home interview [mean and standard deviation (SD) birth weight and weight at one year: 3.5kg (0.6), 10.1kg (1.1) in 992 men and 3.4kg (0.5) and 9.6kg (1.0) in 733 women], and among those who were in the target population and did participate in the home interview [mean and (SD) birth weight and weight at one year: 3.5kg (0.6), 10.2kg (1.1) in 768 men and 3.4kg (0.5) and 9.7kg (1.0) in 714 women].

Men and women who progressed from the baseline home interview to the baseline clinic reported higher levels of car availability, better SF-36 physical function and self-reported walking speed, fewer fractures since 45 years of age, higher Dallosso physical activity scores and less smoking than those who only participated in the baseline home interview (Table 10). Women who progressed from the HCS baseline home interview to baseline clinic were also more likely to have left school at an older age, to owner-occupy their home, were slightly younger, were more likely to have ever been married and were more likely to eat oily fish each week than women who only participated in the home interview (Table 10). Men who progressed from the baseline home interview to baseline clinic took a greater number of medications than men who only participated in the home interview (Table 10).

Response bias was also evident between the HCS baseline clinic and baseline DXA scan (Table 11). The East Hertfordshire men who participated in the baseline DXA scan had better SF-36 physical function, lower rates of fracture since 45 years of age, were less likely to be current smokers and had higher Dallosso physical activity scores than the East Hertfordshire men who only participated in the baseline clinic (Table 11). The East Hertfordshire women who participated in the baseline DXA scan had better SF-36 physical function, were less likely to report slow walking speed, had higher Dallosso physical activity scores, were more likely to eat oily fish each week and had higher grip strength than the East Hertfordshire women who only participated in the baseline clinic (Table 11).

Response bias was less evident between the HCS baseline DXA scan and the East Hertfordshire follow-up study (Table 12). The men who participated in the follow-up study were more likely to owner-occupy their home, were more likely to have experienced any fracture since 45 years of age, were slightly younger and were less likely to be current smokers than those who only participated in the baseline DXA scan (Table 12). The women who participated in the follow-up study had higher current social class, were slightly older and were less likely to be current smokers than those who only participated in the baseline DXA scan (Table 12).

Finally, response bias was strongly evident between the HCS baseline clinic and the HCS clinical outcomes study (Table 13). The men and women who progressed from the baseline clinic to the clinical outcomes study had left school at an older age, were more likely to owner-occupy their home, had better SF-36 physical function, had experienced fewer fractures since 45 years of age, were less likely to be current smokers, were less likely to report slow walking speed, had higher Dallosso physical activity scores, and had higher grip strength than those who only participated in the baseline clinic (Table 13). Women who progressed from the HCS baseline clinic to clinical outcomes study also reported a higher daily intake of calcium from foods, took fewer medications and weighed less than women who only participated in the baseline clinic (Table 13). Men who progressed from the HCS baseline clinic to clinical outcomes study had higher social class at birth and in adulthood than men who only participated in the baseline clinic (Table 13).

Table 10 Response bias between the HCS baseline home interview and clinic

Frequency (%) distribution by HCS participation status	MEN Home interview only (n=105)	MEN Clinic participant (n=1579)	WOMEN Home interview only (n=123)	WOMEN Clinic participant (n=1418)
Social class at birth				
I	1 (1.1)	19 (1.3)	1 (0.9)	11 (0.8)
II	4 (4.2)	107 (7.2)	8 (7.0)	112 (8.4)
IIIN	6 (6.3)	112 (7.5)	11 (9.6)	95 (7.2)
IIIM	44 (46.3)	663 (44.6)	53 (46.1)	639 (48.2)
IV	27 (28.4)	413 (27.8)	32 (27.8)	361 (27.2)
V	13 (13.7)	172 (11.6)	10 (8.7)	109 (8.2)
	p=0.88		*p=0.94*	
Age left full-time education (years)*	15 (15,15.5)	15 (15,16)	15 (14,15)	15 (15,16)
	p=0.32		*p=0.001*	
Social class in adulthood				
I	5 (4.9)	102 (6.7)	4 (3.3)	80 (5.7)
II	32 (31.1)	363 (6.7)	25 (20.3)	322 (22.7)
IIIN	7 (6.8)	158 (10.3)	21 (17.1)	188 (13.3)
IIIM	36 (35.0)	602 (39.3)	48 (39.0)	545 (38.5)
IV	19 (18.5)	253 (16.5)	18 (14.6)	235 (16.6)
V	4 (3.9)	53 (3.5)	7 (5.7)	47 (3.3)
	p=0.47		*p=0.44*	
Owner-occupy home	77 (74.8)	1280 (81.1)	80 (65.0)	1105 (77.9)
	p=0.12		*p=0.001*	
Two or more cars available	30 (29.4)	644 (40.8)	18 (14.6)	357 (25.2)
	p=0.02		*p=0.009*	
Poor SF-36 PF	49 (47.1)	316 (20.0)	50 (41.0)	301 (21.2)
	p<0.001		*p<0.001*	
History of falls in past year	16 (21.3)	124 (14.3)	27 (23.3)	289 (22.5)
	p=0.10		*p=0.86*	
Fracture since 45 years of age	22 (21.0)	213 (13.5)	35 (28.5)	298 (21.0)
	p=0.03		*p=0.06*	
Minor trauma fracture since 45 years of age	17 (16.2)	112 (7.1)	30 (24.4)	254 (17.9)
	p=0.001		*p=0.08*	
Age (years)**	65.9 (3.1)	65.6 (2.9)	67.2 (2.9)	66.6 (2.7)
	p=0.34		*p=0.01*	
Never married	6 (5.7)	79 (5.0)	9 (7.3)	52 (3.7)
	p=0.75		*p=0.05*	
Current smoker	26 (24.8)	238 (15.1)	27 (22.0)	139 (9.8)
	p=0.008		*p<0.001*	
High weekly alcohol (≥22 units men; ≥15 units women)	22 (21.0)	340 (21.6)	7 (5.7)	68 (4.8)
	p=0.89		*p=0.64*	
Walking speed: very slow/ stroll at an easy pace	46 (45.5)	451 (28.6)	48 (40.0)	382 (26.9)
	p<0.001		*p=0.002*	
Dallosso physical activity score**	53.6 (21.1)	60.9 (15.3)	49.0 (23.7)	59.0 (15.7)
	p<0.001		*p<0.001*	
No oily fish per week	12 (12.1)	205 (13.0)	22 (18.0)	128 (9.0)
	p=0.80		*p=0.001*	
Daily calcium from foods (mg)*	1178 (929,1438)	1179 (980,1402)	1045 (905,1242)	1095 (912,1286)
	p=0.98		*p=0.18*	
Number of systems medicated* (British National Formulary)	1 (0,3)	1 (0,2)	1 (1,3)	1 (1,2)
	p=0.002		*p=0.19*	

*Median and interquartile range; **Mean & SD. P-values from Chi-squared, Mann-Whitney or t-tests

Table 11 Response bias between the HCS baseline clinic and HCS baseline DXA scan among East Hertfordshire participants only

Frequency (%) distribution by HCS participation status	MEN Clinic only (n=239)	MEN DXA participant (n=498)	WOMEN Clinic only (n=207)	WOMEN DXA participant (n=468)
Social class at birth				
I	3 (1.3)	8 (1.7)	1 (0.5)	4 (0.9)
II	17 (7.4)	34 (7.4)	13 (6.6)	42 (9.6)
IIIN	14 (6.1)	37 (8.0)	16 (8.1)	32 (7.3)
IIIM	94 (40.9)	175 (37.9)	91 (46.2)	198 (45.0)
IV	71 (30.9)	149 (32.3)	60 (30.5)	134 (30.5)
V	31 (13.5)	59 (12.8)	16 (8.1)	30 (6.8)
	p=0.92		*p=0.83*	
Age left full-time education (years)*	15 (14,16)	15 (15,16)	15 (15,16)	15 (15,16)
	p=0.25		*p=0.33*	
Social class in adulthood				
I	11 (4.9)	26 (5.5)	14 (6.8)	23 (4.9)
II	47 (20.9)	113 (24.0)	47 (22.8)	95 (20.3)
IIIN	18 (8.0)	54 (11.5)	21 (10.2)	64 (13.7)
IIIM	85 (37.8)	184 (39.2)	81 (39.3)	200 (42.7)
IV	50 (22.2)	79 (16.8)	34 (16.5)	72 (15.4)
V	14 (6.2)	14 (3.0)	9 (4.4)	14 (3.0)
	p=0.11		*p=0.54*	
Owner-occupy home	189 (79.1)	421 (84.5)	156 (75.4)	381 (81.4)
	p=0.07		*p=0.07*	
Two or more cars available	109 (45.8)	211 (42.5)	44 (21.3)	125 (26.7)
	p=0.39		*p=0.13*	
Poor SF-36 PF	52 (21.8)	76 (15.3)	73 (35.3)	59 (12.6)
	p=0.03		*p<0.001*	
History of falls in past year	2 (11.8)	2 (25.0)	41 (23.8)	78 (21.1)
	p=0.40		*p=0.48*	
Fracture since 45 years of age	45 (18.8)	63 (12.7)	42 (20.3)	75 (16.0)
	p=0.03		*p=0.18*	
Minor trauma fracture since 45 years of age	25 (10.5)	37 (7.4)	41 (19.8)	66 (14.1)
	p=0.17		*p=0.06*	
Age (years)**	64.3 (2.7)	64.2(2.5)	65.8 (2.5)	65.6 (2.5)
	p=0.66		*p=0.20*	
Never married	17 (7.1)	24 (4.8)	5 (2.4)	18 (3.9)
	p=0.20		*p=0.35*	
Current smoker	51 (21.3)	73 (14.7)	26 (12.6)	45 (9.6)
	p=0.02		*p=0.25*	
High weekly alcohol (≥22 units men; ≥15 units women)	53 (22.2)	123 (24.7)	9 (4.4)	12 (2.6)
	p=0.45		*p=0.22*	
Walking speed: very slow/ stroll at an easy pace	76 (31.9)	131 (26.3)	71 (34.3)	103 (22.0)
	p=0.11		*p=0.001*	
Dallosso physical activity score**	60.2 (16.4)	64.0 (14.8)	55.7 (17.7)	61.3 (14.9)
	p=0.002		*p<0.001*	
No oily fish per week	38 (15.9)	73 (14.7)	30 (14.5)	41 (8.8)
	p=0.66		*p=0.03*	
Daily calcium from foods (mg)*	1208 (1025,1452)	1238 (1020,1444)	1094 (9071348)	1099 (924,1271)
	p=0.90		*p=0.61*	
Number of systems medicated* (British National Formulary)	1 (0,2)	1 (0,2)	2 (1,3)	1 (0,2)
	p=0.18		*p<0.001*	
Height (cm)**	173.8 (6.2)	174.3 (6.8)	160.4 (5.9)	160.9 (5.9)
	p=0.38		*p=0.32*	
Weight (kg)**	82.7 (12.6)	81.7 (12.3)	71.9 (13.5)	70.7 (13.7)
	p=0.32		*p=0.28*	
Grip strength (kg)**	44.4 (7.0)	44.1 (7.3)	25.9 (6.6)	27.7 (5.1)
	p=0.50		*p<0.001*	

*Median & interquartile range; **Mean & SD. P-values from Chi-squared, Mann-Whitney or t-tests

Table 12 Response bias between the HCS baseline DXA scan and East Hertfordshire follow-up study

Frequency (%) distribution by HCS participation status		MEN DXA scan only (n=176)	MEN East follow-up (n=322)	WOMEN DXA scan only (n=148)	WOMEN East follow-up (n=320)
Social class at birth	I	3 (1.9)	5 (1.7)	2 (1.5)	2 (0.7)
	II	12 (7.6)	22 (7.3)	11 (8.0)	31 (10.2)
	IIIN	12 (7.6)	25 (8.3)	10 (7.3)	22 (7.3)
	IIIM	57 (35.9)	118 (38.9)	53 (38.7)	145 (47.9)
	IV	59 (37.1)	90 (29.7)	55 (40.2)	79 (26.1)
	V	16 (10.1)	43 (14.2)	6 (4.4)	24 (7.9)
		p=0.62		*p=0.06*	
Age left full-time education (years)*		15 (15,15)	15 (15,16)	15 (15,16)	15 (15,16)
		p=0.22		*p=0.73*	
Social class In adulthood	I	10 (6.1)	16 (5.2)	2 (1.4)	21 (6.6)
	II	35 (21.3)	78 (25.5)	24 (16.2)	71 (22.2)
	IIIN	17 (10.4)	37 (12.1)	19 (12.8)	45 (14.1)
	IIIM	68 (41.5)	116 (37.9)	71 (48.0)	129 (40.3)
	IV	26 (15.9)	53 (17.3)	30 (20.3)	42 (13.1)
	V	8 (4.9)	6 (2.0)	2 (1.4)	12 (3.8)
		p=0.45		*p=0.02*	
Owner-occupy home		138 (78.4)	283 (87.9)	115 (77.7)	266 (83.1)
		p=0.005		*p=0.16*	
Two or more cars available		71 (40.6)	140 (43.5)	39 (26.4)	86 (26.9)
		p=0.53		*p=0.91*	
Poor SF-36 PF		31 (17.6)	45 (14.0)	22 (14.9)	37 (11.6)
		p=0.28		*p=0.32*	
History of falls in past year		No data	2 (25.0)	30 (24.0)	48 (19.7)
				p=0.34	
Fracture since 45 years of age		15 (8.5)	48 (14.9)	20 (13.5)	55 (17.2)
		p=0.04		*p=0.31*	
Minor trauma fracture since 45 years of age		9 (5.1)	28 (8.7)	17 (11.5)	49 (15.3)
		p=0.15		*p=0.27*	
Age (years)**		64.5 (2.5)	64.0 (2.5)	65.1 (2.2)	65.8 (2.7)
		p=0.02		*p=0.007*	
Never married		12 (6.8)	12 (3.7)	6 (4.1)	12 (3.8)
		p=0.12		*p=0.87*	
Current smoker		35 (19.9)	38 (11.8)	21 (14.3)	24 (7.5)
		p=0.02		*p=0.02*	
High weekly alcohol (≥22 units men; ≥15 units women)		51 (29.0)	72 (22.4)	4 (2.7)	8 (2.5)
		p=0.10		*p=0.90*	
Walking speed: very slow/ stroll at an easy pace		54 (30.7)	77 (23.9)	30 (20.3)	73 (22.8)
		p=0.10		*p=0.54*	
Dallosso physical activity score**		64.0 (15.7)	63.9 (14.3)	60.4 (16.0)	61.7 (14.3)
		p=0.92		*p=0.37*	
No oily fish per week		27 (15.3)	46 (14.3)	15 (10.1)	26 (8.1)
		p=0.75		*p=0.47*	
Daily calcium from foods (mg)		1262 (1027,1450)	1230 (1016,1440)	1094 (902,1270)	1101 (937,1273)
		p=0.10		*p=0.42*	
Number of systems medicated* (British National Formulary)		1 (0,2)	1 (0,1)	1 (0,2)	1 (0.3,2)
		p=0.10		*p=0.18*	
Height (cm)**		174.0 (6.9)	174.4 (6.7)	160.1 (5.6)	161.3 (6.0)
		p=0.55		*p=0.05*	
Weight (kg)**		83.1 (13.4)	80.9 (11.5)	71.4 (14.1)	70.4 (13.5)
		p=0.06		*p=0.48*	
Grip strength (kg)**		43.9 (7.7)	44.1 (7.2)	27.3 (4.8)	27.9 (5.2)
		p=0.71		*p=0.21*	
DXA Total femoral BMD (kg/m^2)**		1.05 (0.13)	1.04 (0.13)	0.89 (0.13)	0.90 (0.13)
		p=0.28		*p=0.52*	

*Median and interquartile range; **Mean & SD. P-values from Chi-squared, Mann-Whitney or t-tests.

Table 13 Response bias between the HCS baseline clinic and the HCS clinical outcomes study (COS) fracture sample

Frequency (%) distribution by HCS participation status	MEN Clinic only (n=486)	MEN COS participant (n=1093)	WOMEN Clinic only (n=369)	WOMEN COS participant (n=1049)
Social class at birth				
I	6 (1.3)	13 (1.3)	5 (1.5)	6 (0.6)
II	29 (6.4)	78 (7.6)	31 (9.1)	81 (8.2)
IIIN	24 (5.3)	88 (8.6)	18 (5.3)	77 (7.8)
IIIM	188 (41.1)	475 (46.2)	158 (46.5)	481 (48.7)
IV	144 (31.5)	269 (26.1)	101 (29.7)	260 (26.3)
V	66 (14.4)	106 (10.3)	27 (7.9)	82 (8.3)
	p=0.01		*p=0.30*	
Age left full-time education (years)*	15 (15,15)	15 (15,16)	15 (15,15)	15 (15,16)
	p=0.001		*p<0.001*	
Social class in adulthood				
I	25 (5.4)	77 (7.2)	14 (3.8)	66 (6.3)
II	87 (18.7)	276 (25.9)	74 (20.1)	248 (23.6)
IIIN	39 (8.4)	119 (11.2)	53 (14.4)	135 (12.9)
IIIM	205 (44.1)	397 (37.2)	147 (40.0)	398 (37.9)
IV	91 (19.6)	162 (15.2)	63 (17.1)	172 (16.4)
V	18 (3.9)	35 (3.3)	17 (4.6)	30 (2.9)
	p=0.002		*p=0.16*	
Owner-occupy home	375 (77.2)	905 (82.8)	263 (71.3)	842 (80.3)
	p=0.008		*p<0.001*	
Two or more cars available	192 (39.6)	452 (41.4)	89 (24.1)	268 (25.6)
	p=0.50		*p=0.59*	
Poor SF-36 PF	132 (27.2)	184 (16.9)	111 (30.1)	190 (18.1)
	p<0.001		*p<0.001*	
History of falls in past year	33 (13.7)	91 (14.6)	82 (24.7)	207 (21.8)
	p=0.74		*p=0.28*	
Fracture since 45 years of age	71 (14.6)	142 (13.0)	71 (19.3)	227 (21.6)
	p=0.39		*p=0.34*	
Minor trauma fracture since 45 years of age	38 (7.8)	74 (6.8)	63 (17.1)	191 (18.2)
	p=0.45		*p=0.64*	
Age (years)**	65.5 (2.9)	65.7 (2.9)	66.7 (2.7)	66.5 (2.7)
	p=0.47		*p=0.19*	
Never married	28 (5.8)	51 (4.7)	15 (4.1)	37 (3.5)
	p=0.36		*p=0.64*	
Current smoker	99 (20.4)	139 (12.7)	45 (12.2)	94 (9.0)
	p<0.001		*p=0.07*	
High weekly alcohol (≥22 units men; ≥15 units women)	105 (21.6)	235 (21.5)	22 (6.0)	46 (4.4)
	p=0.97		*p=0.22*	
Walking speed: very slow/ stroll at an easy pace	176 (36.3)	275 (25.2)	129 (35.0)	253 (24.1)
	p<0.001		*p<0.001*	
Dallosso physical activity score**	59.7 (15.8)	61.4 (15.0)	56.7 (17.0)	59.7 (15.1)
	p=0.04		*p=0.002*	
No oily fish per week	64 (13.2)	141 (12.9)	39 (10.6)	89 (8.5)
	p=0.87		*p=0.23*	
Daily calcium from foods (mg)*	1172 (972,1391)	1182 (984,1416)	1024 (827,1241)	1105 (941,1304)
	p=0.72		*p<0.001*	
Number of systems medicated* (British National Formulary)	1 (0,2)	1 (0,2)	2 (1,3)	1 (0,2)
	p=0.09		*p<0.001*	
Height (cm)**	173.9 (6.6)	174.3 (6.4)	160.4 (5.7)	161.0 (5.9)
	p=0.23		*p=0.07*	
Weight (kg)**	82.7 (13.3)	82.3 (12.4)	72.8 (15.0)	70.9 (12.8)
	p=0.61		*p=0.02*	
Grip strength (kg)**	43.4 (7.6)	44.3 (7.5)	26.0 (5.9)	26.7 (5.7)
	p=0.02		*p=0.04*	

*Median & interquartile range; **Mean & SD; P-values from Chi-squared, Mann-Whitney or t-tests

2.5.2 Comparison of HCS and HSE participants

As described previously (Syddall et al. 2005a), the 1996 (Joint Health Surveys Unit of Social and Community Planning Research and University College London 2001;Prescott-Clarke and Primatesta 1998;Wiggins et al. 2002) and 1998 (Erens and Primatesta 1999;National Centre for Social Research and University College London Department of Epidemiology and Public Health 2002) HSE datasets were accessed from the ESRC UK data archive (www.data-archive.ac.uk). In so doing, I acknowledge: the Joint Health Surveys Unit of Social and Community Planning Research and University College London as the original creators of the HSE 1996 dataset, and the Social and Community Planning Research group as the depositor of this dataset with the UK data Archive; the National Centre for Social Research and University College London, Department of Epidemiology and Public Health as the original creators of the HSE 1998 dataset, and the National Centre for Social Research as the depositor of this dataset with the UK data Archive; the Department of Health as the original source of funding for the 1996 and 1998 Health Surveys for England. These organisations bear no responsibility for my analysis and interpretation of the 1996 and 1998 Health Survey for England datasets.

Data on current social class, weekly alcohol consumption, smoking habit, height, weight, BMI and cardiovascular disease (as a marker of co-morbidity) were extracted from the HSE 1998 database (i.e. the HSE database for the year in which the HCS fieldwork commenced). SF-36 data on health transition in the past year and self-assessed general health were extracted from the HSE 1996 database (i.e. the only year prior to commencement of the HCS fieldwork in which SF-36 data had been ascertained in the HSE). The HSE databases were restricted to the same age range as in the HCS database (i.e. 59 to 73 years) and the characteristics of HSE and HCS participants were compared for men and women separately.

HCS baseline participants were generally comparable with those in the nationally representative HSE (Figure 8 and Figure 9) although some differences were identified; most notably, HCS participants were less likely to be in the extremes of the social class distribution, were taller, had better self-reported general health (SF-36), and HCS women were less likely to be current smokers or heavy drinkers. However, the absolute differences were small and the significant p-values for differences between the two study populations will have arisen, in part, from the large sample sizes studied.

Figure 8 Characteristics of Hertfordshire Cohort Study and Health Survey for England men

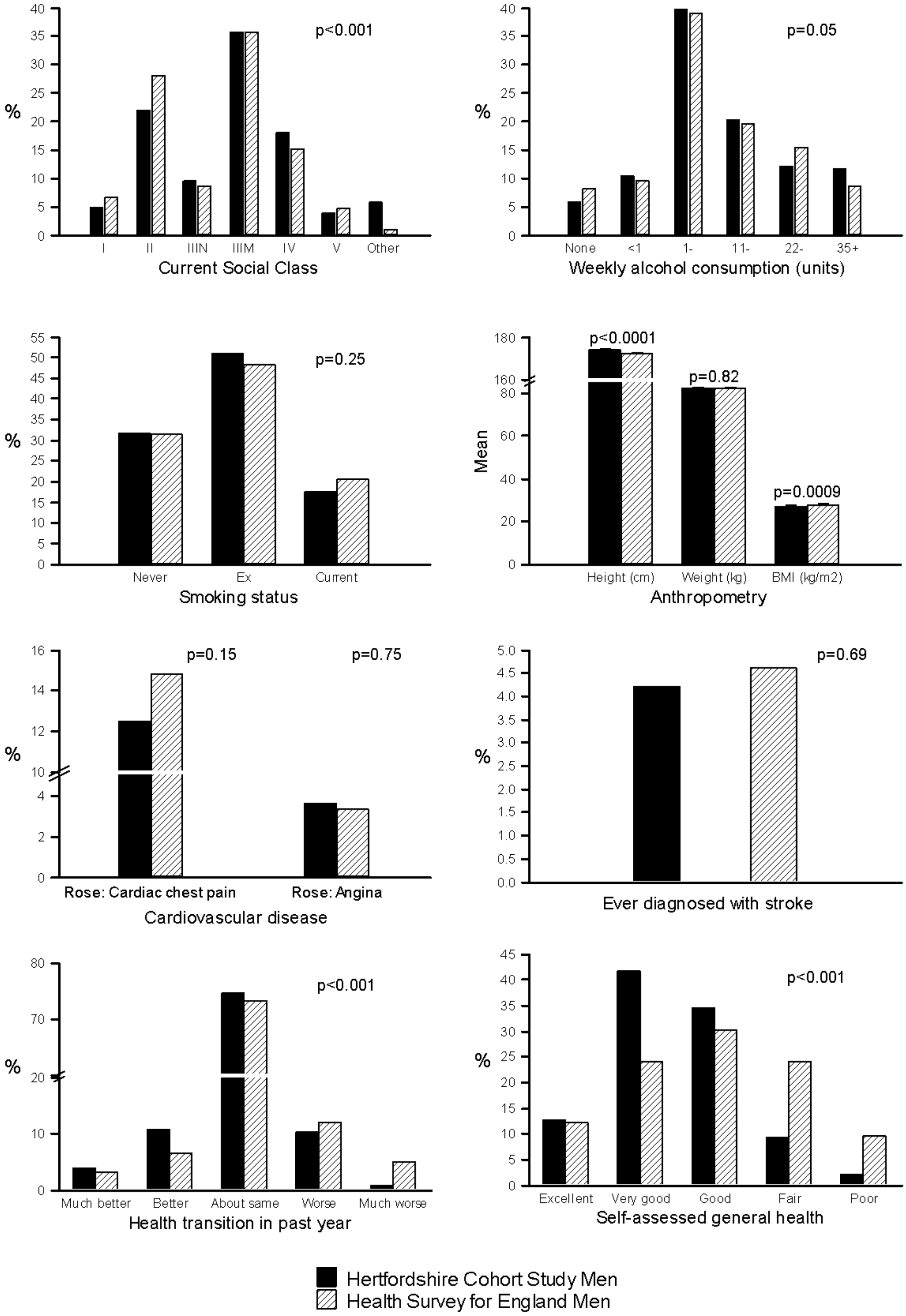


Figure 8 reproduced from (Syddall et al. 2005a)

Figure 9 Characteristics of Hertfordshire Cohort Study and Health Survey for England women

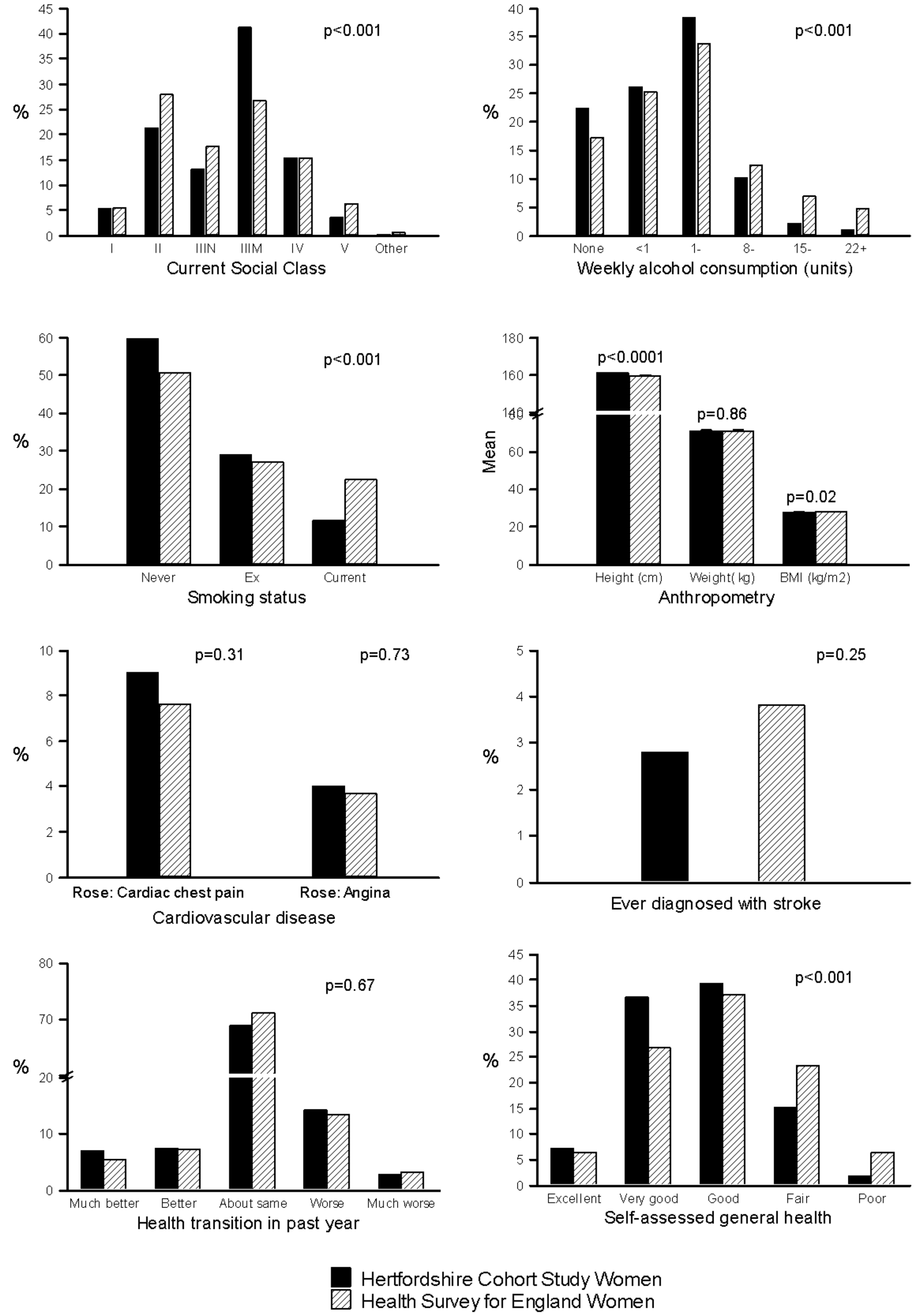


Figure 9 reproduced from (Syddall et al. 2005a)

2.5.3 Comparison of the distribution of housing tenure and car availability among HCS participants with the county of Hertfordshire, and England, as a whole

In this thesis, housing tenure and car availability are used as markers of material deprivation. The appropriateness of this approach may be questioned for studies based in large urban areas such as the London region where public transportation and rental of an apartment may be the best arrangement for many residents. However, although Hertfordshire is geographically adjacent to Greater London on the north side and benefits from good rail and road links in to the city, it is a county region which is entirely distinct from Greater London in terms of administrative organisation and geography (Hertfordshire County Council 2012). Hertfordshire covers an area of 634 sq miles (1,634 sq km) and has an estimated population of just over 1 million, 87% of whom live in the 45 settlements of over 3,000 people. There is one city (St Albans) and a variety of market towns, industrial towns, new towns, commuter villages and rural villages.

The following table (Table 14) derived from Office for National Statistics Census 2001 data (Office for National Statistics 2012a) places the distribution of material deprivation among HCS participants in context relative to the county of Hertfordshire, the country of England and the region of London. Table 14 shows that the pattern of housing tenure and car availability among HCS participants is broadly comparable with the distribution of housing tenure and car availability for the county of Hertfordshire although rates of home ownership and car availability are somewhat higher among HCS participants in comparison with the county overall. However, rates of home ownership and car availability are also higher for the county of Hertfordshire in comparison with England overall; this is unsurprising given that Hertfordshire is located in the relatively affluent South Eastern region of the UK (APHO and Department of Health 2008). The final column of Table 14 confirms that the pattern of housing tenure and car availability among the HCS participants is dissimilar to the pattern of relatively low home ownership and car availability in the urban region of London.

Table 14 Distribution of housing tenure and car availability among HCS participants, the county of Hertfordshire, and England overall

		Census 2001		
Percentage distribution*	HCS	Hertfordshire (county)	England (country)	London (region)
Housing tenure				
Owned/mortgaged	79	73	69	57
Rented	20	26	29	42
Other	1	1	2	1
Car availability for household's use				
None	12	18	27	37
1	56	42	44	43
2	27	32	24	16
3 or more	5	8	5	4

*Denominators of percentages were total number of cohort members (n=3225) for HCS and total number of occupied household spaces for Hertfordshire (420 650), England (20 451 427) and London (3 015 997). All statistics derived from standard tables S049 and S062 for the Census 2001 (Office for National Statistics 2012a)

2.6 Statistical Methods

An overview of the statistical methods used throughout this thesis is provided here; full details may be found in the Methods sections of papers 1 to 3.

Normality of continuously distributed musculoskeletal ageing phenotypes was assessed using visual inspection of histograms and tests of skewness and kurtosis; grip strength, total femoral BMD, pQCT strength strain indices for the radius and tibia, and percentage annualised changes in total femoral BMD between the baseline HCS DXA scan and the East Hertfordshire follow-up study were normally distributed. SF-36 PF scores were negatively skewed (lower scores implied poorer status) and were dichotomised for analysis: participants with scores in the lowest sex-specific fifth of the overall distribution of SF-36 PF in the HCS baseline sample (≤75 for men, ≤60 for women) were classified as having "poor" PF. Height and weight were highly correlated (r=0.45, $p<0.001$ for men and r=0.32, $p<0.001$ for women in the HCS baseline clinic sample); to avoid multi-collinearity problems a sex-specific standardised residual of weight-adjusted-for-height was calculated for inclusion with height in subsequent regression models.

Variables were summarised using means and standard deviations, medians and inter-quartile ranges (IQR) or frequency and percentage distributions as appropriate.

Univariate unadjusted associations between the continuously distributed musculoskeletal ageing phenotypes (e.g. grip strength in paper 1 and total femoral BMD in paper 3) and each marker of socioeconomic position and material deprivation were explored in turn using analysis of variance (ANOVA) and linear regression. Multiple linear regression models were subsequently used to identify which of the markers of socioeconomic position and material deprivation were most strongly associated with the musculoskeletal ageing phenotype in question after mutual adjustment. Multiple linear regression models were further used to explore whether any associations identified in the mutually adjusted models were robust to additional adjustment for the potential mediators and confounders detailed in section 2.4.3. A similar analysis strategy was adopted for binary musculoskeletal ageing phenotypes (e.g. poor SF-36 PF score and history of falls in paper 1, frailty in paper 2, and prevalent and incident fracture in paper 3) but with cross-tabulations of frequencies and percentages and chi-squared tests instead of ANOVA, and logistic rather than linear regression.

Categories of age left full-time education and number of cars available for household use were used for presentational purposes in papers 1 to 3 but p-values for association were obtained from the underlying continuous or ordinal variables throughout. The classification of age left full-time education in HCS (≤14 years versus ≥15 years) was data driven and based on visual inspection of the distribution of age left full time education. However, the statutory minimum school leaving age in the UK was 14 years between 1918 and 1946 but was raised to 15 years of age in 1947; the statutory minimum school leaving age in force for most of the HCS cohort (i.e. those born 1933-9) was therefore 15 years of age and the categorisation of age left full-time education chosen for HCS has therefore largely contrasted individuals who left school before their statutory minimum school leaving age with those who remained in education till the minimum statutory age or older.

Note that social class at birth, although included in preliminary analyses for papers 2 and 3, was not included in the final presentation of results for these papers. Social class at birth was not strongly associated with frailty, or markers of osteoporosis and fracture in these preliminary analyses; hence, with a view to preparation of concise manuscripts for clinically based peer-reviewed journals (which were already going to include many null as well as statistically significant results), it seemed appropriate to drop social class at birth from papers 2 and 3. Further, socioeconomic position and material deprivation tracked strongly across the lifecourse among HCS participants such that markers of socioeconomic position in later life reflected socioeconomic position earlier in the lifecourse (see section 2.4.1.8); on this basis, it is suggested that age left full-time education, social class in adulthood, and current housing tenure and car availability, together provide a sufficient characterisation of an individual's socioeconomic position and material deprivation even in the absence of social class at birth.

All analyses were conducted for men and women separately using the Stata statistical software package, release 11 (StataCorp 2009) or earlier.

Chapter 3. Paper 1: Social inequalities in grip strength, physical function and falls among community dwelling older men and women: findings from the Hertfordshire Cohort Study

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Running head: Social inequalities in grip strength, physical function and falls among community dwelling older people

Abstract

Objectives To explore social inequalities in grip strength, SF-36 physical functioning (PF) and falls among older people. *Methods* We analysed data from 3,225 men and women (age 59-73 years) who participated in the Hertfordshire Cohort Study, UK. Car availability and home ownership were used as markers of material deprivation. *Results* 6.4% of men (17.7% women) had no car and 19.3% of men (23.1% women) did not own their home. Having fewer cars was associated with lower grip and poorer PF among men and women ($p<0.001$), and increased falls among men ($p<0.001$). Not owning one's home was associated with lower grip in men and women ($p<0.001$) and poorer PF in men ($p<0.001$). Lower social class was associated with falls among women only ($p=0.01$). *Discussion* There are social inequalities in grip strength, PF and falls among older people. Interventions should consider the contribution of social inequalities to the problem.

Keywords: social inequalities; material deprivation; grip strength; physical function; falls; older people.

Introduction

Social inequalities in health have been recognised for centuries (Marmot 2001). Even in generally wealthy Western countries, material deprivation and poverty are not uncommon (Groffen et al. 2008) and, irrespective of absolute levels of standards of living, health inequalities exist across relative levels of deprivation (Wilkinson 1997). However, the mechanisms underlying the associations between specific markers of socioeconomic position and deprivation and specific health outcomes need to be identified if inequalities are to be reduced by appropriate intervention and public health policy (Lang et al. 2008;McFadden et al. 2008).

Loss of muscle strength, reduced physical function and falls are major problems in older people. Sarcopenia, the loss of muscle mass and strength with age (American Geriatrics Society et al. 2001;Wickham et al. 1989), has important consequences in terms of disability (Bohannon 2008), morbidity (Sayer et al. 2005;Sayer et al. 2007) and mortality (Bohannon 2008;Rantanen et al. 2000), and in terms of significant healthcare costs (Janssen et al. 2004). Poor physical function is well known to be associated with mobility disability (Guralnik et al. 2000;Ostir et al. 1998) and mobility disability is in turn a major problem in older people with rising prevalence (Ebrahim et al. 2000;Harwood et al. 1998). Sarcopenia is consistently identified as a risk factor for falls (American Geriatrics Society et al. 2001), which are common among community dwelling older men and women (Tinetti et al. 1988) and which have serious consequences in terms of disability, morbidity and mortality as well as economic cost (Kannus et al. 2005;Masud and Morris 2001;Scuffham et al. 2003;Stel et al. 2004).

There is interest in developing interventions to improve muscle strength, physical function and to reduce the risk of falls among older people (Chang et al. 2004;Tinetti et al. 1994;Tinetti 2003). However, progress with primary prevention both in terms of developing suitable screening tools and effective interventions has been slow (Gillespie 2004;Kannus and Khan 2001). Social inequalities in health (Arber and Ginn 1993), mobility impairment and disability (Lang et al. 2008;Nordstrom et al. 2007), disability (Coppin et al. 2006;Melzer et al. 2000) and mortality (McFadden et al. 2008) have been demonstrated among older people but studies of social inequalities in grip strength (ERAS Study Group 2000;Henneberg et al. 2001;Kuh et al. 2005;Rautio et al. 2005), physical function (ERAS Study Group 2000;Groffen et al. 2008;Kuh et al. 2005;Martikainen et al. 1999) and falls (Lawlor et al. 2003;Lyons et al. 2003;Roberts and Goldacre 2003) are limited. Identification of social inequalities in these problems would inform public health policy, help to target intervention and resources to those who might benefit most, and might also suggest an underlying mechanism for social inequalities in mobility disability among older people.

The objective of the current study was to explore social inequalities in grip strength (a marker of sarcopenia), physical functioning (assessed using the Short Form-36 questionnaire (Ware et al. 2000)) and falls among community dwelling older men and women who participated in the Hertfordshire Cohort Study (HCS), United Kingdom (Syddall et al. 2005a). The social circumstances of the HCS men and women were characterised by: social class at birth; age of leaving full-time education; current social class; and housing tenure and car availability as markers of material deprivation (Arber and Ginn 1993;Wiggins et al. 2002).

Methods

Study population

The Hertfordshire Cohort Study has been described previously (Syddall et al. 2005a). In brief, from 1911 to 1948, midwives recorded information on birth weight and weight at one year, on infants born in the county of Hertfordshire, United Kingdom. The records for people born 1911-1930 have been used in a series of studies linking early growth to health in later life. In 1998, a younger cohort (born 1931-39) was recruited to participate in studies examining the interactions between early life, diet, adult lifestyle and genetic factors as determinants of adult disease. 3822 men and 3284 women born between 1931-1939 in Hertfordshire and still living there were traced through the National Health Service Central Register. Permission to contact 3126 (82%) men and 2973 (91%) women was obtained from their General Practitioners.

Between 1998 and 2004, 1684 (54%) men and 1541 (52%) women aged 59-73 years took part in a nurse administered home interview. Social history comprised: full-time occupation of the father at the time of the participant’s birth; age left full-time education; own current or most recent full-time occupation; husband’s current or most recent full-time occupation for ever married women; housing tenure; number of cars and vans available to the household; and marital status. Medical history included: smoking habit; alcohol intake; self-reported walking speed as a marker of physical activity (Bendall et al. 1989); history of falls in the past year (introduced during the study and therefore available for 941 men and 1398 women); self-assessed health related quality of life using the short-form 36 (SF-36) questionnaire (Ware et al. 2000); fracture history; previous diagnosis of high blood pressure, stroke/transient ischaemic attack, or diabetes (out of pregnancy); symptoms of bronchitis; typical angina (Rose chest pain questionnaire); history of coronary artery bypass graft or angioplasty; and details of all currently prescribed medications, coded to the British National Formulary.

1579 (94%) men and 1418 (92%) women subsequently attended a clinic for investigations. Height was measured to the nearest 0.1cm using a Harpenden pocket stadiometer (Chasmors Ltd, London, UK) and weight to the nearest 0.1kg on a SECA floor scale (Chasmors Ltd, London, UK)(Lohman et al. 1988). Grip strength was measured three times on each side using a Jamar handgrip dynamometer (Weiner and Lourie 1969). A 2 hour fasted oral glucose tolerance test (OGTT) was performed using 75g anhydrous glucose and diabetes mellitus classified according to WHO criteria (World Health Org 1999). Resting blood pressure was recorded as the mean of three measurements on a Dinamap Model 8101 (GE Medical Systems, Slough, UK). An electrocardiogram (ECG) was performed and graded to the Minnesota protocol (Prineas et al. 1982). Finally, a clinical hand examination noted presence of Heberden's nodes as a marker of hand osteoarthritis. Intra- and inter-observer studies were carried out during the fieldwork. The study had ethical approval from the Hertfordshire and Bedfordshire Local Research Ethics Committee and all participants gave written informed consent.

Statistical methods

Registrar General's social class at birth, and currently, was coded from the 1990 OPCS Standard Occupational Classification (SOC90) unit group for occupation (Office of Population Censuses and Surveys 1990) using computer assisted standard occupational coding (Elias et al. 1993). Current social class was coded from own current or most recent full-time occupation for men and never-married women, and from husband's occupation for ever-married women (Arber and Ginn 1993).

The best of the six grip measurements was used to characterise maximum muscle strength. SF-36 data were mapped to eight domain scores, including physical function (PF) (Ware et al. 2000). PF scores were negatively skewed (lower scores implied poorer status) and were dichotomised for analysis: participants with scores in the lowest sex-specific fifth of the distribution (≤ 75 for men, ≤ 60 for women) were classified as having "poor" PF. Height and weight were highly correlated ($r=0.45$, $p<0.001$ for men; $r=0.32$, $p<0.001$ for women); to avoid multi-collinearity problems a sex-specific standardised residual of weight-adjusted-for-height was calculated for inclusion with height in regression models.

Cross-tabulations and chi-squared, Mann Whitney and Kruskall Wallis tests were used to describe inter-relationships between the markers of socioeconomic position and deprivation. Analysis of variance and linear regression were used to analyse the univariate unadjusted relationships between grip strength and each of the markers of socioeconomic position and deprivation. Note that categories of age left full-time education (≤14 versus ≥15 years) and number of cars available were used for presentational purposes but p-values for association were obtained from the continuously distributed variables. The important ($p<0.05$) socioeconomic and deprivation variables from the univariate analyses were subsequently included in a mutually adjusted regression model for grip strength; this model accounted for collinearity between the socioeconomic and deprivation variables and identified the important ($p<0.05$) mutually adjusted determinants of grip strength. Finally, the mutually adjusted model was adjusted in stages for the potential confounding influences of : (i) age, height and weight adjusted for height; (ii) also for smoking habit, alcohol intake and marital status; (iii) also for walking speed; (iv) also for co-morbidities. Co-morbidities that were not significant ($p>0.05$) were omitted from the final fully adjusted model. The same analysis strategy was adopted for the SF-36 physical functioning and history of falls outcome variables, but with cross-tabulations and chi-squared tests instead of ANOVA, and logistic rather than linear regression. All analyses were conducted for men and women separately using the Stata statistical software package, release 10.0 (Stata Corporation 2007).

Results

Descriptive statistics

Socioeconomic position and material deprivation are described in Table 15. 19.3% of men and 23.1% of women did not own or mortgage their home and 6.4% of men and 17.7% of women had no car available to their household.

Clinical and lifestyle characteristics are described in Table 16. Average grip strength was higher for men than women (44.0kg vs 26.5kg), men rated their physical functioning more highly than women (median scores 90 vs 85), and a history of falls was less common among men (14.9%) than women (22.6%).

Inter-relationships between socioeconomic and material deprivation variables

Lower social class at birth was associated with younger age of leaving full-time education among men and women ($p<0.001$). Lower social class at birth, and younger age of leaving full-time education, were both associated with lower social class in adulthood for men and women ($p<0.001$ for all), reflecting limited levels of social mobility across the lifecourse. Lower social class in adulthood was associated with greater likelihood of not owning or mortgaging one's home, and having no cars available to the household, among men and women (p<0.001 for all). The prevalence of not having a car available ranged from 0.9% among men of social class I to 21.1% among men of class V (corresponding statistics 14.3% and 44.4% for women) and the prevalence of not owner-occupying one's home ranged from 10.3% to 54.5% for men of social class I in comparison with V (6.0% to 50.0% for women).

Social inequalities in grip strength

Among men, younger age of leaving full-time education, lower social class, not owning one's own home, and having fewer cars available for household use were associated with lower grip strength (Table 17). Housing tenure (p=0.02) and car availability (p=0.03) remained significantly associated with grip strength after adjustment.

Among women, younger age of leaving full-time education, lower social class, not owning one's own home, and having fewer cars available for household use were associated with lower grip strength (Table 18). As for men, housing tenure (p=0.004) and car availability (p=0.002) remained significantly associated with grip strength after adjustment.

Housing tenure and car availability were independent predictors of grip strength among men (p=0.41 for interaction between housing tenure and car availability) and women (p=0.39 for interaction). Average grip strength ranged from 40.1kg among men who did not own their home and had no cars, to 46.0kg among those who owned their home and had 3 or more cars (corresponding statistics 23.8kg to 27.3kg for women, Figure 10).

Social inequalities in physical functioning

Among men, all social variables were associated with self-reported PF in univariate analyses but the associations with housing tenure (p=0.003) and car availability (p<0.001) remained significant after adjustment (
Table 19).

Among women, younger age of leaving full-time education, not owning one's own home and having fewer cars available were associated with a higher prevalence of poor PF (Table 20). Car availability (p=0.05) remained significantly associated with PF after adjustment, but the association with housing tenure was attenuated (p=0.12).

Housing tenure and car availability were independent predictors of PF among men (p=0.60 for interaction) and women (p=0.37 for interaction). The prevalence of poor physical functioning ranged from 52.3% among men who did not own their home and had no cars available, to 14.3% among those who owned their home and had 3 or more cars available (corresponding statistics 41.6% to 15.0% for women, Figure 11).

Social inequalities in history of falls

Men with no access to a car had a higher prevalence of falls history in comparison with men with access to a car (31.9% vs 13.6% falls prevalence). No other social variables were associated with falls in men (Table 21).

Among women, lower social class in adulthood was associated with increased prevalence of falls history (Table 22, *p*=0.01, prevalence ranging from 17.1% in class I to 34.0% in class V). This association was robust to adjustment (*p*=0.05).

Discussion

We have shown that having fewer cars available is associated with lower grip strength and poorer PF among men and women, and increased falls among men. Not owner-occupying one's home was associated with lower grip strength in men and women and poorer PF in men. Lower current social class was associated with increased prevalence of falls among women. All associations were robust to adjustment for adult lifestyle and the range of co-morbidity data available in this study. These findings have three important implications: first, understanding of these relationships may point to effective strategies for reducing frailty and improving health in older people; second, the relevance of conventional occupationally based measures of socioeconomic status to older people should be reappraised; third, social inequalities in muscle function and physical performance do not seem to be attributable to the variety of chronic disorders and co-morbidities that occur with greater frequency among socially disadvantaged individuals (Office for National Statistics 2004).

Social inequalities in mobility impairment and disability (Coppin et al. 2006;Lang et al. 2008;Nordstrom et al. 2007) have been demonstrated among older people but the mechanisms underpinning these associations need to be fully elucidated (Coppin et al. 2006) if inequalities are to be reduced (Lang et al. 2008;McFadden et al. 2008). Our work suggests that reduced grip strength and physical function, and increased falls, might be a mechanism underpinning social inequalities in mobility disability among older people. Our work also suggests that people who experience relatively high levels of material deprivation would benefit most from interventions designed to improve muscle strength, physical function and to reduce falls.

In this study, markers of current material deprivation (car ownership and housing tenure (Arber and Ginn 1993;Wiggins et al. 2002)) were more strongly associated with muscle strength, physical function and falls than occupationally based social class. Although inequalities across social classes could have been masked if the detrimental effects of lower socioeconomic position were offset by a history of more manual work, the retirement status of the HCS population is more likely to be crucial (sixty-five percent of HCS men and 82% of women reported that they had stopped working). Hyde (Hyde and Jones 2007), O’Reilly (O'Reilly 2002), Alwan (Alwan et al. 2007) and Benzeval (Benzeval et al. 1995), have all questioned the appropriateness of commonly used indicators of socioeconomic position for studies of health inequalities among older, post-working, populations. Our work is consistent with this literature and supports Benzeval’s (Benzeval et al. 1995) proposal that an approach that directly considers individuals’ material and social resources is needed.

The observed inequalities in grip strength, physical function and falls across groups of car availability in HCS could have arisen through confounding by co-morbidity (Office for National Statistics 2004). However, we asked specifically about car availability for the household rather than whether an individual still drives which should have limited the potential for confounding. Further, our results were robust to adjustment for walking speed, medical history and clinically measured important co-morbidities, e.g. IHD and diabetes.

Our findings for inequalities in grip strength according to housing tenure and car ownership, but not social class, are consistent with work by Kuh et al (Kuh et al. 2005). Using data from the 1946 National Survey of Health and Development (NSHD), Kuh found no differences in grip strength across social class groups; material deprivation and educational attainment were not analysed. Our results are also consistent with work by: Rautio (Rautio et al. 2005), who showed that higher income was related to hand grip strength in a cohort of elderly people in Finland; Henneberg (Henneberg et al. 2001), who showed that grip strength between 6 and 18 years in a South African cohort was higher among those in better socioeconomic conditions; and the ERAS Study Group, who showed that socioeconomic deprivation was associated with a worse clinical course of rheumatoid arthritis (including worsening grip strength) (ERAS Study Group 2000).

Our results on social inequalities in physical function are consistent with those from: the Dutch SMILE study (Groffen et al. 2008) which demonstrated associations between material deprivation and SF-36 physical function in people aged 55 years and older; Avlund (Avlund et al. 2003), who demonstrated associations between material wealth indicators (including housing tenure) and measures of health (including needing help with mobility) among 75-year-old men and women in Denmark; Nordstrom (Nordstrom et al. 2007), who showed that lower socioeconomic position was associated with increased risk of incident mobility disability in an American cohort; Kuh (Kuh et al. 2005) who demonstrated poorer balance and chair rises time among participants of lower social class in the 1946 NSHD; Arber (Arber and Ginn 1993) who showed that functional disability among older people in the British General Household Survey is influenced by social class; Lang (Lang et al. 2008) who showed that older people living in deprived neighbourhoods are at increased risk of incident mobility difficulties; and Martikainen who identified differences in change in SF-36 functioning across employment grade in Whitehall II (Martikainen et al. 1999).

The literature on social inequalities in falls is limited but our finding of some degree of social inequality in prevalence of falls history (with car ownership in men, and social class in women) is broadly consistent with work by Lawlor et al (Lawlor et al. 2003), Lyons et al (Lyons et al. 2003) and Roberts et al (Roberts and Goldacre 2003).

This study had some limitations. Firstly, we have only considered cross-sectional relationships and our dataset did not permit us to exclude the possibility of reverse causation i.e. the possibility that poorer function throughout life could have led to poorer socioeconomic status and greater material deprivation. Follow-up of the HCS cohort is ongoing and will yield valuable longitudinal information which will help to address this point. Secondly, we had no information on household income, receipt of benefits or highest educational qualification and data on material deprivation were limited to car availability and housing tenure. However, car availability and housing tenure are useful markers of social and material advantage (Arber and Ginn 1993;Wiggins et al. 2002) and reflect the amount and stability of household income (Bartley and Blane 1994). Thirdly, Hertfordshire is in the relatively less deprived South Eastern area of England (APHO and Department of Health 2008). However, our analyses were internal; unless the association between e.g. deprivation and grip strength, is systematically different among sub-groups of the population with lower or higher levels of deprivation, no major bias should have been introduced. Moreover, there is a grading of deprivation levels in Hertfordshire (APHO and Department of

Health 2008), and HCS, and Wilkinson has discussed how relative levels of deprivation matter for health inequalities in addition to absolute levels (Wilkinson 1997).

Our study also had many strengths. Firstly, we analysed a large dataset of individual rather than ecological level data, with direct measurement of grip strength as a marker of sarcopenia. Secondly, the data were rigorously collected according to strict protocols by trained research nurses and doctors (Syddall et al. 2005a). Thirdly, we were able to adjust our analyses for lifestyle, medical history and co-morbidity. Finally, we are confident that our results are generalisable to the wider population of older people in England, because the cohort have been shown to be broadly comparable with participants in the nationally representative Health Survey for England (Syddall et al. 2005a).

Conclusions

We have demonstrated social inequalities in grip strength, physical function and falls among community dwelling older men and women in the UK, with the strongest inequalities identified for current markers of material deprivation (car ownership and housing tenure) rather than occupationally based social class. Our work suggests that interventions designed to reduce the personal and public health burden of sarcopenia, reduced physical function and falls should consider the contribution of social inequalities to the problem. Our work also suggests that inequalities in sarcopenia, reduced physical function and falls could be a mechanism contributing to social inequalities in mobility disability in old age. Future research should focus on longitudinal measures of sarcopenia, physical function and falls and consider markers of social inequality which best reflect the social circumstances of older people.

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Table 15 Socioeconomic position (SEP) and material deprivation among HCS participants

n(%)		Men (n=1,684)	Women (n=1,541)
Socioeconomic position at birth			
Social class at birth+	I Professional	20 (1.3)	12 (0.8)
	II Management and Technical	111 (7.0)	120 (8.3)
	IIINM Skilled non-manual	118 (7.5)	106 (7.4)
	IIIM Skilled manual	707 (44.7)	692 (48.0)
	IV Partly skilled	440 (27.8)	393 (27.3)
	V Unskilled	185 (11.7)	119 (8.3)
Socioeconomic position in adulthood			
Age left full-time education (years)*		15 (15,16)	15 (15,16)
Left full-time education aged ≤14 years		327 (19.4)	276 (17.9)
Social class in adulthood**+	I Professional	107 (6.6)	84 (5.5)
	II Management and Technical	395 (24.2)	347 (22.5)
	IIINM Skilled non-manual	165 (10.1)	209 (13.6)
	IIIM Skilled manual	638 (39.1)	593 (38.5)
	IV Partly skilled	272 (16.7)	253 (16.4)
	V Unskilled	57 (3.5)	54 (3.5)
Material deprivation in adulthood			
Housing tenure	Owned/mortgaged	1357 (80.7)	1185 (76.9)
	Rented/other	325 (19.3)	356 (23.1)
Number of cars available	None	107 (6.4)	273 (17.7)
	1	898 (53.5)	893 (58.0)
	2	552 (32.9)	330 (21.4)
	3	122 (7.3)	45 (2.9)

Registrar General's social class was based on most recent full-time occupation, classified according to the 1990 edition of the standard occupational classification
Missing data: 103 men and 99 women had missing data for social class at birth and 50 men had missing data for social class in adulthood; 2 men had missing data for housing tenure; 5 men had missing data for car availability.
*Median and interquartile range
**Based on social class of the husband for ever married women. 21 women did not have a job code of their own (having never worked or having provided insufficient information about their most recent full-time occupation for successful social class coding) but were assigned a social class on the basis of their husband's job code. 1 woman had missing data for their own and their husband's job code class and no social class was therefore assigned. The woman's own job code was used in 110 cases because job code data for the husband were missing. For 333 women, their own and their husband's social class codes tallied. Use of the husband's social class resulted in 561 women being assigned a higher social class than had their own social class been used and 515 women were assigned a lower social class on this basis.
+ 454 (30%) men and 404 (28%) women tracked social class group from birth to adulthood; 230 (15%) men and 270 (19%) women had lower social class in adulthood than at birth, and 848 (55%) men and 767 (53%) women had higher social class in adulthood than at birth (missing data for social class change for 152 men and 100 women).

Table 16 Grip strength, SF-36 physical functioning (PF), falls history and clinical and lifestyle characteristics among HCS participants

n(%)		Men (n=1,684)	Women (n=1,541)
Clinical outcome measures			
Grip strength (kg)*		44.0 (7.5)	26.5 (5.8)
SF-36 PF score**		90 (80,95)	85 (65,95)
n(%) History of falls in the past year		140 (14.9)	316 (22.6)
Age at home interview (yrs)*		65.6 (2.9)	66.6 (2.7)
Anthropometry			
Height (cm)*		174.2 (6.5)	160.8 (5.9)
Weight (kg)*		82.4 (12.7)	71.4 (13.4)
Lifestyle			
Smoker status:	Never	546 (32.4)	923 (60.0)
	Ex	874 (51.9)	450 (29.2)
	Current	264 (15.7)	166 (10.8)
Alcohol: >21/>14 units per week men/women		362 (21.5)	75 (4.9)
Marital status:	Single (never married)	85 (5.1)	61 (4.0)
	Married	1405 (83.5)	1086 (70.5)
	Divorced/separated	98 (5.8)	113 (7.3)
	Widowed	64 (3.8)	256 (16.6)
	Cohabiting	31 (1.8)	25 (1.6)
Walking speed:	Very slow	93 (5.5)	125 (8.1)
	Stroll at an easy pace	404 (24.1)	305 (19.8)
	Normal speed	654 (39.0)	686 (44.6)
	Fairly brisk	451 (26.9)	339 (22.0)
	Fast	76 (4.5)	83 (5.4)
Co-morbidity			
Ischaemic heart disease		241 (15.5)	143 (10.2)
Stroke/TIA		92 (5.5)	47 (3.1)
Hypertension		630 (40.0)	577 (40.8)
Bronchitis		107 (6.4)	75 (4.9)
Previously diagnosed diabetes		120 (7.6)	83 (5.9)
Newly diagnosed diabetes		124 (7.9)	125 (8.9)
Minor trauma fracture aged 45 or older		129 (7.7)	284 (18.4)
Hand osteoarthritis (OA)		389 (28.0)	741 (53.6)
Number of systems medicated**		1 (0,2)	1 (1,2)

*Mean and standard deviation

**Median and inter-quartile range for SF-36 physical functioning (PF) score and number of systems medicated

Grip strength was measured at clinic and data were available for 1572 men and 1415 women. SF-36 PF score was ascertained at home interview and was available for all but 2 men and 1 woman. The question about falls history was included in the home interview part way through the study; data were therefore available for 941 men and 1398 women.

Table 17 Associations between socioeconomic position and material deprivation and grip strength among HCS men

		Mean(SD) grip strength (kg)	Unadjusted differences in grip strength (95%CI)		Mutually adjusted differences in grip strength (95%CI)[a]		Fully adjusted differences in grip strength (95%CI)[b]	
Socioeconomic position at birth								
Social class at birth	I	42.7 (6.6)	-1.3	-4.8,2.1				
	II	45.5 (6.7)	1.5	-0.1,3.0				
	IIINM	44.9 (6.9)	0.8	-0.7,2.4				
	IIIM	44.0 (7.6)	*Reference*					
	IV	43.6 (7.7)	-0.4	-1.3,0.5				
	V	43.5 (8.0)	-0.5	-1.7,0.8				
			p=0.17 on 5df					
Socioeconomic position in adulthood								
Age left full-time education:	≤14 years	42.1 (7.3)	0.6	0.3,0.9	0.5	0.2,0.7	0.1	-1.1,0.4
	≥15 years	44.5 (7.5)	p<0.001, per year older		*p=0.001,* per year older		*p=0.29,* per year older	
Social class in adulthood	I	44.4 (6.8)	0.6	-1.0,2.2				
	II	44.8 (7.3)	1.0	0.0,2.0				
	IIINM	44.8 (7.3)	1.0	-0.3,2.3				
	IIIM	43.8 (7.6)	*Reference*					
	IV	42.7 (8.2)	-1.1	-2.2,-.0.0				
	V	44.7 (7.4)	0.9	-1.2,3.0				
			p=0.01 on 5df					
Material deprivation in adulthood								
Housing tenure	Owned/mortgaged	44.6 (7.4)	*Reference*		*Reference*		*Reference*	
	Rented/other	41.8 (7.7)	-2.8	-3.8,-1.9	-2.0	-3.0,-1.0	-1.1	-2.0,-0.2
			p<0.0001		*p<0.001*		*p=0.02*	
Number of cars available	None	40.7 (8.2)						
	1	43.6 (7.4)	1.5	1.0,2.0	1.1	0.5,1.6	0.6	0.1,1.1
	2	45.0 (7.4)	*p<0.001,* per extra car		*p<0.001,* per extra car		*p=0.03,* per extra car	
	3	45.6 (7.6)						

SD=standard deviation; kg=kilogram; CI=confidence interval.

a. A mutually adjusted model for grip strength on age left education and social class in adulthood showed that education was the only significant adult socioeconomic position determinant of grip (p=0.08 for SOC90 SC, p<0.001 for education). A mutually adjusted model for grip on housing tenure and car ownership showed that both remained as significant (p<0.001 for both) adult deprivation determinants of grip. As such, only age left education, housing tenure and car ownership were included in the mutually adjusted model for grip. b. The mutually adjusted model for grip on education, housing tenure and car ownership was adjusted in stages for (i) age, height and weight adjusted for height; (ii) also for smoking, alcohol and marital status; (iii) also for walking speed; and (iv) also for co-morbidities [all of the co-morbidities detailed in Table 16 were entered in the model but the non-significant ones (p>0.05) were then removed from the model]. The "fully adjusted" differences in grip in the table were therefore adjusted for age, height, weight for height, smoking, alcohol, marital status, walking speed and diabetes.

Table 18 Associations between socioeconomic position and material deprivation and grip strength among HCS women

		Mean(SD) grip strength (kg)	Unadjusted differences in grip strength (95%CI)		Mutually adjusted differences in grip strength (95%CI)[a]		Fully adjusted differences in grip strength (95%CI)[b]	
Socioeconomic position at birth	I	26.1 (8.9)	-0.6	-0.4,2.8				
Social class at birth	II	25.9 (5.7)	-0.8	-2.0,0.3				
	IIINM	27.4 (5.8)	0.7	-0.5,1.9				
	IIIM	26.7 (5.5)	*Reference*					
	IV	26.2 (5.8)	-0.5	-1.3,0.2				
	V	26.2 (6.1)	-0.5	-1.7,0.7				
			p=0.33 on 5df					
Socioeconomic position in adulthood								
Age left full-time education:	≤14 years	25.9 (5.8)	0.4	0.2,0.6	0.3	0.0,0.5	0.1	-0.2,0.3
	≥15 years	26.6 (5.7)	*p=0.001,* per year older		*p=0.03,* per year older		*p=0.65,* per year older	
Social class in adulthood	I	27.4 (5.1)	0.7	-0.6,2.1				
	II	26.9 (5.6)	0.3	-0.5,1.0				
	IIINM	26.7 (5.4)	0.1	-0.9,1.0				
	IIIM	26.6 (5.8)	*Reference*					
	IV	25.6 (6.1)	-1.0	-1.9,-0.1				
	V	24.9 (6.3)	-1.7	-3.5,-0.0				
			p=0.03 on 5df					
Material deprivation in adulthood								
Housing tenure	Owned/mortgaged	27.0 (5.6)	*Reference*		*Reference*		*Reference*	
	Rented/other	24.9 (6.1)	-2.1	-2.8,-1.4	-1.6	-2.4,-0.9	-1.1	-1.8,-0.3
			p<0.0001		*p<0.0001*		*p=0.004*	
Number of cars available	None	24.6 (5.8)						
	1	26.7 (5.8)	1.1	0.6,1.5	0.7	0.3,1.2	0.7	0.2,1.1
	2	27.3 (5.4)	*p<0.001,* per extra car		*p=0.002,* per extra car		*p=0.002,* per extra car	
	3	26.9 (4.9)						

Abbreviations as in footnotes of Table 17.
a. A mutually adjusted model for grip on age left education and adult social class showed that education was the only significant adult SEP determinant of grip (p=0.09 for social class, p=0.007 for education). A mutually adjusted model for grip on housing tenure and car ownership showed that both remained as significant (p<0.001 for housing and p=0.001 for car) adult deprivation determinants of grip. As such, only age left education, housing tenure and car ownership were included in the mutually adjusted model for grip. b. The mutually adjusted model for grip on education, housing tenure and car ownership was adjusted in stages for (i) age, height and weight adjusted for height; (ii) also for smoking, alcohol and marital status; (iii) also for walking speed; and (iv) also for co-morbidities [all of the co-morbidities detailed in Table 16 were entered in the model but the non-significant ones (p>0.05) were then removed from the model]. The “fully adjusted” differences in grip in the table were therefore adjusted for age, height, weight for height, smoking, alcohol, marital status, walking speed, hypertension, diabetes, minor trauma fracture and number of systems medicated.

Figure 10 Grip strength according to housing tenure and car availability among Hertfordshire Cohort Study men and women

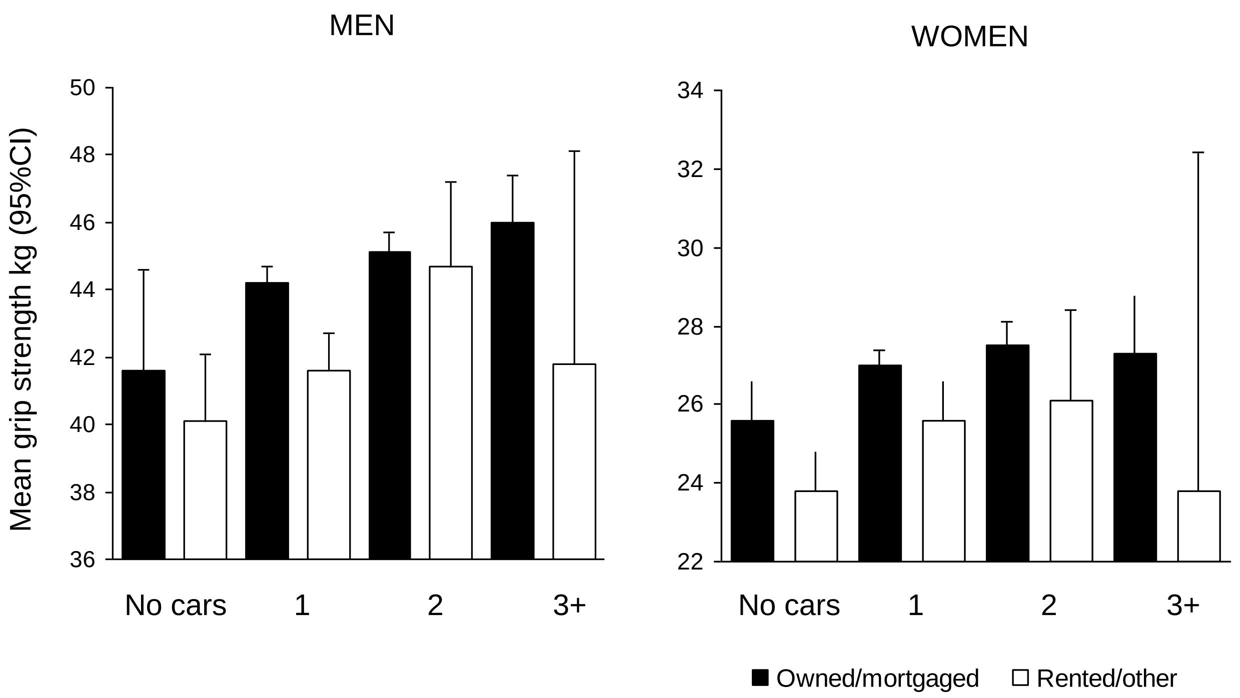

Table 19 Associations between socioeconomic position and material deprivation and self-reported PF among HCS men

		n(%) with poor PF**	Unadjusted odds ratio (OR) for poor PF (95%CI)		Mutually adjusted OR for poor PF (95%CI)[a]		Fully adjusted OR for poor PF (95%CI)[b]	
Socioeconomic position at birth	I	5 (25.0)	1.2	0.4,3.2	1.3	0.4,3.6		
Social class at birth	II	21 (18.9)	0.8	0.5,1.3	1.0	0.6,1.7		
	IIINM	12 (10.2)	0.4	0.2,0.7	0.5	0.3,0.9		
	IIIM	158 (22.4)	*Reference*		*Reference*			
	IV	98 (22.3)	1.0	0.7,1.3	0.9	0.6,1.2		
	V	52 (28.1)	1.4	0.9,2.0	1.1	0.7,1.6		
			p=0.02 on 5df		*p=0.29* on 5df			
Socioeconomic position in adulthood								
Age left full-time education:	≤14 years	85 (26.1)	0.8.	0.7,0.9	0.9	0.8,1.0		
	≥15 years	279 (20.6)	*p<0.001,* per year older		*p=0.08,* per year older			
Social class in adulthood	I	16 (15.0)	0.6	0.3,1.1				
	II	80 (20.3)	0.9	0.6,1.2				
	IIINM	34 (20.6)	0.9	0.6,1.4				
	IIIM	143 (22.4)	*Reference*					
	IV	72 (26.7)	1.3	0.9,1.7				
	V	14 (24.6)	1.1	0.6,2.1				
			p=0.01 for trend					
Material deprivation in adulthood								
Housing tenure	Owned/mortgaged	245 (18.1)	*Reference*		*Reference*		*Reference*	
	Rented/other	120 (36.9)	2.7	2.0,3.5	1.8	1.4,2.4	1.8	1.2,2.7
			p<0.0001		*p<0.001*		*p=0.003*	
Number of cars available	None	48 (44.9)						
	1	235 (26.2)	0.5	0.4,0.6	0.6	0.5,0.7	0.6	0.5,0.8
	2	63 (11.4)	*p<0.001,* per extra car		*p<0.001*, per extra car		*p<0.001,* per extra car	
	3	18 (14.8)						

PF= physical functioning; OR=odds ratio; CI=confidence interval. **Poor PF defined as a score in the bottom quintile of the sex-specific distribution of the SF-36 physical functioning domain. a. A mutually adjusted model for poor physical functioning on age left education and social class in adulthood showed that education was the only significant adult socioeconomic position determinant of poor PF (p=0.003 for education, p=0.18 for trend for SOC90 SC). A mutually adjusted model for poor PF on housing tenure and car ownership showed that housing tenure and car ownership were both significant adult deprivation determinants of poor PF (p<0.001 for housing and car). As such, only age left education, housing tenure and car ownership were included with father's social class in the mutually adjusted model for poor PF. b. Social class at birth and age left full-time education were not significant after adjustment for housing and car use. Hence, a model for poor PF on housing tenure and car ownership was adjusted in stages for (i) age, height and weight adjusted for height; (ii) also for smoking habit, alcohol intake and marital status; (iii) also for walking speed; and (iv) also for co-morbidities [all of the co-morbidities detailed in Table 16 were entered in the model but the non-significant ones (p>0.05) were then removed]. The "fully adjusted" odds ratios for poor PF presented in the table were therefore adjusted for age, height, weight for height, smoking, alcohol, marital status, walking speed, IHD and number of systems medicated.

Table 20 Associations between socioeconomic position and material deprivation and self-reported PF among HCS women

		n(%) with poor PF**	Unadjusted odds ratio (OR) for poor PF (95%CI)		Mutually adjusted OR for poor PF (95%CI)[a]		Fully adjusted OR for poor PF (95%CI)[b]	
Socioeconomic position at birth	I	3 (25.0)	1.2	0.3,4.4				
Social class at birth	II	29 (24.2)	1.1	0.7,1.8				
	IIINM	21 (19.8)	0.9	0.5,1.5				
	IIIM	152 (22.0)	*Reference*					
	IV	91 (23.2)	1.1	0.8,1.4				
	V	28 (23.7)	1.1	0.7,1.8				
			p=0.96 on 5df					
Socioeconomic position in adulthood								
Age left full-time education:	≤14 years	70 (25.4)	0.8	0.7,0.9	0.9	0.8,1.0		
	≥15 years	281 (22.2)	*p=0.003,* per year older		*p=0.07,* per year older			
Social class in adulthood	I	15 (17.9)	0.8	0.4,1.4				
	II	76 (22.0)	1.0	0.7,1.4				
	IIINM	48 (23.0)	1.1	0.7,1.6				
	IIIM	128 (21.6)	*Reference*					
	IV	65 (25.7)	1.3	0.9,1.8				
	V	18 (33.3)	1.8	1.0,3.3				
			p=0.28 on 5df					
Material deprivation in adulthood								
Housing tenure	Owned/mortgaged	222 (18.8)	*Reference*		*Reference*		*Reference*	
	Rented/other	129 (36.2)	2.5	1.9,3.2	2.1	1.6,2.7	1.4	0.9,2.1
			p<0.0001		*p<0.001*		*p=0.12*	
Number of cars available	None	94 (34.4)						
	1	193 (21.6)	0.6	0.5,0.8	0.8	0.7,0.9	0.8	0.6,1.0
	2	56 (17.0)	*p<0.001,* per extra car		*p=0.01,* per extra car		*p=0.05,* per extra car	
	3	8 (17.8)						

Abbreviations and definitions as in footnotes of Table 19. a. A mutually adjusted model for poor physical functioning on housing tenure and car ownership showed that these were both significant adult deprivation determinants of poor PF (p<0.001 for housing, p=0.006 for car) and as such, these were included with age left full-time education in the mutually adjusted model for poor PF. b. Age left full-time education was not significant (p=0.07) after adjustment for housing and car use. Hence, a model for poor PF on housing tenure and car ownership was adjusted in stages for (i) age, height and weight adjusted for height; (ii) also for smoking habit, alcohol intake and marital status; (iii) also for walking speed; and (iv) also for co-morbidities [all of the co-morbidities detailed in Table 16 were entered in the model but the non-significant ones (p>0.05) were then removed]. The “fully adjusted” odds ratios for poor PF presented in the table were therefore adjusted for age, height, weight for height, smoking, alcohol, marital status, walking speed, IHD, diabetes and number of systems medicated.

Figure 11 Prevalence of poor SF-36 physical functioning (PF) according to housing tenure and car availability among Hertfordshire Cohort Study men and women

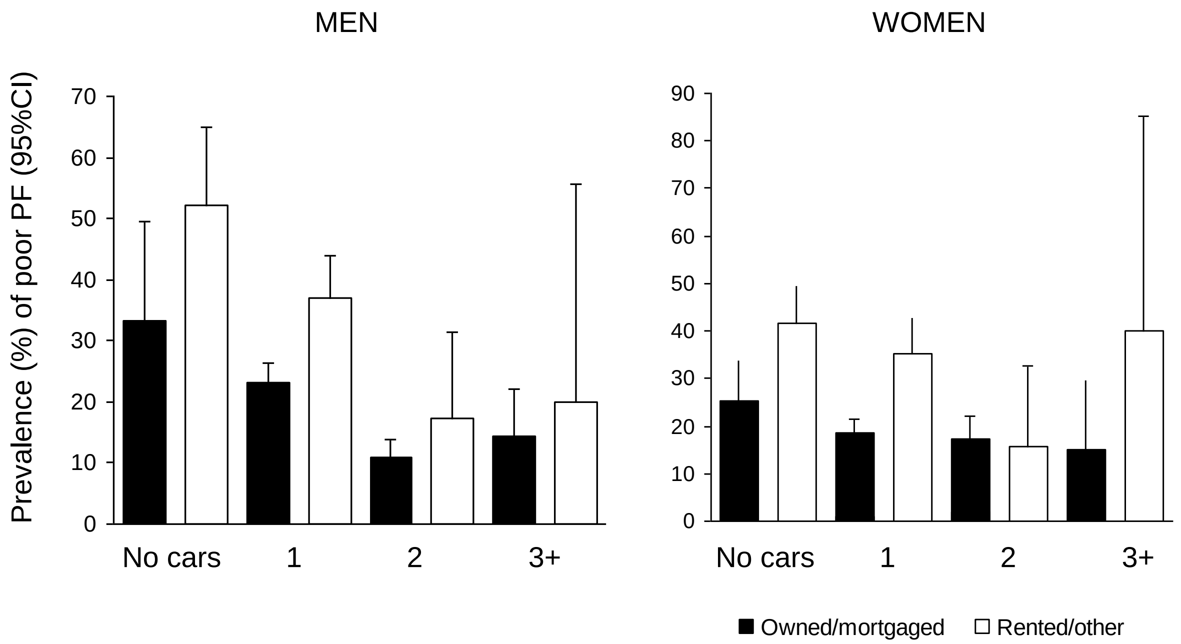

Table 21 Associations between socioeconomic position and material deprivation and history of falling in the past year among HCS men

		n(%) having fallen during past year	Unadjusted odds ratio (OR) for falls (95%CI)		Adjusted odds ratios for falls in men with no, compared with any, car availability (95%CI)
Socioeconomic position at birth	I	1 (12.5)	0.9	0.1,7.3	
Social class at birth	II	11 (18.0)	1.4	0.7,2.8	
	IIINM	10 (15.2)	1.1	0.5,2.3	OR = 3.2 (1.8,5.7), p<0.001 for no cars vs any; adjusted for age, height and weight adjusted for height
	IIIM	61 (13.9)	*Reference*		
	IV	33 (15.0)	1.1	0.7,1.7	
	V	15 (16.3)	1.2	0.7,2.2	
			p=0.96 on 5df		OR = 3.2 (1.7,6.0), p<0.001 for no cars vs any, also adjusted for smoking, alcohol and marital status
Socioeconomic position in adulthood					
Age left full-time education:	≤14 years	29 (17.9)	1.0	0.8,1.1	
	≥15 years	111 (14.3)	*p=0.50,* per year older		
Social class in adulthood	I	10 (14.1)	1.1	0.5,2.3	OR = 2.8 (1.5,5.3), p=0.001 for no cars vs any, also adjusted for walking speed
	II	37 (16.1)	1.3	0.8,2.1	
	IIINM	17 (17.9)	1.5	0.8,2.7	
	IIIM	48 (12.9)	*Reference*		OR = 2.7 (1.4,5.1), p=0.003 for no cars vs any, also adjusted for IHD and number of systems medicated[a]
	IV	21 (15.3)	1.2	0.7,2.1	
	V	6 (20.7)	1.8	0.7,4.5	
			p=0.72 on 5df		
Material deprivation in adulthood					
Housing tenure	Owned/mortgaged	106 (14.2)	*Reference*		
	Rented/other	34 (17.4)	1.3	0.8,1.9	
			p=0.28		
Number of cars available	None	22 (31.9)			
	1	76 (14.6)	3.0	1.7,5.1	
	2	32 (11.0)	*p<0.001* for no cars versus any		
	3	10 (16.1)			

CI=confidence interval; OR=odds ratio; IHD=ischaemic heart disease; vs=versus.

a. Note that all co-morbidities [IHD, stroke/TIA, hypertension, bronchitis, diabetes, minor trauma fracture, hand OA and number of systems medicated] were entered in the model but the non-significant ones (p>0.05) were removed from the final fully adjusted model.

Table 22 Associations between socioeconomic position and material deprivation and history of falling in the past year among HCS women

		n(%) having fallen during past year	Unadjusted odds ratio (OR) for falls (95%CI)		Adjusted odds ratios for falls in women per lower band of SOC90 SC (95%CI)
Socioeconomic position at birth	I	3 (27.3)	1.4	0.4,5.3	OR = 1.1 (1.0,1.2), p=0.06
Social class at birth	II	30 (28.9)	1.5	0.9,2.4	adjusted for age, height and
	IIINM	19 (19.8)	0.9	0.5,1.6	weight adjusted for height
	IIIM	133 (21.1)	*Reference*		
	IV	78 (22.0)	1.1	0.8,1.4	OR = 1.1 (1.0,1.2), p=0.07
	V	26 (23.2)	1.1	0.7,1.8	also adjusted for smoking, alcohol and
			p=0.61 on 5df		marital status
Socioeconomic position in adulthood					
Age left full-time education:	≤14 years	63 (25.3)	1.0	0.9,1.1	OR = 1.1 (1.0,1.2), p=0.06
	≥15 years	253 (22.0)	*p=0.47* per year older		also adjusted for walking speed
Social class in adulthood	I	13 (17.1)	0.7	0.4,1.4	
	II	65 (20.3)	0.9	0.6,1.3	OR = 1.1 (1.0,1.2), p=0.05
	IIINM	43 (22.3)	1.0	0.7,1.5	also adjusted for IHD and hypertension[a]
	IIIM	115 (21.9)	*Reference*		
	IV	63 (27.3)	1.3	0.9,1.9	
	V	17 (34.0)	1.8	1.0,3.4	
			p=0.01 for trend		
Material deprivation in adulthood					
Housing tenure	Owned/mortgaged	230 (21.5)	*Reference*		
	Rented/other	86 (26.3)	1.3	1.0,1.7	
			p=0.07		
Number of cars available	None	66 (26.1)			
	1	186 (23.1)	1.3	0.9,1.7	
	2	54 (18.2)	*p=0.14* for no cars vs any		
	3	10 (24.4)			

CI=confidence interval; OR=odds ratio; IHD=ischaemic heart disease; vs=versus.

a. Note that all co-morbidities [IHD, stroke/TIA, hypertension, bronchitis, diabetes, minor trauma fracture, hand OA and number of systems medicated] were entered in the model but the non-significant ones (p>0.05) were removed from the final fully adjusted model.

Declaration of authorship for paper 1

Holly Syddall: conducted the literature review; planned and executed the statistical analyses; designed and prepared the tables and figures; and drafted all versions of the manuscript.

Maria Evandrou: provided direction for the social inequalities component of the literature review; provided feedback on early drafts of the manuscript and reviewed the final version.

Cyrus Cooper took overall responsibility for the Hertfordshire Cohort Study and reviewed the final version of the manuscript.

Avan Aihie Sayer: designed and managed the Hertfordshire Cohort Study; helped to iterate the analytical strategy and presentation of results; and provided feedback on early drafts of the manuscript and reviewed the final version.

Signatures of all co-authors confirming the accuracy of the declaration of authorship provided above for paper 1:

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Chapter 4. Paper 2: Prevalence and correlates of frailty among community dwelling older men and women: findings from the Hertfordshire Cohort Study

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Abstract

Background

Frailty, a multi-dimensional geriatric syndrome, confers a high risk for falls, disability, hospitalisation and mortality. The prevalence and correlates of frailty in the UK are unknown.

Methods

Frailty, defined by Fried, was examined among community dwelling ‘young-old’ (64 to 74 years) men (n=320) and women (n=318) who participated in the Hertfordshire Cohort Study, UK.

Results

The prevalence of frailty was 8.5% among women and 4.1% among men (p=0.02). Among men, older age (p=0.009), younger age of leaving education (p=0.05), not owning/mortgaging one’s home (odds ratio [OR] for frailty 3.45 [95%CI 1.01 to 11.81], p=0.05, in comparison with owner/mortgage occupiers) and reduced car availability (OR for frailty 3.57 per unit decrease in number of cars available [95%CI 1.32, 10.0], p=0.01) were associated with increased odds of frailty. Among women, not owning/mortgaging one’s home (p=0.02) was associated with frailty. With the exception of car availability among men (p=0.03), all associations were non-significant (p>0.05) after adjustment for co-morbidity.

Conclusions

Frailty is not uncommon even among community dwelling ‘young-old’ men and women in the UK. There are social inequalities in frailty which appear to be mediated by co-morbidity.

Keywords: frailty; prevalence; older people; social inequalities; co-morbidity

Key points

Frailty confers a high risk for falls, disability, hospitalisation and mortality. However, research into the prevalence of frailty and its correlates, particularly social influences, is limited.

Using data from the Hertfordshire Cohort Study we have shown that frailty, defined by the Fried criteria, is not uncommon even among ‘young-old’ community dwelling men and women, aged 64-74 years, in the UK (prevalences: 8.5% women; 4.1% men).

We have demonstrated social inequalities in frailty (across levels of education, home ownership and car availability) which are largely mediated by co-morbidity.

Introduction

Frailty is a multidimensional geriatric syndrome (Bauer and Sieber 2008); it may be described as a state of increased vulnerability which results from decreased physiological reserves, multi-system dysregulation and limited capacity to maintain homeostasis (Abellan van Kan et al. 2008). Although overlapping, frailty is not synonymous with either co-morbidity or disability (Fried et al. 2004;Wong et al. 2010); rather, co-morbidity may be considered a risk factor for frailty and disability a consequence of frailty. Frailty confers high risk for falls, disability, hospitalisation and mortality (Fried et al. 2001).

However, frailty remains an evolving concept lacking unique diagnostic criteria for use in clinical practice and epidemiological research (Hogan et al. 2003;Hubbard et al. 2009;Rothman et al. 2008;Topinkova 2008). Approaches to the characterisation of frailty have included: an index based on the proportion of accumulated deficits (Rockwood and Mitnitski 2007); presence of problems in at least two of the physical, nutritive, cognitive and sensory domains (Strawbridge et al. 1998); a 7-point Clinical frailty scale (Rockwood et al. 2005); dependency e.g. needing assistance from another person for bathing or taking medications (Brody et al. 1997); and grip strength has been proposed as a useful single marker of frailty (Syddall et al. 2003). However, the Fried criteria (Fried et al. 2001) are the most widely implemented objective approach to the classification of frailty as a biological functional limitation or impairment (Morley et al. 2006), defining frailty as present if a person has at least three of the following criteria: weight loss, weakness, exhaustion, slowness and low activity (Fried et al. 2001). Frailty defined by Fried has predictive validity for adverse health outcomes, including disability (Avila-Funes et al. 2008;Fried et al. 2001).

Data on the prevalence and correlates of frailty (defined by Fried) are largely from US studies. The prevalence of frailty among 5,317 community dwelling men and women aged 65 years and older who participated in the American Cardiovascular Health Study was 6.9% with a four year incidence of 7.2% (Fried et al. 2001); frailty was associated with older age, male gender, being African American, having lower education and income, poorer health and higher rates of co-morbid chronic disease and disability. In the Women's Health and Aging Study-I, the prevalence of frailty among 749 community-dwelling women aged 65 years and older who were moderately to severely disabled was 25% and frailty was associated with incident difficulties in performing activities of daily living (Boyd et al. 2005). Ottenbacher (Ottenbacher et al. 2005) studied frailty among 621 Mexican Americans, average age 78 years: 22% of women and 17% of men were classified as frail and upper extremity strength, disability, co-morbidities, and mental status scores predicted frailty among men, and lower extremity strength, disability and body mass index predicted frailty among women. The prevalence of frailty in the Women's Health Initiative Observational Study (Woods et al. 2005) was 16.3% and older age, co-morbidity, smoking, depressive symptoms, lower income, living alone and poorer self-reported health were associated with increased frailty. Cawthon et al (Cawthon et al. 2007b) estimated a frailty prevalence of 4% among American men aged 65 years and older and the seven and a half year incidence of frailty among 420 community dwelling women aged 70-79 years who participated in the Women's Health and Aging Study II and were not frail at baseline was 9% (Xue et al. 2008).

European studies on the prevalence and determinants of frailty are limited. The French Three-City Study demonstrated a frailty prevalence of 7% among 6,078 community dwelling men and women aged 65 years and older (Avila-Funes et al. 2008); frailty was associated with older age, female gender, lower education, lower income, poorer self-reported health status and more chronic diseases in addition to incident disability. The recent Survey of Health, Aging and Retirement in Europe (SHARE) (Santos-Eggimann et al. 2009), which did not include UK data, studied 16,584 men and women aged 50 years and older; the prevalence of frailty was 4.1% among participants aged 50-64 years and 17% among those aged 65 and older, with a higher prevalence of frailty among women. The SHARE study demonstrated higher prevalences of frailty in southern than northern Europe and concluded that education contributed to this geographical variation. We are not aware of any prevalence data on frailty defined by the Fried criteria from the United Kingdom.

The United Kingdom has an ageing population (Bray 2008). Within the context of this demographic change, the UK government's ageing strategy recognises the importance of building a society which enables individuals to live a healthy and independent old age (HM Government 2009a). The UK government also acknowledges the need for effective planning to enable health and social systems to have the capability to support and care for inevitably increasing numbers of frail older people over time (HM Government 2009b). Although social factors such as lower education and income are broadly acknowledged as playing an important role in frailty (Walston et al. 2006), research focused on the social patterning of frailty is limited (Avila-Funes et al. 2008;Fried et al. 2001;Santos-Eggimann et al. 2009;Woods et al. 2005). Understanding of the social context in which frailty occurs would (i) inform local and national public health policy and planning by identifying subgroups of the population in which the burden of frailty is focused and (ii) provide clues to aetiology and give direction for where best to target initiatives and interventions which aim to reduce frailty.

The objective of the current study was to describe the prevalence of frailty, and to examine its associations with lifestyle and social characteristics, among community dwelling 'young-old' men and women who participated in the Hertfordshire Cohort Study, UK (Syddall et al. 2005a).

Methods

Study population

Study participants comprised the 322 men and 320 women aged 64 to 74 years who participated in the home interviews and clinic visits for the East Hertfordshire follow-up study in 2004-5, Figure 6 (Syddall et al. 2005a). At the follow-up clinic visit, medical and social histories were updated. Information was collected on frailty status using the Fried criteria (Fried et al. 2001). Self-assessed health related quality of life was ascertained using the short-form 36 (SF-36) questionnaire and SF-36 data were mapped to eight domain scores including physical function (PF). Hand grip strength was measured three times on each side using a Jamar handgrip dynamometer and participants completed a timed 3 metre walk. Please see Appendix 4 of this thesis and the Age and Ageing website (http://www.ageing.oxfordjournals.org/) for a full description of the study population and methodology.

The Fried frailty criteria define frailty as presence of three or more of the following items: unintentional weight loss (greater than 10lb over the past year), weakness, self-reported exhaustion, slow walking speed and low physical activity. In this study, these criteria were operationalised as follows: weakness was defined as a maximum grip strength of ≤30kg for men and ≤20kg for women (Lauretani et al. 2003); exhaustion was identified if the participant felt that everything they did was an effort for either moderate amounts or most of the time in the past week; slow walking speed was defined as a 3m walk time in the slowest fifth of the HCS sex-specific distribution (≥3.82 seconds for men and ≥3.98 seconds for women); and low physical activity was identified if the participant had an SF-36 physical functioning score in the bottom fifth of the HCS sex-specific distribution (≤75 for men and ≤60 for women). Four participants had missing data for the Fried frailty score and were excluded from all analyses.

Statistical methods

Cross-tabulations of frequencies and percentages, and univariate and multiple logistic regression models were used to analyse the relationships between frailty and the characteristics of the study participants. Univariate analyses were conducted initially, followed by mutually adjusted, and co-morbidity adjusted, analyses for lifestyle and social variables that were significantly associated with frailty ($p<0.05$) in the univariate analyses. Categories of age, smoking status, alcohol intake, age left full-time education, social class and number of cars were used for presentational purposes but p-values for association were obtained from continuously distributed variables. All analyses were conducted for men and women separately using Stata, release 10.0 (Stata Corporation 2007).

Results

Table 23 shows the summary characteristics of the study participants who were aged 64 to 74 years at the time of the follow-up clinic visit. Table 24 shows the prevalence of each of the components of the Fried frailty criteria according to gender; the overall prevalence of frailty was 8.5% for women and 4.1% for men (p=0.02 for gender difference).

Table 25 shows the univariate associations between the characteristics of the HCS participants and Fried frailty status. Among men, older age, younger age of leaving full-time education, not owning or mortgaging one's home and having fewer cars available for household use were all associated with increased odds of being frail. Among women, lower alcohol intake and not owning or mortgaging one's home were associated with increased odds of being frail.

Among men, a mutually adjusted logistic regression model for frailty versus all of the variables that were significant in univariate analyses showed that the associations between frailty and age of leaving education (p=0.58) and home ownership (p=0.23) were attenuated (see Appendix 4 for details). The adjusted odds ratios for frailty in relation to age (odds ratio [95%CI] per year older 1.27 [0.96,1.69], p=0.10) and car availability (odds ratio [95%CI] per extra car 0.35 [0.11,1.04], p=0.06) remained sizeable but the associations were not significant at the five percent level.

Among women, a mutually adjusted logistic regression model for frailty versus alcohol intake and home ownership demonstrated that the association with home ownership remained significant (odds ratio for frailty for not owning or mortgaging one's home [95%CI] 2.47 [1.01,6.03], p=0.05) whilst the association with alcohol intake was attenuated (p=0.10) (see Appendix 4 for details).

Finally we analysed the associations between frailty and co-morbidities among men and women (ischaemic heart disease, stroke/TIA, high blood pressure, bronchitis, diabetes, minor trauma fracture, hand osteoarthritis and history of falling) to identify which co-morbidities should be included as adjustment factors in the analyses of frailty versus lifestyle and social factors. Ischaemic heart disease (p<0.001), stroke/TIA (p=0.04) and high blood pressure (p=0.02) were associated with frailty among men and ischaemic heart disease (p<0.001), high blood pressure (p=0.01) and diabetes (p=0.05) were associated with frailty among women. The association between car availability and frailty among men was strengthened by adjustment for these significant co-morbidities (p=0.03) but the associations between frailty and age (p=0.14), education (p=0.72) and home ownership (p=0.64) were further attenuated (see Appendix 4 for details). The association between frailty and home ownership among women was attenuated by adjustment for ischaemic heart disease, high blood pressure and diabetes (p=0.21) (see Appendix 4 for details).

Discussion

We have shown that the prevalence of frailty, as defined by Fried, among community dwelling 'young-old' men and women aged 64 to 74 years who participated in the Hertfordshire Cohort Study, UK, was 8.5% for women and 4.1% for men. Among men, frailty was associated with older age, younger age of leaving full-time education, not owning or mortgaging one's home and having fewer cars available for household use. Among women, not owning or mortgaging one's home was associated with increased frailty. However, with the exception of reduced car availability and frailty among men, these associations were not significant (p>0.05) after adjustment for co-morbidity. These findings, the first from a UK study, have two important implications. First, frailty is not uncommon even among 'young-old' community dwelling men and women in the UK. Second, there are social inequalities in frailty which appear to be largely mediated by the variety of chronic disorders and co-morbidities that occur with greater frequency among socially disadvantaged individuals. Our results identify subgroups of the population in which the burden of frailty is focused and could inform planning for the capability of health and social systems to care for increasing numbers of frail older people over time. Our results also provide some direction for where best to target initiatives and interventions which aim to reduce frailty.

Our prevalence statistics, the first to be published from a UK study, are broadly comparable with published US and European prevalence data for frailty defined by the Fried criteria (4% to 25% (Avila-Funes et al. 2008;Boyd et al. 2005;Cawthon et al. 2007b;Fried et al. 2001;Ottenbacher et al. 2005;Santos-Eggimann et al. 2009;Woods et al. 2005;Xue et al. 2008)) although the relatively young age of the HCS participants has perhaps led to a relatively low prevalence of frailty in the current study. However, our results highlight the need for increased planning of geriatric medicine services if frailty, even in this relatively young cohort, is already approaching 10% prevalence in at least one gender group. The wide variation in published frailty prevalence estimates is unsurprising owing to different: study designs and geographical locations; inclusion and exclusion criteria; gender, age and ethnicity of study participants; and variations in the implementation of the Fried criteria. However it is perhaps of note that the prevalence found in this study was more similar to that reported by the French Three-City Study (Avila-Funes et al. 2008) and the European-wide SHARE study (Santos-Eggimann et al. 2009) than to that reported by the US studies.

Home ownership and car availability are useful markers of social and material advantage (Arber and Ginn 1993) which reflect the amount and stability of household income (Bartley and Blane 1994). Our univariate findings support the argument that social factors play a role in frailty (Walston et al. 2006) and are consistent with the limited literature on social influences on frailty (Avila-Funes et al. 2008;Fried et al. 2001;Santos-Eggimann et al. 2009). Further, our adjusted results suggest that social inequalities in frailty may be largely attributable to the variety of chronic disorders and co-morbidities that occur with greater frequency among socially disadvantaged individuals (Office for National Statistics 2004). Our results identify subgroups of the population in which the burden of frailty is focused and could inform planning for the capability of health and social systems to care for increasing numbers of frail older people over time.

The observed gender difference in frailty (8.5% among women, 4.1% among men) in this study is consistent with available literature (Avila-Funes et al. 2008;Ottenbacher et al. 2005;Puts et al. 2005a;Santos-Eggimann et al. 2009) and is not unexpected given that women have lower average lean mass and strength than men (Evans 1995;Fried et al. 2001), and that older women are more likely than men to live alone with consequences for poorer nutrition, sarcopenia, and frailty (Evans 1995). Other explanations for the gender difference in frailty prevalence include: differences in patterns of physical activity and physical performance; the fact that men of a given age have higher mortality rates but women have more morbidity and disability; and women having lower baseline levels of muscle mass and lower levels of neuroendocrine and hormonal factors such as testosterone which may predispose them to reaching frailty (Puts et al. 2005b).

This study had some limitations. Firstly, we have only considered cross-sectional relationships between lifestyle and social factors and frailty. However, follow-up of the HCS cohort is ongoing (e.g. postal and clinical follow-ups are planned and the cohort are flagged with the National Health Services Central Register for ongoing notification of deaths) and will yield valuable longitudinal information on frailty incidence and progression. Secondly, additional information on social factors such as household income or receipt of benefits would have been useful. Thirdly, Hertfordshire is in the relatively less deprived South Eastern area of England and we studied community dwelling 'young-old' men and women who might reasonably be expected to be at the less frail end of the spectrum among older people. Finally, response bias analyses (see section 2.5.1) demonstrated that baseline age, health behaviours such as smoking, and social factors such as not owning one's home or lower social class, influenced likelihood of taking part in the follow-up study, although co-morbidity and frailty components such as grip strength did not. However, our analyses were internal; unless the association between e.g. home ownership and frailty, is systematically different among sub-groups of the population defined by health behaviours, social factors and frailty level, no major bias should have been introduced.

Our study also had many strengths. Firstly, the data were rigorously collected according to strict protocols by trained research nurses and doctors (Syddall et al. 2005a). Secondly, we operationalised frailty using the accepted and objective Fried criteria (Morley et al. 2006). Finally, we are confident that our results are generalisable to the wider population of older people in England, because the cohort have been shown to be broadly comparable with participants in the nationally representative Health Survey for England (Syddall et al. 2005a).

Conclusions

In conclusion, we have shown that frailty (operationalised by the Fried criteria) is not uncommon even among 'young-old' community dwelling men and women in the United Kingdom and that there are social inequalities in frailty which appear to be largely mediated by co-morbidity.

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Table 23 Summary characteristics of study participants

n(%)		Men (n=320)	Women (n=318)
Age (years)*		69.2 (2.5)	69.5 (2.6)
Smoking status	Never	120 (37.5)	200 (63.5)
	Ex	173 (54.1)	98 (31.1)
	Current	27 (8.4)	17 (5.4)
Alcohol (units per week)	Non-drinker	17 (5.3)	78 (24.7)
	Very low (<1)	44 (13.8)	72 (22.8)
	Low (1-10 men;1-7 women)	139 (43.4)	120 (38.0)
	Moderate (11-21 men;8-14 women)	67 (20.9)	36 (11.4)
	Fairly high (22-35 men;15-21 women)	36 (11.3)	5 (1.6)
	High (>35 men;>21 women)	17 (5.3)	5 (1.6)
Age left full-time education (years)**		15 (15,16)	15 (15,16)
Left full-time education aged ≤14 years		62 (19.4)	62 (19.5)
Social class in adulthood***	I Professional	16 (5.3)	21 (6.6)
	II Management and Technical	78 (25.7)	70 (22.0)
	IIINM Skilled non-manual	37 (12.2)	45 (14.2)
	IIIM Skilled manual	115 (37.8)	129 (40.6)
	IV Partly skilled	52 (17.1)	41 (12.9)
	V Unskilled	6 (2.0)	12 (3.8)
Housing tenure	Owned/mortgaged	281 (87.8)	266 (83.7)
	Rented/other	39 (12.2)	52 (16.4)
Number of cars available	None	12 (3.8)	40 (12.6)
	1	168 (52.5)	192 (60.4)
	2	116 (36.3)	77 (24.2)
	3	24 (7.5)	9 (2.8)

*Mean and standard deviation **Median and interquartile range
***Based on social class of the husband for ever married women.

Table 24 Prevalence of Fried frailty and its component items

n(%)	Men (n=320)	Women (n=318)
Unintentional weight loss (>10lb over the past year)	17 (5.3)	11 (3.5)
Weakness*	22 (6.9)	68 (21.5)
Self-reported exhaustion**	18 (5.6)	32 (10.1)
Slow walking speed***	63 (19.8)	63 (19.9)
Low physical activity+	85 (26.6)	69 (21.7)
Frail on the Fried score (presence of three or more of above criteria)	13 (4.1)	27 (8.5)

*Maximum grip strength ≤30kg men and ≤20kg for women
**The participant felt that everything they did was an effort for moderate amounts to most of the time in the past week
***Timed up and go 3 metre walk ≥3.82 seconds for men and ≥3.98 seconds for women
+SF-36 physical functioning score in the bottom fifth of the sex-specific distribution (≤75 for men and ≤60 for women)

Table 25 Univariate associations between frailty and the lifestyle and social characteristics of HCS participants

		MEN			WOMEN		
		n(%) frail on the Fried score	Univariate odds ratios (95%CI) for frailty		n(%) frail on the Fried score	Univariate odds ratios (95%CI) for frailty	
Age (years)	≤67.7	1 (0.9)	1.39	(1.09,1.78)	7 (6.6)	1.07	(0.92,1.24)
	-70.8	5 (4.3)	*p=0.009, per year*		12 (12.1)	*p=0.40, per year*	
	≥70.9	7 (7.4)			8 (7.1)		
Smoking status	Never	4 (3.3)			12 (6.0)		
	Ex	8 (4.6)	1.18	(0.48,2.89)	14 (14.3)	1.62	(0.89,2.96)
	Current	1 (3.7)	*p=0.72, per increased band of smoking*		1 (5.9)	*p=0.12, per increased band of smoking*	
Alcohol intake (units per week)	Non-drinker	3 (17.7)			10 (12.8)		
	Very low (<1)	1 (2.3)			7 (9.7)		
	Low (1-10 M;1-7 W)	5 (3.6)			9 (7.5)		
	Moderate (11-21 M;8-14 W)	3 (4.5)	0.71	(0.42,1.17)	1 (2.8)	0.66	(0.45,0.97)
	Fairly high (22-35 M;15-21 W)	0 (0.0)	*p=0.18, per increased band of intake*		0 (0.0)	*p=0.04, per increased band of intake*	
	High (>35 M;>21 W)	1 (5.9)			0 (0.0)		
Age left full-time education (years)	≤14	6 (9.7)	0.50	(0.25,1.01)	5 (8.1)	0.85	(0.59,1.22)
	≥15	7 (2.7)	*p=0.05, per year older*		22 (8.6)	*p=0.37, per year older*	
Social class in adulthood	I Professional	0 (0.0)			1 (4.8)		
	II Management and Technical	0 (0.0)			6 (8.6)		
	IIINM Skilled non-manual	1 (2.7)	1.65	(0.99,2.77)	3 (6.7)	1.19	(0.86,1.64)
	IIIM Skilled manual	10 (8.7)	*p=0.06, per lower band of social class*		9 (7.0)	*p=0.30, per lower band of social class*	
	IV Partly skilled	2 (3.9)			7 (17.1)		
	V Unskilled	0 (0.0)			1 (8.3)		
Housing tenure	Owned/mortgaged	9 (3.2)	*Reference*		18 (6.8)	*Reference*	
	Rented/other	4 (10.3)	3.45	(1.01,11.81)	9 (17.3)	2.88	(1.22,6.84)
			p=0.05			*p=0.02*	
Number of cars available	None	2 (16.7)			6 (15.0)		
	1	9 (5.4)	0.28	(0.10,0.76)	15 (7.8)	0.64	(0.35,1.19)
	2	2 (1.7)	*p=0.01,* per extra car		6 (7.8)	*p=0.16,* per extra car	
	3	0 (0.0)			0 (0.0)		

Declaration of authorship for paper 2

Holly Syddall: conducted the literature review; planned and executed the statistical analyses; designed and prepared the tables; and drafted all versions of the manuscript.

Helen Roberts reviewed the final version of the manuscript.

Maria Evandrou: provided direction for the social inequalities component of the literature review and provided feedback on the final version of the manuscript.

Cyrus Cooper took overall responsibility for the Hertfordshire Cohort Study and reviewed the final version of the manuscript.

Howard Bergman reviewed the final version of the manuscript.

Avan Aihie Sayer: designed and managed the Hertfordshire Cohort Study; helped to iterate the analytical strategy and presentation of results; and provided feedback on early drafts of the manuscript and reviewed the final version.

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Chapter 5. Paper 3: Social inequalities in osteoporosis and fracture among community dwelling older men and women: findings from the Hertfordshire Cohort Study

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Running head: Social inequalities in osteoporosis and fracture among community dwelling older people

Abstract

Introduction Osteoporosis and osteoporotic fracture are major public health issues for society; the burden for the affected individual is also high. It is unclear whether osteoporosis and osteoporotic fracture are socially patterned.

Objective To analyse social inequalities in osteoporosis and osteoporotic fracture among the 3,225 community dwelling men and women, aged 59-73 years, who participated in the Hertfordshire Cohort Study (HCS), UK.

Methods A panel of markers of bone health (fracture since 45 years of age; DXA bone mineral density and loss rate at the total femur; pQCT strength strain indices for the radius and tibia; and incident fracture) were analysed in relation to the social circumstances of the HCS participants (characterised at the individual level by: age left full-time education; current social class; housing tenure and car availability).

Results We found little strong or consistent evidence among men, or women, for social inequalities in prevalent or incident fracture, DXA bone mineral density, bone loss rates, or pQCT bone strength, with or without adjustment for age, anthropometry, lifestyle and clinical characteristics. Reduced car availability at baseline was associated with lower pQCT radius and tibia strength strain indices at follow-up among men only ($p=0.02$ radius and $p<0.01$ tibia unadjusted; $p=0.05$ radius and $p=0.01$ tibia, adjusted for age, anthropometry, lifestyle and clinical characteristics).

Conclusions Our results suggest that fracture and osteoporosis do not have a strong direct social gradient and that public health strategies for prevention and treatment of osteoporosis should continue to focus on the whole population.

Mini-abstract

It is unknown whether osteoporosis is socially patterned. Using data from the Hertfordshire Cohort Study we found no consistent evidence for social inequalities in prevalent or incident fracture, bone mineral density or loss rates, or bone strength. Public health strategies for prevention of osteoporosis should focus on the whole population.

Keywords: osteoporosis; osteoporotic fracture; socioeconomic position; material deprivation; social inequalities

Introduction

Osteoporosis is a skeletal disorder characterised by low bone mass and microarchitectural deterioration of bone tissue which predisposes to fracture (Harvey and Cooper 2003), typically of the hip, spine or wrist. The prevalence of osteoporosis increases rapidly with older age (Sambrook and Cooper 2006) and it has been estimated that the remaining lifetime risk of fracture at the hip, spine or wrist is 40% among white women and 13% among white men at age 50 years (Melton et al. 2005). The annual cost to the NHS of managing osteoporotic fractures is £2.1 billion, with over 80% of this figure attributable to hip fracture (Kanis et al. 2008). Osteoporosis is a major public health issue for society, but the burden of osteoporosis for the affected individual is also high; fracture is typically associated with hospitalisation, increased risk of subsequent mortality, long term morbidity and loss of function (Walker-Bone et al. 2001). Although treatments are available that have been shown to decrease the risk of fracture, problems arise in identifying individuals at high risk of fracture so that intervention can be effectively targeted (Kanis et al. 2009).

Social inequalities in health have been recognised for centuries (Marmot 2001). Even in generally wealthy Western countries, material deprivation and poverty are not uncommon (Groffen et al. 2008) and, irrespective of absolute levels of standards of living, health inequalities exist across relative levels of deprivation (Wilkinson 1997). However, little is known about social inequalities in osteoporosis and fracture. Brennan et al have recently conducted systematic reviews of the associations between socioeconomic status (income, education, occupation, and type of residence) and bone mineral density (Brennan et al. 2011) and osteoporotic fracture (Brennan et al. 2009) among population based adults. Brennan concluded that limited good quality evidence exists for social inequalities in bone mineral density and fracture and that further research, ideally from cohort studies rather than ecological or case-control studies, is required to elucidate the relationships between individual level markers of socioeconomic status and bone mineral density and fracture. Clarification of whether osteoporosis and fracture are socially patterned would inform planning for health and social care services and would enable public health strategies for prevention, intervention and treatment of osteoporosis and fracture to be effectively targeted (Kanis et al. 2009).

The objective of the current study was to explore social inequalities in osteoporosis (bone mineral density, bone strength and bone loss rates) and osteoporotic fracture (prevalent and incident), among community dwelling older men and women who participated in the Hertfordshire Cohort Study (HCS), United Kingdom (Syddall et al.

2005a). The social circumstances of the HCS men and women were characterised at the individual level by: age of leaving full-time education; current social class; and housing tenure and car availability as markers of material deprivation (Arber and Ginn 1993;Wiggins et al. 2002).

Methods

Study population

The Hertfordshire Cohort Study (HCS) has been described previously (Syddall et al. 2005a). In brief, from 1911 to 1948, midwives recorded information on birth weight and weight at one year, on infants born in the county of Hertfordshire, United Kingdom. The records for people born 1911-1930 have been used in a series of studies linking early growth to health in later life. In 1998, a younger cohort was recruited to participate in studies examining the interactions between early life, diet, adult lifestyle and genetic factors as determinants of adult disease. 3822 men and 3284 women born between 1931-1939 in Hertfordshire and still living there were traced through the National Health Service central register. Permission to contact 3126 (82%) men and 2973 (91%) women was obtained from their General Practitioners.

1684 (54%) men and 1541 (52%) women aged 59-73 years took part in a nurse administered home interview and 1579 (94%) men and 1418 (92%) women subsequently attended a clinic for investigations (herein referred to as the HCS baseline interview and clinic, Figure 12). Social history included: age left full-time education; own current or most recent full-time occupation; husband's current or most recent full-time occupation for ever married women; housing tenure; number of cars and vans available to the household; and marital status. Medical history included: smoking habit; alcohol intake; physical activity (Dallosso et al. 1988); fracture history; details of all currently prescribed and over-the-counter medications, coded to the British National Formulary; dietary calcium intake derived from an administered food frequency questionnaire; and menopausal status and HRT use among women. Clinical investigations included measurement of height (to the nearest 0.1cm using a Harpenden pocket stadiometer, Chasmors Ltd, London, UK) and weight (to the nearest 0.1kg on a SECA floor scale, Chasmors Ltd, London, UK (Lohman et al. 1988)).

The HCS fieldwork was phased by region of the county for practical reasons; 737 of the men and 675 of the women who participated in the HCS baseline clinic were resident in East Hertfordshire. Bone mineral content (BMC), bone area and bone mineral density

(BMD) were measured in a subgroup of 498(68%) of these men and 468(69%) of these women by dual-energy X-ray absorptiometry at the proximal femur using a Hologic QDR 4500 instrument (Dennison et al. 2005); herein referred to as the HCS baseline DXA scan (Figure 12). Measurement precision error, expressed as coefficient of variation, was 1.45% for total femur and 1.83% for femoral neck BMD for the Hologic QDR 4500; these figures were obtained by twenty five volunteers who were not part of the study undergoing 2 scans on the same day, getting on and off the table between examinations. Short-term (2 month) precision error for the QDR 4500 was less than 1% (manufacturer's figures). Individuals taking drugs known to alter bone metabolism (such as bisphosphonates) were excluded from this part of the study, although women taking Hormone Replacement Therapy (HRT) were allowed to participate. There were no other exclusion criteria to this part of the study, and subjects were approached for consent as they attended the baseline HCS clinic.

In 2004-5, a follow-up study was performed in East Hertfordshire (Dennison et al. 2010;Oliver et al. 2007); herein referred to as the East Hertfordshire follow-up study (Figure 12). In brief, of the original 498 men and 468 women who had undergone the HCS baseline DXA scan, 8 had died, 6 had moved away, we were unable to obtain GP permission to approach 4 people, 47 were no longer on family doctor lists, and 17 were unavailable. Hence, 437 men and 447 women were invited to take part in the follow-up study. Of these, 322 men (74%) and 320 women (72%) agreed to attend a follow-up clinic and DXA bone mineral measurements of the total femur were repeated, enabling calculation of annualised percentage change in bone mineral density at this site. Peripheral quantitative computed tomography (pQCT) was also performed of the radius and tibia (non-dominant side) using a Stratec 4500 instrument for 313 (97%) of the men, and 318 (99%) of the women (Oliver et al. 2007). Bone strength was estimated with respect to torsion (polar strength strain index) or bending with respect to the X or Y axis (fracture load X and fracture load Y). Measurements were made at two sites for the radius (4% and 66% slice) and three for the tibia (4%, 14% and 38% slice). Cadaveric studies have confirmed the high precision of pQCT and validated its use as a technique for assessing bone strength (Louis et al. 1996;Sievanen et al. 1998).

In 2007, a cohort-wide postal questionnaire was used to ascertain clinical outcomes, including fracture, since the baseline HCS clinic; herein referred to as the HCS clinical outcomes study (Figure 12). Of the original 2997 baseline clinic participants, 157 had died, 48 had moved away and 15 had withdrawn from the study (due to illness or at the participant's request). Hence, the questionnaire was posted to 2777 HCS participants of whom 2299 (83%) replied; 1093 of the men and 1049 of the women provided information on incident fractures since the HCS baseline clinic.

Intra- and inter-observer studies were carried out during the fieldwork. The study had ethical approval from the Hertfordshire and Bedfordshire Local Research Ethics Committee and all participants gave written informed consent.

Statistical methods

Registrar General's social class was coded from the 1990 OPCS Standard Occupational Classification (SOC90) unit group for occupation (Office of Population Censuses and Surveys 1990) using computer assisted standard occupational coding (Elias et al. 1993). Current social class was coded from own current or most recent full-time occupation for men and never-married women, and from husband's occupation for ever-married women (Arber and Ginn 1993).

Height and weight were highly correlated ($r=0.45$, $p<0.001$ for men; $r=0.32$, $p<0.001$ for women); to avoid multi-collinearity problems a sex-specific standardised residual of weight-adjusted-for-height was calculated for inclusion with height in regression models.

Analysis of variance, chi-squared tests, and multiple linear and logistic regression were used to analyse the relationships between each of the markers of socioeconomic position (SEP) and material deprivation as assessed at HCS baseline and: fracture since 45 years of age and DXA bone mineral density at HCS baseline; change in BMD from repeat DXA scans and bone strength indices from pQCT scans at the East Hertfordshire Follow-up study; and incident fracture between the HCS baseline and the HCS clinical outcomes study. Analyses were conducted with and without adjustment for HCS baseline age, anthropometry (height and weight-adjusted-for-height), smoking status, alcohol intake, marital status, physical activity, dietary calcium intake, HRT use and menopausal status (for women only), number of systems medicated as a marker of co-morbidity, bone medications (male sex hormones, oral steroids, tamoxifen, bisphosphonates and raloxifene) and fracture status and follow-up duration (the latter two for longitudinal analyses only). Categories of age left full-time education (≤14 versus ≥15 years) and number of cars available were used for presentational purposes but p-values for association were obtained from the continuously distributed variables. All analyses were conducted for men and women separately using Stata, release 11.0 (StataCorp 2009).

Results

Descriptive statistics

Socioeconomic position (SEP) and material deprivation among the HCS participants are described in Table 26. The average age of the HCS participants at baseline was 65.6 years for men and 66.6 years for women. 19.4% of men and 17.9% of women left full-time education aged 14 years or younger. 19.3% of men and 23.1% of women did not own or mortgage their home and 6.4% of men and 17.7% of women had no car available to their household.

Osteoporosis and fracture among the HCS participants are described in Table 26. At HCS baseline, 235 (14.0%) men and 333 (21.6%) women reported that they had sustained a fracture since 45 years of age (7.7% of men and 18.4% of women having sustained a minor trauma fracture). Women had lower baseline total femoral bone mineral density than men (0.90 g/cm^2 vs 1.04 g/cm^2 respectively). On average, between the HCS baseline and East Hertfordshire follow-up DXA scans, men and women had lost bone at the total femur (-0.09%/year and -0.55%/year respectively). Radius and tibia strength strain indices from the pQCT scans were higher among men than women. Between the HCS baseline study and the clinical outcomes follow-up questionnaire, 4.2% (46) of men and 10.8% (113) of women reported sustaining an incident fracture (33 and 62 of which were first fractures since 45 years of age for men and women respectively). The proportions of men and women taking bone medications (i.e. male sex hormones, oral steroids, tamoxifen, bisphosphonates or raloxifene) increased during the HCS study from 1.8% among men and 5.3% among women at baseline, to 5.6% of men and 10.0% of women at the East Hertfordshire follow-up DXA and pQCT scans, to 5.1% of men and 16.0% of women at the clinical outcomes study.

Cross-sectional associations between socioeconomic position, material deprivation and fracture and bone mineral density

Among men (Table 27), there were no significant cross-sectional associations ($p<0.05$) between social class, age left full-time education, home ownership or car availability and fracture since 45 years of age (all fractures or minor trauma) or total femoral BMD, with or without adjustment for age, anthropometry and lifestyle and clinical characteristics.

Among women (Table 28), there were few significant associations between social class, age left full-time education, home ownership or car availability and fracture or bone mineral density. Reduced car availability was associated with an increased likelihood of having sustained a fracture since 45 years of age (p=0.02 for trend for all fractures, p=0.04 for minor trauma fractures) but adjustment for age, anthropometry and lifestyle and clinical characteristics attenuated these associations (adjusted p=0.07 for trend for all fractures, p=0.20 for minor trauma fractures). Average levels of total femoral BMD were actually lower among women of higher social class (p=0.01 in unadjusted analyses) and this association was also attenuated by adjustment for age, anthropometry and lifestyle and clinical characteristics (adjusted p=0.22 for total femoral BMD).

Longitudinal associations between socioeconomic position, material deprivation and bone loss rates, bone strength and incident fracture

Among men (Table 29), there was little evidence for association between the panel of markers of socioeconomic position and material deprivation and bone loss rates, bone strength, or incident fracture in unadjusted or adjusted analyses. The only significant associations identified were between reduced car availability at HCS baseline and lower pQCT radius (p=0.02 unadjusted, p=0.05 adjusted) and tibia (p<0.01 unadjusted, p=0.01 adjusted) strength strain indices at the East Hertfordshire Follow-up study.

Among women (Table 30), there was again little consistent evidence for association between socioeconomic position and material deprivation and bone loss rates, bone strength, or incident fracture in unadjusted or adjusted analyses. Furthermore, even the associations which were statistically significant did not suggest a consistent social patterning of bone health; reduced car availability at HCS baseline was associated with lower radius strength strain index (p=0.02 unadjusted; p=0.02 adjusted) while not owning or mortgaging one's home at HCS baseline was associated with higher tibia strength strain index at the East Hertfordshire Follow-up (p=0.05 unadjusted; p=0.03 adjusted).

Discussion

Using data from the Hertfordshire Cohort Study we have analysed the associations between a panel of individual-level markers of socioeconomic position (social class and age left full-time education) and material deprivation (home ownership and car availability) and fracture and osteoporosis among community dwelling ‘young-old’ men and women. We found no strong or consistent evidence among men, or women, for social inequalities in prevalent or incident fracture, DXA total femoral bone mineral density, pQCT radius or tibia bone strength, or total femoral bone loss rate. Our results suggest that fracture and osteoporosis do not have a strong direct social gradient and that public health strategies for prevention, intervention and treatment of osteoporosis and fracture should continue to focus on the whole population, rather than targeting specific subgroups of the population.

Limited good quality evidence exists for social inequalities in bone mineral density (Brennan et al. 2011) and fracture (Brennan et al. 2009) among older people and the limited number of UK studies which have previously addressed this issue have typically either employed an ecological study design (Jones et al. 2004;West et al. 2004) (which cannot adequately account for confounding factors and which may yield associations at the area level which are not replicated at the individual level) or have used a cross-sectional design but with an area based measure such as the Index of Multiple Deprivation (Dugue et al. 2010;Hamilton et al. 2010;Quah et al. 2011) (IMD) or the Carstairs score (Court-Brown et al. 2011) as an indicator of an individual’s socioeconomic position. Furthermore, the results from these previous UK studies are inconsistent; Quah (Quah et al. 2011), Court-Brown (Court-Brown et al. 2011) and Dugue (Dugue et al. 2010) concluded that higher levels of deprivation (IMD or Carstairs) were associated with higher rates of hip fracture or lower levels of BMD but, in parallel with our findings, Hamilton (Hamilton et al. 2010), West (West et al. 2004) and Jones (Jones et al. 2004) found no evidence for association between their area level markers of socioeconomic status (IMD or Townsend) and hip fracture, hospital admissions for fracture or accident and emergency presentations for fracture. The COSHIBA (Cohort for Skeletal Health in Bristol and Avon) study of 3,200 women aged 65-84 years resident in south-west England is the only previous UK study to have collected cross-sectional individual-level data on history of fracture after 50 years of age and socioeconomic status (Clark et al. 2010); in parallel with our findings, no associations were identified between socioeconomic status and fracture among the COSHIBA women.

The results from international cross-sectional, case-control or ecological study designs are similarly inconsistent. For example, Zingmond (Zingmond et al. 2006) (using an ecological study design) and Farahmand (Farahmand et al. 2000) (using a case-control study design) concluded that lower levels of income were associated with higher rates of hip fracture among American men and women and among Swedish women respectively. In contrast, Johnell (Johnell et al. 2007) identified an association between lower levels of economic prosperity and lower rates of hip fracture using a country-level ecological study design. In further contrast, Hokby (Hokby et al. 2003) conducted a cross-sectional study of Swedish men and women and found no association between home ownership and hip fracture rates and Vestergaard (Vestergaard et al. 2006) found no association between income or education and any fracture in his case-control study of Danish men and women. Wang (Wang and Dixon 2006) and Varenna (Varenna et al. 1999) conducted cross-sectional studies of women in the USA and Italy respectively; both concluded that lower levels of education or income were associated with lower levels of DXA bone mineral density.

No previous UK studies have analysed social inequalities in incident fracture using a cohort study design; one international study has addressed this issue. Wilson (Wilson et al. 2006) conducted a prospective cohort study of 5,630 community-dwelling elderly people 70 years or older who participated in the Asset and Health Dynamics Survey (USA). During a 2-year study period, 102 participants reported a new hip fracture; individuals with insufficient health insurance, those without a high-school diploma and those who lived in mobile homes were at more than a 2-fold risk of hip fracture. No previous studies in the literature have considered social inequalities in bone loss rates or pQCT bone strength.

The absence of convincing evidence for social inequalities in fracture and osteoporosis among our HCS participants is not surprising in the context of the limited and inconsistent literature on social inequalities in bone health. It is also possible that inequalities across social class groups in the HCS cohort may have been masked if the detrimental effects of lower socioeconomic position on bone health were offset by a history of more manual work. The retirement status of the HCS cohort may also play a role; sixty-five percent of HCS men and 82% of women reported that they had stopped working and Benzeval (Benzeval et al. 1995) has questioned the appropriateness of social class for studies of health inequalities among older people. In addition, physical activity is a major determinant of bone health; it is possible that we have not fully accounted for the potential confounding influence of physical activity (both currently, and across the lifecourse, in occupation and leisure) on social inequalities in fracture and osteoporosis. Finally, Clark (Clark et al. 2005) et al have studied the association between social position of the mother in pregnancy and bone mass of the child at age 10 years among 6,702 children who participated in the Avon Longitudinal Study of Parents and Children (ALSPAC) study and concluded that social position exerted opposing height- and weight-dependent effects on bone mineral content and area in childhood such that overall inequalities in bone health were masked; height and weight may have exerted similar divergent effects in our study. However, when we repeated our analyses with adjustment for height alone, with adjustment for weight alone, or with adjustment for height and weight-for-height but no other potential confounders, the results were little different from the fully adjusted results presented in tables 27 to 30. Moreover, if the underlying social gradient in fracture and osteoporosis was strong among the HCS participants one would expect to have observed inequalities in spite of the possibilities advanced above; such associations were not evident and overall our results suggest that fracture and osteoporosis do not have a strong direct social gradient.

This study had some limitations. Firstly, we had no information on household income, receipt of benefits or highest educational qualification and data on material deprivation were limited to car availability and housing tenure. However, car availability and housing tenure are useful markers of social and material advantage (Arber and Ginn 1993;Wiggins et al. 2002) and reflect the amount and stability of household income (Bartley and Blane 1994). We suggest that these markers will function well as markers of social and material advantage among this ‘young-old’ cohort of men and women who are predominantly retired (as described above) and are settled in a county which is distinct from, though geographically close to, the London region. Secondly, Hertfordshire is in the relatively less deprived South Eastern area of England (APHO and Department of Health 2008). However, our analyses were internal; unless the association between e.g. deprivation and bone mineral density, is systematically different among sub-groups of the population with lower or higher levels of deprivation, no major bias should have been introduced. Moreover, there is a grading of deprivation levels in Hertfordshire (APHO and Department of Health 2008), and HCS, and Wilkinson has discussed how relative levels of deprivation matter for health inequalities in addition to absolute levels (Wilkinson 1997). Thirdly, the data on incident fracture between the HCS baseline and clinical outcomes study were ascertained by self-report. Such reports are subject to errors of recall and recall bias has the potential to create spurious statistical results. However, in a large study that assessed the validity of self-reported non-spine fracture using medical records, in men and women aged over 60 only 8% of self-reported fractures proved to be false-positives and an even smaller proportion turned out to be false-negatives (Ismail et al. 2000). As such, we suggest that the potential for recall bias to have affected our results is small. Fourthly, the HCS participants are a group of relatively ‘young-old’ community dwelling men and women in whom incident fracture rates will still be relatively low in comparison with older men and women. It would be fascinating to replicate our study in suitable cohorts of older and frailer men and women. Finally, financial and practical constraints dictated that only a sub-group of HCS participants underwent DXA and pQCT scans and, additionally, participants were lost to follow-up. Unsurprisingly, as described in section 2.5.1 of this thesis, a healthy participant effect was evident for the men and women who participated in the East Hertfordshire follow-up study or who responded to the clinical outcomes postal questionnaire. However, as above, our analyses were internal; unless the associations between SEP and deprivation and our panel of markers of osteoporosis and fracture were systematically different among men and women who did or did not participate in various components of the HCS study then no major bias should have been introduced.

Our study also had many strengths. Firstly, we analysed a large dataset of individual rather than ecological level data which included directly ascertained individual level markers of socioeconomic status. Brennan et al specifically recommended this type of further research in their recent systematic reviews of social inequalities in bone mineral density and fracture (Brennan et al. 2009;Brennan et al. 2011). Secondly, we have considered a range of markers of bone health including prevalent and incident fracture, bone mineral density ascertained by DXA scans, bone strength ascertained by pQCT scans, and bone loss rate assessed by repeat DXA scans. Thirdly, the data were rigorously collected according to strict protocols by trained research nurses and doctors (Syddall et al. 2005a). Fourthly, we were able to adjust our analyses for lifestyle, medical history and co-morbidity. Finally, we are confident that our results are generalisable to the wider population of older people in England, because the cohort have been shown to be broadly comparable with participants in the nationally representative Health Survey for England (Syddall et al. 2005a).

Conclusions

In conclusion, our results suggest that fracture and osteoporosis do not have a strong direct social gradient and that public health strategies for prevention, intervention and treatment of osteoporosis and fracture should continue to focus on the whole population, rather than targeting specific subgroups of the population.

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Figure 12 Phases of data collection for the Hertfordshire Cohort Study (HCS)

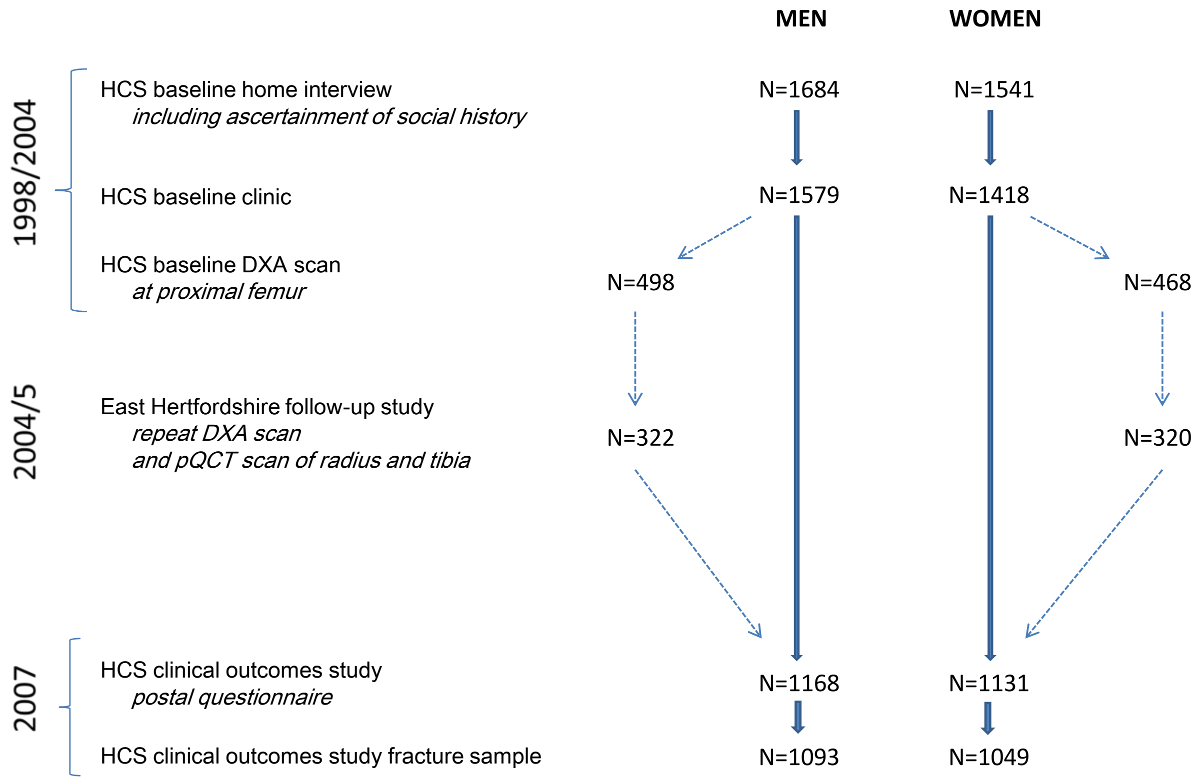

Table 26 Socioeconomic position (SEP), material deprivation and markers of bone health among HCS participants

n(%)		Men	Women
Socioeconomic position at HCS baseline		*n=1684*	*n=1541*
Age left full-time education (years)*		15 (15,16)	15 (15,16)
Left full-time education aged ≤14 years		327 (19.4)	276 (17.9)
Social class[a]	I Professional	107 (6.6)	84 (5.5)
	II Management and Technical	395 (24.2)	347 (22.5)
	IIINM Skilled non-manual	165 (10.1)	209 (13.6)
	IIIM Skilled manual	638 (39.1)	593 (38.5)
	IV Partly skilled	272 (16.7)	253 (16.4)
	V Unskilled	57 (3.5)	54 (3.5)
Material deprivation at HCS baseline			
Housing tenure	Owned/mortgaged	1357 (80.7)	1185 (76.9)
	Rented/other	325 (19.3)	356 (23.1)
Number of cars available	None	107 (6.4)	273 (17.7)
	1	898 (53.5)	893 (58.0)
	2	552 (32.9)	330 (21.4)
	3 or more	122 (7.3)	45 (2.9)
Fracture and bone mineral density at HCS baseline		*n=1684*	*n=1541*
Age (years)**		65.6 (2.9)	66.6 (2.7)
Any fracture since 45yrs of age		235 (14.0)	333 (21.6)
Minor trauma fracture since 45yrs of age		129 (7.7)	284 (18.4)
HCS baseline DXA scan		*n=498*	*n=468*
DXA Total femoral BMD (g/cm^2)**		1.04 (0.13)	0.90 (0.13)
East Hertfordshire follow-up study		*n=322*	*n=320*
Age (years)**		69.8 (2.5)	70.1 (2.6)
Follow-up time since HCS baseline (years)*		5.2 (4.8,5.6)	3.5 (3.0,4.0)
DXA total femoral change in BMD (%/yr) **,[b]		-0.09 (0.70)	-0.55 (1.20)
pQCT radius strength strain index (SSI)**		397 (82)	226 (51)
pQCT tibia strength strain index (SSI)**		2072 (328)	1400 (227)
HCS clinical outcomes study fracture sample		*n=1093*	*n=1049*
Age (years)**		71.7 (2.5)	71.6 (2.5)
Follow-up time since HCS baseline (years)*		5.8 (5.0,7.3)	4.9 (4.1,6.1)
Incident fracture since HCS baseline		46 (4.2)	113 (10.8)

*Median and interquartile range
**Mean and standard deviation
[a] Registrar General's social class was based on most recent full-time occupation, classified according to the 1990 edition of the standard occupational classification and was based on social class of the husband for ever married women. 21 women did not have a job code of their own (having never worked or having provided insufficient information about their most recent full-time occupation for successful social class coding) but were assigned a social class on the basis of their husband's job code. 1 woman had missing data for their own and their husband's job code class and no social class was therefore assigned. The woman's own job code was used in 110 cases because job code data for the husband were missing. For 333 women, their own and their husband's social class codes tallied. Use of the husband's social class resulted in 561 women being assigned a higher social class than had their own social class been used and 515 women were assigned a lower social class on this basis.
[b] Change in BMD defined as BMD at the East Hertfordshire follow-up study minus BMD at the HCS baseline DXA scan, divided by BMD at the HCS baseline DXA scan and annualised per year of follow-up to yield a change variable with units of percentage change per year and with positive values indicating an increase in bone over time and negative values a decrease in bone over time.

Table 27 Cross-sectional associations between SEP and material deprivation and baseline HCS fracture and DXA BMD for men

	Any fracture since 45yrs of age			Minor trauma fracture since 45yrs of age			DXA Total femoral BMD		
	OR	95%CI	*p*	OR	95%CI	*p*	beta	95%CI	*p*
Registrar General's current social class (vs IIIM)									
I	1.08	(0.59,1.99)		1.37	(0.65,2.92)		-0.01	(-0.07,0.04)	
II	1.11	(0.77,1.62)		1.27	(0.78,2.07)		0.01	(-0.02,0.04)	
IIINM	1.34	(0.83,2.17)		1.17	(0.60,2.29)		-0.03	(-0.07,0.01)	
IV	1.46	(0.98,2.17)		1.38	(0.81,2.35)		-0.01	(-0.05,0.02)	
V	0.84	(0.35,2.03)		0.83	(0.25,2.77)		-0.02	(-0.09,0.06)	
		p for trend	*0.76*		*p for trend*	*0.57*		*p for trend*	*0.56*
			0.51[a]			*0.87*[a]			*0.64*[a]
Age left full-time education									
≤14yrs vs ≥15yrs	1.26	(0.90,1.75)	*0.92*	1.18	(0.76,1.82)	*0.14*	-0.03	(-0.06,-0.01)	*0.63*
			0.46[a]			*0.41*[a]			*0.85*[a]
Home ownership (vs owned/mortgaged)									
Rented/other	1.02	(0.72,1.44)	*0.92*	1.35	(0.89,2.07)	*0.16*	0.00	(-0.03,0.03)	*0.89*
			0.85[a]			*0.14*[a]			*0.70*[a]
Car availability (vs 3 or more)									
None	1.10	(0.55,2.19)		1.41	(0.59,3.42)		-0.07	(-0.14,0.00)	
1	0.83	(0.50,1.39)		0.98	(0.49,1.95)		-0.01	(-0.06,0.04)	
2	0.73	(0.42,1.25)		0.74	(0.35,1.53)		0.00	(-0.05,0.05)	
		p for trend	*0.55*		*p for trend*	*0.18*		*p for trend*	*0.07*
			0.78[a]			*0.53*[a]			*0.11*[a]

OR=odds ratio; CI=confidence interval; yrs=years; beta=regression coefficient in units of the bone variable concerned; I, II, IIIM, IIINM, IV and V represent social classes one, two, three non-manual, three manual, four and five; *p* = p-value; BMD=bone mineral density; DXA=dual-energy x-ray absorptiometry.
Unless indicated otherwise, p-values are for unadjusted, univariate associations and are for trend across social classes and categories of car availability, and are for the underlying continuous variable for age left full-time education.
[a] Adjusted for age, height, weight-for-height, smoking, alcohol, marital status, physical activity, dietary calcium from foods, bone medication and number of systems medicated.

Table 28 Cross-sectional associations between SEP and material deprivation and baseline HCS fracture and DXA BMD for women

	Any fracture since 45yrs of age			Minor trauma fracture since 45yrs of age			DXA Total femoral BMD		
	OR	95%CI	*p*	OR	95%CI	*p*	beta	95%CI	*p*
Current social class (vs IIIM)									
I	0.99	(0.56,1.74)		1.03	(0.57,1.88)		-0.08	(-0.14,-0.02)	
II	1.24	(0.91,1.71)		1.26	(0.91,1.77)		-0.02	(-0.05,0.02)	
IIINM	1.01	(0.68,1.49)		0.92	(0.60,1.41)		-0.02	(-0.05,0.02)	
IV	1.03	(0.72,1.48)		1.03	(0.70,1.51)		0.02	(-0.01,0.06)	
V	1.36	(0.72,2.59)		1.51	(0.78,2.91)		-0.01	(-0.08,0.06)	
		p for trend	*0.63*		*p for trend*	*0.67*		*p for trend*	*0.01*
			0.78[a]			*0.85*[a]			*0.22*[a]
Age left full-time education									
≤14yrs vs ≥15yrs	1.33	(0.98,1.80)	*0.54*	1.52	(1.11,2.07)	*0.33*	-0.03	(-0.06,-0.00)	*0.75*
			0.62[a]			*0.51*[a]			*0.59*[a]
Home ownership (vs owned/mortgaged)									
Rented/other	1.11	(0.84,1.48)	*0.46*	1.14	(0.84,1.53)	*0.41*	-0.01	(-0.04,0.03)	*0.74*
			0.93[a]			*0.96*[a]			*0.26*[a]
Car availability (vs 3 or more)									
None	1.46	(0.62,3.45)		1.71	(0.64,4.55)		-0.03	(-0.11,0.05)	
1	1.76	(0.77,3.99)		2.14	(0.83,5.49)		-0.06	(-0.13,0.02)	
2	0.97	(0.41,2.29)		1.20	(0.45,3.20)		-0.03	(-0.10,0.05)	
		p for trend	*0.02*		*p for trend*	*0.04*		*p for trend*	*0.28*
			0.07[a]			*0.20*[a]			*0.45*[a]

OR=odds ratio; CI=confidence interval; yrs=years; beta=regression coefficient in units of the bone variable concerned; I, II, IIIM, IIINM, IV and V represent social classes one, two, three non-manual, three manual, four and five; *p* = p-value; BMD=bone mineral density; DXA=dual-energy x-ray absorptiometry. Unless indicated otherwise, p-values are for unadjusted, univariate associations and are for trend across social classes and categories of car availability, and are for the underlying continuous variable for age left full-time education.

[a] Adjusted for age, height, weight-for-height, smoking, alcohol, marital status, physical activity, dietary calcium from foods, bone medication, systems medicated & also HRT use & menopausal status.

Table 29 Longitudinal associations between SEP and material deprivation and change in DXA BMD, pQCT bone strength and incident fracture among men

	DXA total femoral Change (%/yr)[b]			pQCT radius SSI			pQCT tibia SSI			Fracture between HCS and COS[a]		
	beta	95%CI	*p*	beta	95%CI	*p*	beta	95%CI	*p*	OR	95%CI	*p*
Current social class (vs IIIM)												
I	0.00	(-0.42,0.41)		-24.16	(-67.57,19.26)		-33.86	(-206.15,138.43)		1.50	(0.48,4.68)	
II	0.00	(-0.22,0.23)		-5.79	(-30.18,18.61)		19.55	(-79.26,118.36)		1.35	(0.63,2.92)	
IIINM	0.20	(-0.09,0.48)		-15.81	(-46.96,15.35)		98.7	(-27.85,225.24)		1.71	(0.67,4.34)	
IV	0.02	(-0.23,0.27)		-8.14	(-36.42,20.14)		-40.61	(-153.94,72.72)		1.05	(0.40,2.79)	
V	-0.06	(-0.64,0.53)		33.92	(-34.11,101.95)		22.34	(-247.33,292.01)		1.66	(0.36,7.61)	
		p for trend	*0.87*		*p for trend*	*0.33*		*p for trend*	*0.50*		*p for trend*	*0.48*
			0.97[c]			*0.18*[c]			*0.61*[c]			*0.40*[c]
Age left full-time education												
≤14yrs vs ≥15yrs	-0.06	(-0.28,0.16)	*0.68*	-0.75	(-24.31,22.82)	*0.96*	19.92	(-76.77,116.60)	*0.83*	0.95	(0.44,2.07)	*0.03*
			0.35[c]			*0.32*[c]			*0.44*[c]			*0.13*[c]
Home ownership (vs owned/mortgaged)												
Rented/other	0.07	(-0.18,0.33)	*0.58*	4.04	(-24.28,32.35)	*0.78*	-62.44	(-185.06,60.17)	*0.32*	1.36	(0.66,2.78)	*0.41*
			0.25[c]			*0.82*[c]			*0.19*[c]			*0.53*[c]
Car availability (vs 3 or more)												
None	-0.22	(-0.75,0.31)		-21.77	(-80.07,36.53)		-105.4	(-351.77,140.98)		0.46	(0.09,2.37)	
1	-0.04	(-0.36,0.27)		-6.59	(-42.06,28.89)		-56.55	(-195.01,81.90)		0.62	(0.25,1.55)	
2	-0.09	(-0.42,0.23)		24.67	(-11.76,61.11)		106.21	(-35.80,248.22)		0.45	(0.16,1.22)	
		p for trend	*0.87*		*p for trend*	*0.02*		*p for trend*	*0.00*		*p for trend*	*0.69*
			0.59[c]			*0.05*[c]			*0.01*[c]			*0.42*[c]

pQCT=peripheral quantitative computed tomography; SSI=strength strain index. All other abbreviations and labels as in footnotes for Tables 27 and 28

Unless indicated otherwise, p-values are for unadjusted, univariate associations and are for trend across social classes and categories of car availability, and are for the underlying continuous variable for age left full-time education. [a] All new fracture events arising between the baseline HCS study and the Clinical Outcomes Study (COS) follow-up postal questionnaire [b] Change in BMD defined as BMD at East Hertfordshire follow-up minus BMD at HCS baseline DXA scan, divided by BMD at HCS baseline DXA scan and annualised per year of follow-up to yield a change variable with units of percentage change per year and with positive values indicating an increase in bone over time and negative values a decrease in bone over time.

[c] Adjusted for age, height, weight-for-height, smoking, alcohol, marital status, physical activity, dietary calcium from foods, bone medication, number of systems medicated, follow-up duration and HCS baseline fracture status.

Table 30 Longitudinal associations between SEP and material deprivation and change in DXA BMD, pQCT bone strength and incident fracture among women

	DXA total femoral Change (%/yr)[b]			**pQCT radius SSI**			**pQCT tibia SSI**			**Fracture between HCS and COS[a]**		
	beta	95%CI	*p*	beta	95%CI	*p*	beta	95%CI	*p*	OR	95%CI	*p*
Current social class (vs IIIM)												
I	0.26	(-0.31,0.83)		-31.1	(-54.57,-7.63)		-50.4	(-161.50,60.71)		0.63	(0.24,1.64)	
II	0.02	(-0.35,0.38)		-3.09	(-17.91,11.73)		-3.77	(-71.89,64.35)		0.78	(0.46,1.33)	
IIINM	-0.35	(-0.78,0.08)		7.48	(-9.80,24.75)		-17.05	(-96.45,62.34)		1.10	(0.61,2.00)	
IV	0.05	(-0.40,0.50)		-2.56	(-20.61,15.50)		0.35	(-85.23,85.93)		0.63	(0.33,1.19)	
V	-0.46	(-1.17,0.26)		-23.3	(-53.39,6.80)		21.24	(-114.95,157.43)		3.28	(1.42,7.59)	
		p for trend	*0.45*		*p for trend*	*0.45*		*p for trend*	*0.46*		*p for trend*	*0.17*
			0.51[c]			*0.75[c]*			*0.90[c]*			*0.17[c]*
Age left full-time education												
≤14yrs vs ≥15yrs	-0.02	(-0.38,0.34)	*0.71*	-7.70	(-22.03,6.64)	*0.76*	-27.9	(-93.69,37.90)	*0.26*	0.99	(0.57,1.71)	*0.68*
			0.89[c]			*0.64[c]*			*0.09[c]*			*0.84[c]*
Home ownership (vs owned/mortgaged)												
Rented/other	0.14	(-0.23,0.51)	*0.45*	0.51	(-14.65,15.68)	*0.95*	71.82	(1.22,142.43)	*0.05*	0.75	(0.44,1.27)	*0.28*
			0.35[c]			*0.65[c]*			*0.03[c]*			*0.34[c]*
Car availability (vs 3 or more)												
None	-0.26	(-1.18,0.67)		-22.81	(-59.70,14.07)		2.07	(-172.06,176.19)		1.36	(0.30,6.26)	
1	-0.15	(-1.01,0.71)		-15.55	(-49.73,18.63)		-46.69	(-208.00,114.61)		2.21	(0.52,9.42)	
2	-0.22	(-1.10,0.67)		-3.28	(-38.61,32.04)		-2.41	(-169.08,164.26)		1.05	(0.23,4.80)	
		p for trend	*0.83*		*p for trend*	*0.02*		*p for trend*	*0.65*		*p for trend*	*0.24*
			0.56[c]			*0.02[c]*			*0.94[c]*			*0.36[c]*

pQCT=peripheral quantitative computed tomography; SSI=strength strain index. All other abbreviations and labels as in footnotes for Tables 27 and 28

Unless indicated otherwise, p-values are for unadjusted, univariate associations and are for trend across social classes and categories of car availability, and are for the underlying continuous variable for age left full-time education. [a] All new fracture events arising between the baseline HCS study and the Clinical Outcomes Study (COS) follow-up postal questionnaire [b] Change in BMD defined as BMD at East Hertfordshire follow-up minus BMD at HCS baseline DXA scan, divided by BMD at HCS baseline DXA scan and annualised per year of follow-up to yield a change variable with units of percentage change per year and with positive values indicating an increase in bone over time and negative values a decrease in bone over time.
[c] Adjusted for age, height, weight-for-height, smoking, alcohol, marital status, physical activity, dietary calcium from foods, bone medication, number of systems medicated, follow-up duration, HCS baseline fracture status and HRT use and menopausal status.

Declaration of authorship for paper 3

Holly Syddall: conducted the literature review; planned and executed the statistical analyses; designed and prepared the tables; and drafted all versions of the manuscript.

Maria Evandrou reviewed the final version of the manuscript.

Elaine Dennison designed and managed the Hertfordshire Cohort Study and reviewed the final version of the manuscript.

Cyrus Cooper took overall responsibility for the Hertfordshire Cohort Study and reviewed the final version of the manuscript.

Avan Aihie Sayer: designed and managed the Hertfordshire Cohort Study and reviewed the final version of the manuscript.

Signatures of all co-authors confirming the accuracy of the declaration of authorship provided above for paper 3:

	Signature:	Date:
Prof. Maria Evandrou	M. Evandrou	3.10.12
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Chapter 6. Discussion

6.1 Summary of key findings

The UK population is ageing; the already substantial burden of musculoskeletal disorders on health and social care systems will only increase over time as the population ages. Social inequalities in health are well documented for the UK in general but little is known about social inequalities in musculoskeletal ageing. The three papers presented in this thesis have therefore analysed social inequalities in grip strength, physical function, falls, frailty, fracture and osteoporosis, as markers of musculoskeletal ageing, among the 'young-old' community dwelling men and women who participated in the internationally renowned Hertfordshire Cohort Study (HCS).

Paper 1 showed that having fewer cars available for household use is associated with lower grip strength and poorer PF (self-reported according to SF-36 physical functioning domain) among men and women, and increased falls among men. Not owner-occupying one's home was associated with lower grip strength in men and women and poorer PF in men. All associations were robust to adjustment for adult lifestyle and the range of co-morbidity data available in HCS.

Paper 2 demonstrated that frailty, defined by the Fried criteria, is not uncommon even among community dwelling 'young-old' men and women. Paper 2 demonstrated social inequalities in frailty (across age of leaving full-time education, current home ownership and car availability) which were largely mediated by co-morbidity.

Paper 3 found little strong or consistent evidence among men, or women, for social inequalities in prevalent or incident fracture, DXA bone mineral density, bone loss rates, or pQCT bone strength, with or without adjustment for age, anthropometry, lifestyle and clinical characteristics.

Overall, the three papers presented in this thesis suggest that muscle strength and physical function among community dwelling older men and women in the UK are strongly socially patterned across markers of current material deprivation (housing tenure and car availability) but there is no convincing evidence for a social gradient in fracture or bone mineral density.

Firstly, these results add to, and widen, the UK evidence base for social inequalities in health presented in the Marmot Review. They also suggest that any interventions designed to improve muscle strength and physical function should be targeted proportionately across the social gradient with the twin objectives of improving muscle strength and physical function for all, while also aiming to narrow the social gradient in these musculoskeletal disorders. Intervention strategies to reduce fracture and osteoporosis should continue to have a universal population focus; the absence of evidence for a strong social gradient in fracture and osteoporosis in this thesis is consistent with the wider literature described in paper 3.

Second, the specific nature of the results presented in papers 1 to 3, with clear evidence for social inequalities in muscle strength and physical function but not fracture and bone mineral density, may provide clues to the relative aetiology of these aspects of musculoskeletal ageing and thereby inform development of interventions.

Third, the results presented in this thesis suggest that the burden of poor muscle strength and physical function in later life is likely to be focused among a materially disadvantaged subgroup of older men and women; this has relevance for planning and provision of health, social care and support services. The results presented in this thesis also have implications for current Government policy on provision of care and support and health and social care.

The remainder of this Discussion will expand on these themes by: discussing possible mechanisms underpinning the social inequalities presented in this thesis; discussing the strengths and limitations of the thesis; making recommendations for further research and development of clinical interventions; and discussing the wider implications of the thesis for policy.

6.2 Mechanisms underpinning social inequalities in health

It is unclear how social inequalities in health, including loss of muscle strength and physical function, arise although material/physical and psychosocial explanations exist; Marmot suggests that both explanations have merit and that in reality a combination of the material/physical and psychosocial features associated with socioeconomic position will contribute to social gradients in health (Marmot 2001). Psychosocial explanations for social inequalities in health will be considered further in section 6.2.2.

The material/physical explanation suggests that there are structurally determined differences in the way that people of different socioeconomic position lead their lives; this is consistent with the layers of social determinants of health (Figure 2, Dahlgren and Whitehead 1991) exerting their influence on muscle strength and physical function through direct impact on the lifestyle choices that individuals make and the heath behaviours that they adopt.

The issue of how to address the complex challenge of social inequalities in health is a government wide issue and responsibility does not rest with one policy sector or department (Exworthy and Hunter 2011) or with action on any one health behaviour. Indeed, Hunter (Hunter et al. 2010) has argued that the phenomenon of “lifestyle drift” has even led to a lack of progress on health inequalities i.e. governments have started with a commitment to deal with the broad social determinants of health in a bid to address social inequalities in health but have ended up instigating narrow lifestyle interventions on individual health behaviours with uncertain impact on social inequalities (Exworthy et al. 2006).

Against this backdrop, it would be naive to suggest that variation in any one specific clinical characteristic of the HCS participants could have given rise to the results presented in this thesis. Nonetheless, it is instructive to consider what role anthropometry, physical activity, diet, smoking habit and alcohol consumption may have played in generating the pattern of social inequalities identified in this thesis. Such consideration may provide: clues to specific pathways through which the broad layers of the social determinants of health may have acted to create the pattern of social inequalities described in this thesis; insight into the relative importance of health behaviours for muscle strength as opposed to bone; and direction for clinical interventions with the focused objective of maintaining or improving e.g. muscle strength among older people.

6.2.1 Lifestyle choices and health behaviours

Sections 6.2.1.1 to 6.2.1.4 will briefly explore the role of anthropometry, physical activity, diet, smoking habit and alcohol consumption as possible mediators of the results presented in this thesis with reference to both the literature and further analysis of the HCS data. Attention will be focused on grip strength and DXA total femoral BMD only at this point; these have been selected because they showed the strongest or weakest evidence for a social gradient in HCS respectively, they were objectively measured, and they are phenotypes for the two key tissues underlying the range of markers of musculoskeletal ageing considered in this thesis i.e. muscle and bone.

6.2.1.1 Anthropometry

Social inequalities

Evidence from the literature suggests that height exhibits a strong social gradient across a range of markers of socioeconomic position, irrespective of gender and age; on average, individuals with an advantaged socioeconomic position have greater stature and these inequalities are evident from as young as two years of age (Batty et al. 2009). Obesity is also strongly socially patterned; for example, even as early as ten years of age, the prevalence of obesity among English children is increased in neighbourhoods with higher levels of deprivation, irrespective of region of residence (Marmot 2010).

Social inequalities in height, weight, and weight for height were examined in HCS (Appendices 5 to 7). Consistent with the literature, height was socially patterned among HCS men such that having left education at an older age or owning or mortgaging one's home were both associated with greater stature among men, and higher current social class was associated with greater stature among women (Appendix 5). There was no strong evidence for a social gradient in weight (Appendix 6), or weight for height (Appendix 7), among HCS men across any of the markers of socioeconomic position considered. However, HCS women who did not own or mortgage their home and who had fewer cars available for household use were heavier, on average, than women who owned or mortgaged their home or had greater car availability (Appendices 6 and 7).

Association with muscle strength

Evidence from the literature suggests that there is a strong positive correlation between grip strength and greater stature and skeletal size (Desrosiers et al. 1995;Hirsch et al. 1997;Kuh et al. 2002;Mohd et al. 2010). Bassey explains this by describing how larger, taller, people with greater muscle size and mass are in general going to be stronger than their shorter, smaller, counterparts because the strength of a muscle depends on the cross-sectional area of its contractile elements and this area will generally be greater among larger people (Bassey 1999).

The literature presents generally weaker correlations between grip strength and total body weight than between grip strength and height (Desrosiers et al. 1995;Inskip et al. 2007;Kuh et al. 2002;Mohd et al. 2010). However, studies which have considered a more subtle measure of obesity or fat mass have shown that greater levels of obesity and fat mass are associated with poorer grip strength, possibly via increased inflammation and insulin resistance (Koster et al. 2011;Stenholm et al. 2011). For example, Koster studied 2,000 men and women aged 70 to 79 years who participated in the Health Ageing and Body Composition (ABC) Study and showed that higher levels of DXA total body fat mass were associated with poorer muscle quality and accelerated loss of muscle mass over an 8 year follow-up period (Koster et al. 2011). Stenholm conducted a longitudinal study of Finnish men and women aged 55 years and older and demonstrated that earlier onset of obesity was associated with reduced grip strength in later life, independent of current weight; Stenholm concluded that maintaining a healthy body weight through life may help to maintain adequate muscle strength in old age (Stenholm et al. 2011).

The general consensus from the literature is therefore that shorter stature and higher levels of fat confer lower grip strength; results based on a crude assessment of weight must be approached with due consideration as to whether a weight measurement in any given study is reflecting greater skeletal body size (which might be better marked by height) or greater obesity and fatness, or a combination of both.

The association between grip strength and height, and a residual of weight for height, among HCS men and women is shown in Appendix 8. The weight for height variable attempts to encapsulate body weight, over and above that which would be expected for the skeletal size indicated by height; other assessments of body fat e.g. percentage body fat estimated from skinfold measurements, could also be considered in HCS but weight for height has been used in the appendices for consistency with the approach taken in the papers comprising this thesis and has the advantage of being independent of height. Consistent with the literature, the results in Appendix 8 show that taller stature was strongly associated with higher grip strength among HCS men and women (univariate correlations for grip strength and height: men $r=0.40$, $p<0.001$; women $r=0.28$, $p<0.001$) but the associations between grip strength and weight, over and above height, were modest in comparison (univariate correlations for grip strength and weight for height: men $r=0.07$, $p=0.004$; women $r=-0.02$, $p=0.44$); these results were little altered by adjustment for age, self-reported walking speed, oily fish consumption, smoking habit and alcohol intake.

Association with bone mineral density

In 2009, Papaioannou conducted a systematic review of the risk factors for lower bone mineral density and bone loss in healthy men age 50 years and older; low weight and weight loss were consistent risk factors for low BMD or bone loss but the evidence for height or height loss was weak (Papaioannou et al. 2009). Wardlaw considered the determinants of BMD among women and concluded that a low body weight increases osteoporosis risk and a more generous body weight, to a point, confers some protection against osteoporosis and related fracture risk; greater body weight and increased fat mass may exert beneficial effects on BMD through increased skeletal loading, altered production of hormones including estrogen, differences in nutrient intakes, and increased fat mass may also act as a physical cushion against bone trauma in a fall (Wardlaw 1996). However, Wardlaw cautions that it is unclear how much body weight is needed to confer a reduced risk of osteoporosis and that a woman should not strive for an obese state; indeed, if weight is increased to an excessive level this will be to the detriment of bone health through reduced mobility and increased tendency to fall. Walker-Bone reviewed risk factors for BMD and fracture among men and women and concluded that loss of body fat and thin body build are associated with accelerated bone loss and increased fracture risk but the importance of height for BMD is less clear (Walker-Bone et al. 2001). In addition to BMD, femoral geometry is recognised as a risk factor for osteoporotic fracture in men and women with, for example, a greater hip axis length conferring a greater bending moment in the femoral neck during a fall and consequently increased risk of hip fracture; taller individuals with greater hip axis length are therefore likely to be at increased risk of hip fracture through femoral geometry (Gregory and Aspden 2008).

The association between total femoral DXA BMD and height, and a residual of weight for height, among HCS men and women is shown in Appendix 9. The opposite pattern of association was identified between anthropometry and total femoral BMD to that between anthropometry and grip strength in HCS. Heavier weight, over and above skeletal size, was strongly associated with higher total femoral BMD among HCS men and women (univariate correlations versus weight for height: men $r=0.40$, $p<0.001$; women $r=0.44$, $p<0.001$) but the associations between total femoral BMD and height, were modest in comparison (univariate correlations: men $r=0.11$, $p=0.01$; women $r=0.12$, $p=0.01$); these results were little altered by adjustment for age, Dallosso physical activity score, dietary calcium from foods, smoking habit and alcohol intake and are entirely consistent with the literature described above.

Summary of section 6.2.1.1

This section of the thesis has established that shorter stature is the dominant anthropometric correlate of lower grip strength and increased fat mass is also a factor. Shorter stature and higher levels of fat both arise with greater frequency among socially disadvantaged individuals; it is therefore entirely plausible that variations in anthropometry across different socioeconomic groups contribute to the social gradient in grip strength as presented in this thesis. In contrast, greater body weight and increased fat mass, which arise with greater frequency among individuals of lower socioeconomic position, actually offer some protection against low BMD and osteoporosis; it is plausible that the social gradient in obesity has contributed to the general absence of evidence for social inequality in BMD and fracture in this thesis and indeed the wider literature. In summary, variations in anthropometry are likely to play a role in social inequalities in muscle strength; this is entirely consistent with a general absence of evidence for social inequality in osteoporosis.

6.2.1.2 Physical activity

The importance of physical activity for older people

The UK Department of Health published its “Start Active Stay Active” report in 2011 in advance of the London 2012 Olympic year (Department of Health 2011). The report: emphasised that regular physical activity can reduce the risk of many chronic conditions, musculoskeletal conditions included; highlighted the importance of physical activity for people of all ages; cautioned against the risks of sedentary behaviour, and provided guidelines for target levels of physical activity for health for different age groups. The guidelines for older adults, aged 65 years and over, recommended that any physical activity has health benefits but more provides greater benefits; over a week, activity should add up to at least two and a half hours of moderate intensity activity (e.g. brisk walking or ballroom dancing) in bouts of ten minutes or more. The report explicitly recommended that, “on at least two days a week, older adults should undertake activities that strengthen muscles by using body weight or working against a resistance e.g. carrying or moving heavy loads such as groceries or activities that involve stepping and jumping such as dancing”.

The Age UK “Healthy Ageing Evidence Review” has also highlighted the importance of physical activity for older people (Age UK 2010). The Age UK report recommended that physical activity not only benefits the cardiovascular system, promotes emotional wellbeing and increases energy and reduces fatigue but also aids mobility and muscle strength, reduces declines in muscle and bone strength with advancing age and reduces falls and fracture risk.

Fries argues that physical activity will be a cornerstone to achievement of a compression of morbidity i.e. a scenario such that a healthy life is one which is vigorous and vital until shortly before its natural close and in which the inevitable period of morbidity which arises later in life is compressed to a short time frame and disability free life expectancy is increased (Fries 1996).

Social inequalities

The Marmot review (Marmot 2010) noted that many of the key health behaviours significant in the development of chronic disease follow the social gradient; within this, physical activity decreases and sedentary behaviours increase with disadvantaged socioeconomic position. Marmot presented evidence that inequalities in physical activity are established early in life with, for example, children from high income households taking part in sports out of school nearly twice as much as those from low income households. The “Start Active Stay Active” report also described clear and significant inequalities in physical activity according to gender, age, income, ethnicity and disability with lower physical activity levels in lower income households (Department of Health 2011).

For compatibility with previous HCS publications, this thesis has used self-reported walking speed as a marker of physical activity in analyses considering grip strength (Bendall et al. 1989;Sayer et al. 2006) and the Dallosso physical activity score for analyses considering osteoporosis and fracture (Dallosso et al. 1988;Dennison et al. 2005). These are clearly crude markers which can only begin to reflect the variations in type, pattern, frequency and duration of current levels of physical activity which will be evident among HCS participants. Neither can these markers reflect trajectories of physical activity across the lifecourse, they cannot distinguish between physical activity undertaken in leisure time rather than as part of an occupation either concurrently or previously in life, they do not distinguish between customary levels of physical activity as opposed to physical activity undertaken specifically as exercise e.g. at a gym, and they do not enable separation of resistance and aerobic exercise. However, they were the only markers of physical activity which were available cohort wide for HCS and they did at least enable some preliminary assessment of the potential confounding influence of physical activity on the associations explored in papers 1 to 3 of this thesis.

Whilst acknowledging their limitations as markers of physical activity, social inequalities in self-reported walking speed and Dallosso physical activity score were explored in the HCS cohort (Appendices 10 and 11). Univariate analyses demonstrated social inequalities in self-reported walking speed across most of the markers of socioeconomic position and material deprivation available for HCS men and women. However, mutually adjusted analyses suggested that the strongest associations were for a higher prevalence of poor walking speed (defined as a self-reported typical walking speed of ‘very slow’ or ‘strolling at an easy pace’ as opposed to ‘normal speed’, ‘fairly brisk’ or ‘fast’) among men of lower social class at birth, who did not own or mortgage their home, and who had fewer cars available for household use (Appendix 10). Mutually adjusted analyses for women showed that those who did not own or mortgage their home had a significantly greater prevalence of poor walking speed than their counterparts who owned or mortgaged their home (Appendix 10). Results were similar for the Dallosso physical activity score with mutually adjusted analyses for men and women both providing clear evidence of lower physical activity (lower average scores) among individuals who did not own or mortgage their home and who had fewer cars available for household use (Appendix 11). Although the associations between the physical activity markers and car availability could have arisen from reverse causation (i.e. with individuals who are unfit and unwell selecting themselves out of driving), the car availability variable was ascertained for the household and, moreover, the housing tenure variable shows consistent evidence for social inequality in physical activity but is likely to be little affected by reverse causation given the age range of the HCS participants.

In summary, consistent with the literature described above, there is clear evidence for social inequality in self-reported walking speed and Dallosso physical activity score across markers of current material deprivation among HCS men and women.

Association with muscle strength

In postnatal life, nutrition, hormones and loading during physical activity all contribute to the increase in skeletal muscle mass which occurs during the growth phase in humans. In contrast, increased mass of adult skeletal muscle is primarily driven by mechanical factors i.e. exercise and physical loading (Shavlakadze and Grounds 2006). Given that maintenance of adequate muscle mass is essential for healthy independent living it is therefore no surprise that the Department of Health’s “Start Active Stay Active” report and Age UK’s “Healthy Ageing Evidence Review” both emphasised the importance of physical activity for older people; the “Start Active Stay Active” report specifically noted that resistance training is highly effective in increasing or preserving muscle strength, even in very old age.

There is ample evidence in the literature for the benefit of resistance exercise for muscle strength among older people. A Cochrane review of 121 randomised controlled trials involving 6,700 participants considered the importance of progressive resistance training (PRT) performed two or three times a week at high intensity for physical function in older adults; the review concluded that PRT improved physical function measures including gait speed and getting out of a chair, and also had a positive effect on muscle strength (Liu and Latham 2009). A more recent meta analysis by Peterson included randomised controlled trials and observational studies which had explored the association between resistance exercise and explicit measures of upper and lower body muscle strength in adults aged 50 years or older; Peterson's review concluded that high intensity resistance exercise clearly improves muscular strength in older people (Peterson et al. 2010).

Overall, the evidence from these reviews is consistent with older muscle retaining a high degree of plasticity in later life and remaining highly malleable in response to increased loading via resistive training such that the loss of muscle strength with age can be substantially reduced by strength training (Narici et al. 2004).

Other studies in the literature have considered the broad association between physical activity and muscle strength among older people but have not distinguished between resistance exercise as opposed to other types of physical activity. For example, Martin et al described the cross-sectional associations between customary physical activity and a battery of physical performance measurements (including grip strength) among the subset of HCS participants who were resident in West Hertfordshire and who completed an extensive physical activity questionnaire; higher levels of customary physical activity ascertained by questionnaire were associated with better physical performance among women but not men (Martin et al. 2008). Cooper et al examined the associations between leisure-time physical activity across adulthood (self-reported prospectively at ages 36, 43 and 53 years of age) and grip strength, standing balance and chair rise times at age 53 years among approximately 2,400 men and women who participated in the UK MRC National Survey of Health and Development; higher levels of physical activity across adulthood were associated with improved performance on the chair rise and standing balance tests at age 53 years among men and women but physical activity was not associated with grip strength in women, and only physical activity at age 53 years was associated with grip strength at the same age among men (Cooper et al. 2011b).

Martin and Cooper's studies did not dissect the relative contribution of leisure and occupational physical activity to muscle strength in later life. It could be postulated that a history of manual work with high physical demands might confer increased muscle strength for an individual both at the time of employment and in later life if any effect of greater occupational physical activity on muscle strength were to be maintained into later, post-retirement, life. However, a study by Russo explored the association between retrospectively assessed lifetime history of manual versus non-manual work among a cohort of 273 Italian men and women of average age 85 years and found evidence for the converse situation i.e. that jobs with higher physical demands do not necessarily confer superior muscle strength in later life and indeed, particularly when found in combination with high physical stress, a history of manual work appeared (Russo et al. 2006) to be associated with low physical function and muscle strength in later life. Berger has described the impact of retirement on physical activity among 699 participants in the West of Scotland Twenty-07 Study who were 60 years of age at baseline interview in 1991 and who were followed up five years later (Berger et al. 2005). Berger found that a substantial amount of physical activity occurred at work but was lost among those who had retired; although those who were not working were more active at home or at leisure than those who were still working, this was not sufficient to compensate for the loss of work-based activity. In summary, although the evidence for the beneficial effect of resistance exercise on muscle strength is clear, clarification of the impact of occupational, leisure and customary physical activity across the lifecourse on muscle strength in later life is required.

Association with bone mineral density

In 2009, Guadalupe-Grau et al conducted a review of the evidence for association between exercise training and bone measurements in cross-sectional and longitudinal studies of adults and concluded that overall, high impact and weight lifting exercises have the greatest bone building (osteogenic) potential among adults; however, the review noted that results varied according to study design, intensity and duration of the exercise protocol, and the bone density measurement techniques used (Guadalupe-Grau et al. 2009). Moreover, the review emphasised that the evidence for the impact of exercise training on bone among older adults was weaker with only slight increases, maintenance or attenuation of BMD losses in postmenopausal women. Older men had been less studied than women and the review noted that a randomised longitudinal study of the effects of exercise on bone mass in elderly men and women was lacking.

In 2012, Gomez-Cabello conducted a systematic review of the effects of different types of exercise training programmes on bone mass in older adults (Gomez-Cabello et al. 2012). The review included 59 controlled trials, 7 meta-analyses and 8 reviews and concluded that the typical decline in bone mass which arises with ageing may be attenuated by participation in specific training programmes. Strength exercise appeared to be most crucial for improvement or maintenance of bone mass during the ageing process. The review also noted that although many previous studies may have found unremarkable effects of exercise on DXA BMD, this does not preclude the possibility that the potential benefits of exercise on bone may be better revealed by studies which include pQCT scanning of volumetric bone density, bone strength and geometric properties. The review concluded that future studies should include long term exercise training programmes, the use of pQCT measurements in addition to DXA, and more trials of men and older participants.

In line with the evidence from these two reviews, the Department of Health's "Start Active Stay Active" report (Department of Health 2011) noted that although physical activity can produce a beneficial bone response at all adult ages, older bone responds more slowly than young bone and older bone responds more slowly than older muscle in response to physical activity. The report suggested that if the evidence for the effect of resistance exercise on muscle strength, mass and power may be regarded as strong, then in contrast, there is only moderate evidence for an association between higher levels of physical activity and reduced rates of hip fracture and increased levels of hip BMD in later life.

Summary of section 6.2.1.2

Evidence from the literature combined with further analysis of HCS data has shown that there are clear social inequalities in physical activity in early and later life. Resistance exercise exerts a clear benefit on muscle strength in later life but the evidence for the benefit of physical activity on bone mass in the ageing skeleton is comparatively modest at best (Taaffe and Marcus 2000). This may be because ageing skeletal muscle is a highly malleable tissue which is still very responsive to physical activity in later life in a way that ageing bone is not. It is therefore plausible that variations in physical activity across the social gradient could contribute substantially to social inequalities in muscle strength in later life in a way that they do not for BMD.

6.2.1.3 Diet

Social inequalities

Food intakes fall and the risk of poor nutrition increases with older age (Bartali et al. 2003) and also varies between older people according to socioeconomic position (Lee and Berthelot 2010). In 2008 the Scientific Advisory Committee on Nutrition (SACN) published its report summarising the results of the British National Diet and Nutrition Surveys (NDNS) which were conducted between 1992 and 2001: these nationally representative surveys aimed to review the nutritional status of the British population. The SACN report concluded that many sections of the population were failing to achieve UK dietary targets and recommendations which aim to promote health and prevent nutrition related chronic disease (Scientific Advisory Committee on Nutrition 2008). Of specific relevance for this thesis, the report concluded that adults aged 65 years and over were failing to meet the recommendations for consumption of fruit and vegetables, oily fish and vitamin D. Moreover, there were marked differences in diet and nutritional status according to socioeconomic position; for example, fruit and vegetable consumption and intakes of some vitamins and minerals were lower among people living in benefit households or from manual social class groups in comparison with other socioeconomic groups. However, the Food Standard Agency's (FSA) Low Income Diet and Nutrition Survey (LIDNS) noted that not all aspects of diet and nutrition are socially patterned; for example, although mean fruit and vegetable consumption and intakes of fibre and iron were lower among the adult low income population in comparison with the general adult population in the UK, intakes of fat and saturated fat were similar. The results of the LIDNS concur with Robertson's observation that low income groups have diets which appear to particularly lack the quality and variety required for health as opposed to necessarily lacking in quantity in comparison with the general population (Robertson 2001). The SACN report concluded that people of lower socioeconomic status comprise a specific population group who are at risk of poor dietary variety, low nutrient intake and biochemical status and to whom strategies to achieve dietary behaviour change should be targeted.

Appendices 12 and 13 provide an indication of the social gradient in diet among HCS participants. Two specific dietary characteristics were selected for presentation in these appendices i.e. weekly consumption of oily fish and estimated daily dietary calcium from foods, both ascertained by food frequency questionnaire (Robinson et al. 2009). These were selected because of their likely relevance for muscle and bone respectively and previous use as exposure variables or confounders in analyses involving HCS dietary data (Dennison et al. 2007;Robinson et al. 2008). Appendix 12 shows that leaving school before 15 years of age, lower social class in adulthood, not owning or mortgaging one's home and having fewer cars available for household use were associated with greater likelihood of not consuming any oily fish per week among men and women in univariate analyses; current social class and housing tenure were the strongest correlates of oily fish consumption in mutually adjusted analyses for men, and housing tenure and car availability were most strongly associated with oily fish consumption in mutually adjusted analyses for women. In contrast, estimated daily calcium intake from foods only varied among men according to car availability, and to a lesser extent housing tenure (appendix 13). These results suggest that, consistent with the conclusions of the FSA's Low Income Diet and Nutrition survey, aspects of diet do not follow a universal social gradient.

Although there are concerns about the use of FFQs to assess diet, the absence of strong evidence for a social gradient in dietary calcium intake, but a marked effect on oily fish consumption among HCS participants is unlikely to be due to methodological problems. Firstly, oily fish is consumed infrequently which means FFQs are particularly suited to assess oily fish consumption, and assessed intakes are comparable with other dietary methods (Welch et al. 2006). Secondly, more than 40% of dietary calcium is provided by milk and dairy products (Scientific Advisory Committee on Nutrition 2008) which means that valid estimates of calcium intake can be obtained from FFQ assessment of a limited number of foods; correlation coefficients comparing FFQ-estimates of calcium intake with reference methods such as 24 hour recalls are generally high (Osowski et al. 2007). Although the choice to consume low-fat or high-fat dairy foods is socially patterned, total milk consumption does not appear to be, which would contribute to lesser social gradients in calcium intake than for other dietary characteristics such as oily fish intake (Sanchez-Villegas et al. 2003). The HCS data are therefore consistent with expected differences in diet quality in relation to socioeconomic circumstances (Darmon and Drewnowski 2008).

Association with muscle strength

Robinson et al recently reviewed the evidence linking diet to sarcopenia (the loss of muscle mass and function with age) and concluded that diets of adequate quality and variety are important to ensure sufficient intakes of protein, vitamin D and antioxidant nutrients (including carotenoids, vitamin E and selenium) for prevention, or at least deceleration, of the loss of muscle mass and strength with age (Robinson et al. 2012). Robinson has previously explored the association between diet and grip strength among HCS participants in detail and identified strong associations between increased intakes of oily fish and higher grip strength among men and women (Robinson et al. 2008); given that oily fish is one of the richest sources of n-3 long-chain polyunsaturated fatty acids (LCPUFAs) in the UK diet, Robinson suggested that the anti-inflammatory actions of n-3 fatty acids could also be important in the prevention of sarcopenia. Appendix 8 recaps the association between oily fish consumption and grip strength among HCS men and women and confirms that these associations were robust to adjustment for age and the lifestyle characteristics being considered in this discussion i.e. height, weight for height, self-reported walking speed as a marker of physical activity, smoking habit and alcohol intake. Paper 1 did not adjust for oily fish intake among the HCS participants; for completeness, appendix 14 therefore recaps the “fully adjusted” analyses for social inequalities in grip strength as presented in paper 1 and also subjects these analyses to additional adjustment for oily fish intake. As expected, oily fish intake explained variation in grip strength but adjustment for it did not substantively alter the evidence for social inequality in grip strength according to housing tenure and car availability among the HCS participants.

Association with bone mineral density

Calcium and vitamin D are the most important nutrients for bone health among older people (Earl et al. 2010). Calcium is one of the main mineral constituents of bone and an adequate supply is needed at all stages of the lifecourse. However, intakes of calcium among elderly people may be reduced from levels earlier in life for reasons including monotonous diet associated with a declining appetite (Bartali et al. 2003). Vitamin D is essential for absorption of calcium and is obtained primarily from dietary sources and sunlight, the latter of which has been proposed as the most important contributor to vitamin D status among the elderly population of the UK (Lawson et al. 1979). As such, the association between dietary vitamin D and BMD will not be considered further in this thesis. Protein and vitamin K may also influence bone health in later life but the evidence for a relationship between dietary protein and bone metabolism is inconsistent and the mechanism through which vitamin K may be important for bone is unclear (Earl et al. 2010).

Appendix 9 presents simple, preliminary correlations between estimated daily calcium intake from foods and total femoral BMD among HCS men and women; no significant associations were identified among men or women, with or without adjustment for age, height, weight for height, Dallosso physical activity score, smoking habit and alcohol intake. Further analysis would clearly be required to explore the associations between bone mineral density and the full range of potentially relevant foods, nutrients and dietary patterns available in HCS but the results in Appendices 8 and 9 suggest, if nothing else, that any association between dietary calcium from foods and total femoral

BMD among the HCS participants is not perhaps as strong as that between oily fish intake and grip strength.

Summary of section 6.2.1.3

People of lower socioeconomic status comprise a specific population group who are at risk of poor dietary variety and quality, low nutrient intake and biochemical status. In older adults, such diets may be less likely to provide sufficient intakes of protein, vitamin D and antioxidant nutrients for prevention of loss of muscle mass and strength with age. It is therefore plausible that social variations in the key nutrients required to support optimal muscle mass and function have contributed to social inequalities in grip strength among HCS participants. However, aspects of diet do not follow a universal social gradient; it is possible that a broadly poor quality diet, whilst disadvantageous for muscle health, might nonetheless provide an adequate level of the key nutrients required for bone owing to wide availability of calcium rich foods such as milk and dairy products. This argument is consistent with the specific patterns of social inequality in muscle strength and bone mineral density presented in this thesis.

6.2.1.4 Smoking habit and alcohol consumption

Social inequalities

Smoking follows a strong social gradient with higher prevalence among socially disadvantaged individuals (Marmot 2010). Conversely, overall levels of alcohol consumption are lower among low income groups but the harms from alcohol arise more frequently among socially disadvantaged groups. For example, in England, hospital admissions for alcohol-specific conditions are associated with increased levels of deprivation, irrespective of region and gender (Marmot 2010). Smoking habit was strongly socially patterned among HCS men and women across most of the markers of socioeconomic position and material deprivation considered (Appendix 15). The evidence for socioeconomic variation in total weekly alcohol intake among HCS participants was more limited although a greater prevalence of high weekly alcohol intake was evident among women of higher current social class (Appendix 16).

Association with muscle strength

Although smoking habit and alcohol consumption are widely included as potential confounders in epidemiological studies, few articles in the literature have directly studied the association between smoking, alcohol and grip strength. Strand et al described the association between smoking history and physical performance in midlife using data from the British 1946 Birth Cohort Study; lifetime cigarette pack-years were strongly related to lower overall physical performance and performance in standing balance and chair rising but there was no association with grip strength (Strand et al. 2011b). Castillo et al examined risk factors for sarcopenia among 55-98 year old men and women who participated in the Rancho Bernardo Study; current smoking was identified as a risk factor for sarcopenia (defined as a fat free mass of two or more standard deviations below the gender-specific mean of a young reference population) but the association between grip strength and smoking was not reported (Castillo et al. 2003). Nelson et al investigated smoking and alcohol in relation to physical function among community dwelling white American women aged 65 years and older; current smokers had significantly poorer performance than never smokers in tests of agility and coordination, gait and balance but no difference in grip strength (Nelson et al. 1994). Nelson found that non-drinkers had significantly poorer function on most of the performance measures, including grip strength, in comparison with moderate drinkers; assessment of a dose response effect was limited by a small number of heavy drinkers in Nelson's study. Cawthon et al studied the association between alcohol use and physical performance among 5,962 American men aged 65 years and older. Consistent with Nelson's results for women, Cawthon established that men with moderate alcohol intake generally had better physical performance scores, including stronger grip strength, in comparison with non-drinkers; heavy drinkers performed similarly to abstainers (Cawthon et al. 2007a).

Smoking habit and alcohol intake were not strongly associated with grip strength among HCS men or women (Appendix 8).

Association with bone mineral density

Smoking is consistently associated with low BMD, bone loss and fracture risk in men and women and smoking has been incorporated within the FRAX algorithm which estimates an individual's ten year fracture risk from information on key risk factors for fracture (Dimai and Chandran 2011;Drake et al. 2012;Papaioannou et al. 2009;Ward and Klesges 2001).

High intakes of alcohol have adverse effects on skeletal health (Kanis et al. 2005) and clinical guidelines recommend avoidance of excessive alcohol intake in the management of osteoporosis among men and women (North American Menopause Society 2010;Watts et al. 2012). However, the evidence for the effects of moderate consumption is less clear and indeed, a systematic review by Papaioannou concluded that the evidence for an association between alcohol consumption and low BMD among healthy older men was inconsistent or weak (Papaioannou et al. 2009).

Smoking habit and alcohol intake were not strongly associated with total femoral BMD among HCS men or women (Appendix 9).

Summary of section 6.2.1.4

Smoking habit is strongly socially patterned according to evidence from the literature and further analysis of HCS data. However, the scant evidence from the literature combined with further analysis of HCS data suggests that smoking does not appear to be an important risk factor for grip strength which in turn suggests that smoking habit is unlikely to have contributed to the social gradient in grip strength as presented in this thesis. The strong social gradient in smoking might have perhaps been expected to contribute to a social gradient in BMD given that smoking is established as a risk factor for bone health; however, smoking was not actually associated with total femoral BMD among HCS participants and no strong evidence for a social gradient in BMD was evident in this thesis or indeed in the literature reviewed in paper 3.

Patterns of social inequality in alcohol are complex and variation in alcohol intake across the low to moderate range does not appear to be an important risk factor for grip strength or BMD in the literature or in HCS. Alcohol intake therefore seems unlikely to have played a role in the presence of a social gradient in grip strength, or the absence of a social gradient in total femoral BMD, in this thesis

6.2.1.5 Summary

Sections 6.2.1.1 to 6.2.1.4 have considered the likely contribution of variations in height, weight, physical activity, diet, smoking habit and alcohol intake to the results presented in this thesis. Review of the literature, in combination with further analysis of the HCS data, has suggested that evidence for a social gradient in grip strength coupled with a broad absence of evidence for a social gradient in BMD is entirely plausible. Three factors seem particularly likely to have contributed to the specific nature of the social inequalities in grip strength and total femoral BMD which have been presented in this thesis. Firstly, height and weight follow divergent social gradients such that shorter stature and increased fat mass arise with greater frequency among socially disadvantaged individuals; this would be to the detriment of muscle strength whilst affording some protection for BMD. Secondly, ageing skeletal muscle remains highly responsive to variations in physical activity in a way that ageing bone does not. Thirdly, socioeconomic disadvantage is associated with poor dietary variety and quality and diets which are unlikely to provide sufficient intakes of the protein, vitamins and antioxidant nutrients which are crucial for muscle mass and strength; however, such diets may provide sufficient intakes of the key nutrients required for bone owing to wide availability of calcium rich milk and dairy products. Variations in smoking habit and alcohol intake seem unlikely to have played an important role in the results presented in this thesis.

6.2.2 Psychosocial explanations for social inequalities in health

Psychosocial explanations for social inequalities in health focus on how social inequality makes people feel and how the biological consequences of these feelings influence health. Psychosocial explanations suggest that a social gradient in health arises because of an unequal social distribution of psychosocial risk factors such as social support, work demands, levels of control or imbalances in effort-reward (Skalicka et al. 2009). The psychosocial stressors associated with socioeconomic disadvantage are thought to exert their effect on health outcomes through psychobiological processes which may alter inflammatory, neuroendocrine, immune or cardiovascular responses (Steptoe et al. 2005).

Given that increased inflammation and altered hormonal levels rank among the mechanisms which are thought to contribute to the development of sarcopenia (Burton and Sumukadas 2010) it is therefore plausible that psychosocial mechanisms could contribute to social inequalities in markers of sarcopenia such as grip strength. For example, raised levels of the inflammatory cytokine interleukin-6 (IL-6) have been consistently associated with sarcopenia (Beyer et al. 2012) and IL-6 levels have been shown to increase in response to acute psychological stress among healthy individuals participating in laboratory testing (Kanel von et al. 2006;Steptoe et al. 2001) and also vary according to positive affect and well-being status among healthy community-dwelling women who participated in the Whitehall II study (Steptoe et al. 2008).

Alterations in hypothalamic pituitary adrenal (HPA) axis activity might also plausibly contribute to a social gradient in grip strength. HPA axis activity is thought to play an important role in translating chronic stress into ill-health as a consequence of stressful stimuli activating the axis and causing an increase in circulating cortisol levels which, if sustained over time, can ultimately compromise HPA responses and lead to ill-health (Friedman et al. 2012). In turn, elevated lifecourse exposure to cortisol has been proposed as a potential mechanism for sarcopenia (Gardner et al. 2011;Marcell 2003). For example, Friedman has demonstrated associations between a sustained history of social strain and altered daily cortisol rhythms in midlife among the men and women who participated in a detailed clinical follow-up component of the National Survey of Midlife Development in the United States (MIDUS) study (Friedman et al. 2012) and Gardner has described how dysregulation of the HPA axis is associated with worse physical performance (walking speed and balance time) in later life among men who participated in the Caerphilly Prospective Study (Gardner et al. 2011). Although Gardner did not specifically consider grip strength, the results from the Caerphilly Prospective Study are consistent with alterations in HPA axis activity playing a contributory role in social inequalities in markers of physical performance, grip strength included (Stevens et al. 2012).

Section 6.2.2 has emphasised the importance of psychosocial explanations for social inequalities in health and has highlighted the potential role of alterations in IL-6 and HPA axis activity as specific examples of inflammaging and neuroendocrine processes which could contribute to the social inequalities in grip strength which have been presented in this thesis. However, investigation of the psychobiological processes which underpin psychosocial explanations for social inequalities in health represents a challenging and extensive area for future research.

6.3 Strengths and limitations of the thesis

6.3.1 Strengths

Firstly, the HCS data are individual level and were ascertained by face to face contact between research nurses and study participants. Data were ascertained according to strict study protocols with inter- and intra-observer assessments of measurement variability conducted throughout the fieldwork. The HCS database is a high quality research database; data entry, record keeping, computer processing and statistical analyses have been carried out to an exceptionally high standard under the supervision of an experienced multi-disciplinary team of research scientists. The extensive range of data collected for HCS has enabled social inequalities in musculoskeletal ageing to be explored without and with adjustment for age, anthropometry, physical activity, diet, smoking and alcohol habit, medication use and co-morbidities.

Secondly, a range of markers of socioeconomic position have been considered in this thesis. Housing tenure and car availability have been considered as markers of current material deprivation among HCS participants in addition to occupation based social class which, as outlined in section 2.4.1, may be less relevant to groups of predominantly retired older individuals such as the HCS participants.

Finally, no published papers have considered the relative social patterning of muscle strength, physical function, falls, frailty and osteoporosis. This thesis has been able to explore the evidence for social inequalities across a range of markers of musculoskeletal ageing and has demonstrated specific patterns of social inequality for different aspects of musculoskeletal ageing with strong evidence for social inequality in muscle strength and physical function but not for fracture and osteoporosis. The specific nature of these results adds weight to the evidence for social inequality in muscle strength and physical function and suggests that these results are not simply arising as a consequence of generally poorer lifestyles and greater co-morbidity among socially disadvantaged groups, or, on this basis one might also expect to have identified social inequalities in bone health. The specific nature of the social inequalities observed in this thesis also provides clues to aetiology and suggests lifestyle factors which may be most appropriate for intervention with the objective of narrowing social inequalities in muscle strength and physical function.

6.3.2 Limitations

The HCS database included data on a widely used panel of markers of socioeconomic position and material deprivation but did not include data on direct measures of income, wealth or receipt of benefits or detailed data on housing quality and access to amenities other than a car or van. Future research into social inequalities in musculoskeletal ageing would be well advised to collect data on an even wider range of markers of socioeconomic position if feasible.

The physical activity data in HCS are only broad, simple, cross-sectional markers in later life which cannot reflect the full complexity of variations in patterns of customary and occupational physical activity across the lifecourse. Further research is required to elucidate how customary and occupational physical activity across the lifecourse relate to markers of musculoskeletal ageing cross-sectionally and longitudinally, and how physical activity might contribute to the social gradient in mobility disability, muscle strength and physical function.

The observed social inequalities in grip strength and PF in paper 1 could be a consequence of greater co-morbidity among people who experience greater levels of material deprivation and socioeconomic disadvantage (Office for National Statistics 2004). However, the HCS contains individual level data on a panel of co-morbidities and the social inequalities in grip strength and PF presented in paper 1 were robust to adjustment for these. In addition, whatever degree of social inequality in co-morbidity is apparent in HCS it was not sufficient to create social inequalities in osteoporosis. Nonetheless, the possibility that unmeasured co-morbidities may have contributed to social inequalities in grip strength and PF cannot be completely discounted. Future studies could try to collect data on, and adjust for, an even greater number of co-morbidities than those ascertained in HCS. However, even if some of the social inequalities identified in this thesis arose in part due to a greater burden of co-morbidity among socially disadvantaged individuals, the findings of social inequalities in muscle and PF still have relevance in terms of identifying current subgroups of the population in whom greater co-morbidity has translated in to poorer muscle strength and PF and who are likely to be at relatively greater risk of consequent mobility disability and loss of independence as they age. If the observed inequalities in muscle strength and PF in HCS are a direct consequence of inequalities in co-morbidities this would however shift the emphasis for consideration of how best to intervene to reduce inequalities in muscle and PF; however, the range of co-morbidity which can be adjusted for in HCS suggests that the observed inequalities in muscle and PF are not entirely a reflection of inequalities in co-morbidity.

Data on DXA total femoral BMD were only available among the subgroup of 996 men and women who participated in the baseline HCS DXA scan; limited power owing to smaller sample size, combined with a possible healthy-participant effect, could have contributed to the overall absence of evidence for social inequalities in DXA BMD in paper 3. To investigate this possibility, the key analyses from paper 1 pertaining to social inequalities in grip strength and PF by housing tenure and car availability were repeated among the subgroup of men and women who participated in the baseline HCS DXA scan (see appendices 17 and 18). Results were generally weaker although social inequalities in PF were still present among DXA men according to car availability and among DXA women according to housing tenure. Grip strength remained socially patterned across housing tenure and car availability among DXA men but not among DXA women. Section 2.5 of the Introduction considered selection bias in HCS and showed that the East Hertfordshire men who participated in the baseline DXA study tended to report better SF-36 physical function, lower rates of fracture since 45 years of age, were less likely to be current smokers and had higher Dallosso physical activity scores than the East Hertfordshire men who only participated in the baseline clinic and the East Hertfordshire women who participated in the baseline DXA scan had better SF-36 physical function, were less likely to report slow walking speed, had higher Dallosso physical activity scores, were more likely to eat oily fish each week and had higher grip strength than the East Hertfordshire women who only participated in the baseline clinic.

These results suggest that the DXA participants were, overall, a group of healthy participants who had better, and more homogenous, overall physical functioning and grip strength than the wider sample of HCS participants which would be consistent with the weaker evidence for social inequalities in grip strength and PF among the DXA participants, and which might have contributed to the absence of evidence for social inequalities in DXA BMD among these men and women. However, the absence of strong evidence for social inequalities in osteoporosis in HCS is consistent with the general literature as reviewed in paper 3 and moreover, we found no convincing evidence for social inequality in fracture in HCS and yet those data were available for the full HCS sample. Furthermore, Fried frailty data were only available in the subgroup of the baseline DXA participants who also went on to participate in the East Hertfordshire follow-up study and yet there was clear evidence for social variation in frailty among these HCS participants, as presented in paper 2. In summary, selection bias may have contributed to the absence of evidence for social inequalities in DXA BMD among HCS men and women; however, consideration of the wider literature and the results presented in papers 1 to 3 and appendices 17 and 18, suggests that it is as likely that DXA total femoral BMD is simply not particularly strongly socially patterned.

This thesis has primarily explored cross-sectional associations between markers of socioeconomic position and material deprivation and musculoskeletal ageing. Future research could consider longitudinal associations between socioeconomic position across the lifecourse and changes in markers of musculoskeletal ageing over time e.g. by considering trajectories of grip strength and physical function across the lifecourse.

Unsurprisingly, a “healthy”, or “health-aware” responder bias has previously been described in HCS and was also evident in the response bias analyses presented in section 2.5.1 (Breslow and Day 1987;Coggon et al. 1997). Such response bias would only be a major concern for this thesis if the relationships between markers of socioeconomic position and markers of musculoskeletal ageing differed systematically in men and women who participated fully in HCS and those who did not; this seems unlikely.

Generalisability of results is a concern for all epidemiological studies. HCS participants are local to Hertfordshire and losses have occurred at several stages of follow-up (Figure 5). However, mortality patterns in the Hertfordshire cohort have been shown to be broadly similar to England and Wales as a whole (Syddall et al. 2005b) and the characteristics of HCS participants are broadly similar to those in the nationally representative Health Survey for England (Figure 8 and Figure 9). On this basis, it is suggested that results from HCS can be reasonably generalised to the wider population of older men and women in England.

A further issue of concern for generalisability of results from HCS is that study participants reside in the relatively affluent county of Hertfordshire in South East England. However, a range of socioeconomic circumstances are still evident among HCS participants and indeed in the county of Hertfordshire generally (APHO and Department of Health 2008) and section 2.5.2 of this thesis has demonstrated that the social class distribution of HCS participants is not dramatically different from that of participants in the nationally representative Health Survey for England. As discussed above, even if the extremes of the distribution of socioeconomic position are not evident among HCS participants, nonetheless the analyses presented in this thesis are internal to the HCS sample so no major bias should have been introduced. Moreover, if evidence for social inequality in grip strength and physical function is evident across the comparatively narrow range of social conditions in HCS then how much greater might be the full extent of social inequality in aspects of musculoskeletal ageing if considered across the wider population of England?

Finally, no epidemiological study can exclude the possibility that its findings are due to chance; this thesis is no exception. However, there is no particular reason to suspect that the results presented in this thesis are due to chance and the results are plausible and consistent with the wider relevant literature as described in papers 1 to 3.

6.4 Future research

The work presented in this thesis has many implications for further research on social inequalities in musculoskeletal ageing.

First, studies of social inequalities in health among older people should be careful to ascertain data on markers of socioeconomic position and material deprivation which are relevant to older people. The pattern of results presented in this thesis supports the argument that occupationally based social class is not a good reflection of the social circumstances of older people who are mainly post-retirement, and supports Benzeval's call for an approach that directly considers individuals' material and social resources (Benzeval et al. 1995).

Second, future research on social inequalities in musculoskeletal ageing should ascertain information on a wider panel of markers of socioeconomic circumstances and material deprivation than was available in HCS. Potentially relevant markers of socioeconomic position include characterisation of an individual's income, wealth, receipt of benefits, full educational history and highest educational qualification; information on housing quality and access to amenities both at home and in an individual's residential area would provide additional characterisation of material deprivation. The 1946 NSHD includes extensive data on lifecourse socioeconomic position which together with ascertainment of physical performance among its study participants at age 53 years (Wadsworth et al. 2006), and most recently at age 60-64 years (Kuh et al. 2011), is an important resource for research in to social inequalities in musculoskeletal ageing in the UK (Kuh et al. 2005;Strand et al. 2011a).

Third, future research could explore the relative influence of individual-level and area-level aspects of socioeconomic position and material deprivation on social inequalities in musculoskeletal ageing e.g. by considering area level variables such as the index of multiple deprivation which is assigned to an individual on the basis of their postcode of residence; these data are available for all HCS baseline participants. Murray et al have examined the association between lifecourse area-level indicators of socioeconomic position and physical capability in the 1946 NSHD and cautioned that this is a research area which is not without its methodological challenges (Murray et al. 2012).

Fourth, future research could expand the panel of markers of musculoskeletal ageing which have been explored in this thesis; for example, it might be interesting to examine the evidence for social inequalities in common and disabling musculoskeletal disorders such as osteoarthritis (WHO Scientific Group 2003).

Fifth, high resolution pQCT scanning techniques have recently become available which provide measurements of bone microarchitecture, quality and quantity which are not available from DXA and pQCT bone scans (Amin and Kholsla 2012); future research could investigate whether there is more evidence for a social gradient in these aspects of bone than there was for the fracture, DXA and pQCT based bone variables which have been considered in this thesis.

Sixth, the data available in HCS were insufficient to enable the impact of specific types of physical activity on social inequalities in musculoskeletal ageing to be fully explored; future research should aim to differentiate between the different types of physical activity which are relevant for particular aspects of musculoskeletal ageing e.g. resistance exercise for muscle and load bearing exercise for bone. Further exploration of the cross-sectional and longitudinal relative influences of specific types of physical activity on muscle and bone, and the responses of these tissues to different exercise stimuli, could help to elucidate why this thesis, and indeed the literature, generally supports social inequalities in mobility disability, muscle strength and physical function but not fracture or osteoporosis.

Seventh, this thesis has identified a specific pattern of social inequality in musculoskeletal ageing among the HCS participants with evidence for a social gradient in muscle but not bone. These findings require replication in longitudinal studies which enable inferences about cause and effect to be made with greater confidence than from cross-sectional studies. Replication studies might be possible using resources such as the English Longitudinal Study of Ageing (Dept.of Epidemiology and Public Health 2012) or the latest wave of data collection for the 1946 NSHD which includes measurement of study participants' grip strength, functional capacity, and DXA and pQCT bone parameters at 60 to 64 years of age (Kuh et al. 2011). It might also be possible to explore associations between lifecourse trajectories of socioeconomic circumstances and grip strength and physical function by implementing the HALCyon collaboration's approach to the harmonisation of data across cohort studies (Kuh et al.

2012;MRC Unit for Lifelong Health and Ageing 2012). It should be noted that Mishra et al. have recently developed a structured approach to modelling the effects of binary exposure variables over the lifecourse and that this approach could be useful in helping to identify whether the impact of lifecourse socioeconomic position on musculoskeletal ageing in any given cohort study is consistent with an accumulation, critical period or effect modification hypothesis (Mishra et al. 2009;Murray et al. 2011).

Eighth, the patterns of social inequalities in musculoskeletal ageing presented in this thesis require replication in wider social and ethnic contexts. For example, do the results presented in this thesis apply: to the oldest old community dwelling men and women resident in the UK?; to the very frail older men and women who are resident in nursing homes in the UK?; across the wider spectrum of socioeconomic position and material deprivation which is evident among older people in the whole of the UK?; across wider ethnic contexts within the UK?; to wider ethnic and social contexts internationally?

Ninth, further research could investigate the cellular mechanisms underpinning the social gradient in grip strength as described in this thesis. Although methodologically challenging and time consuming, muscle biopsy studies are feasible and acceptable among older people and have been conducted in HCS (Patel et al. 2011;Patel et al. 2010). Muscle biopsy studies yield data on aspects of muscle including cross sectional fibre area and number and ratio of fast twitch (Type II) to slow twitch (Type I) fibre types. In general, older age is particularly associated with a loss of Type II fast twitch fibres (which are responsible for muscle strength) rather than Type I slow twitch fibres (which are of primary importance for endurance) (Lang et al. 2010); on the basis of the results presented in this thesis, it would therefore be hypothesised that lower socioeconomic position and greater levels of material deprivation may be associated with a lower ratio of fast to slow twitch fibre types.

Tenth, research in to the developmental origins of health and adult disease has shown that muscle strength in later life is associated with lower birth weight or weight at one year (Sayer et al. 2008). A novel area for further research would be to explore whether the deleterious effects of social disadvantage across the lifecourse on muscle based aspects of musculoskeletal ageing are particularly emphasised among individuals of lower birth weight and weight at one year; this research question could be readily explored in the HCS and the 1946 NSHD (MRC Unit for Lifelong Health and Ageing 2012).

Eleventh, the results presented in this thesis contribute to the debate on how best to intervene clinically in order to delay and reduce the loss of muscle mass and function with age (Burton and Sumukadas 2010). The results from this thesis suggest that health behaviour interventions which jointly promote increased levels of physical activity (particularly resistance exercise), consumption of a varied and high quality diet (which provides the nutrients required for muscle), and maintenance of a healthy body weight, may have a beneficial effect on muscle strength in later life. However, it is important to emphasise that the results presented in this thesis are primarily from cross-sectional analyses; evidence for the efficacy of a combined behaviour change intervention programme on muscle strength among older people would be required from a randomised intervention study before an intervention could be considered for use in clinical settings. Moreover, the eventual implementation of any intervention designed to delay and reduce the loss of muscle mass and function with age must be carried out proportionately across the social gradient; if any intervention is universally applied it may well improve muscle strength among older people overall but may also have the unintended consequence of widening social inequalities in muscle strength among older people (Buck and Frosini 2012).

Finally, interventions are needed to tackle social inequalities in health but in general there is little evidence to date that interventions based on the broader social determinants of health (such as access to health and social care services, unemployment and welfare, working conditions, education and transport) have an impact on health inequalities (Bambra et al. 2010). However, systematic reviews suggest that housing based interventions do have some impact on social inequalities in health whether through interventions aimed at improving neighbourhood area characteristics or interventions designed to improve housing warmth and energy efficiency for vulnerable individuals (Bambra et al. 2010;Gibson et al. 2011). Housing tenure is also recognised as a pathway through which housing can act as a social determinant of health given that owning one's home can confer greater feelings of security or prestige and reflect greater long term command of financial resources in comparison with social or private rental of a property; however, there is no evidence from intervention studies for an impact of altered housing tenure on health inequalities (Gibson et al. 2011). Future qualitative and quantitative research could usefully explore the mechanisms through which housing tenure exerts its influence on social inequalities in musculoskeletal ageing.

6.5 Relevance to current health and social care policy

Section 6.5 will place this thesis within its policy context and outline possible implications for current health and social care policy.

6.5.1 Policy context

In the same year that the Marmot review described social inequalities in health in the UK (Marmot 2010), a National Equality Panel report described "the anatomy of economic inequality in the UK" (National Equality Panel 2010). The report considered "economic outcomes" including educational outcomes, employment status, earnings, incomes, wealth (including housing or pension assets) and identified deep-seated and systematic differences in these outcomes according to gender, ethnicity, social class, deprivation and geographical region. The report noted that differences in economic outcomes according to socioeconomic background accumulated across the lifecourse and often transferred between generations; the report called for action on economic, and consequent health, inequalities across the lifecourse.

Recognising the need to tackle stark economic and health inequalities in the UK population, the government's 2010 Equality Act imposed a duty on the public sector such that "an authority, when making strategic decisions, must have due regard to the desirability of exercising them in a way that is designed to reduce the inequalities of outcome which result from socioeconomic disadvantage" (HM Government 2010). In plain terms, this means that all government departments (not just the Department of Health) and key public bodies must act with due consideration of the implications of their decisions for social inequalities in both economic and health outcomes; this government wide responsibility to tackle social inequalities is consistent with Marmot's argument that the social gradient in health will only be reduced by government wide action in conjunction with the involvement of private and third sector organisations (Marmot 2010).

The 2012 Health and Social Care Act has formalised the duty of the health and social care system to address social inequalities in health (HM Government 2012b). From 2013, health and social care services will be commissioned by a central NHS Commissioning Board (NHSCB) in conjunction with local Clinical Commissioning Groups (CCG's). The newly created CCG's will be led by local GP's, other clinicians and managers and will control 60% of the NHS budget; reduction of social inequalities in health is stated in the Health and Social Care act as an explicit duty of the NHSCB and the CCG's. Locally based CCG's should have the capability to commission the health and social care services most needed by their local populations and therefore have the potential to act to narrow social inequalities in health if they act to address health problems in the populations they serve in proportion to the frequency with which such problems arise.

The 2012 Health and Social Care act also addresses health inequalities by strengthening the public health system. Public Health England will be established at the national level but power to address health and health inequalities will also be shifted to local authorities and communities. Public Health England will have overall responsibility for implementation of the government's "Healthy Lives, Healthy People" 2010 public health strategy (Department of Health 2010). This strategy commits to "improve the health of the poorest, fastest", in the light of Marmot's "Fair society, healthy lives" report on social inequalities in health (Marmot 2010) and advocates a lifecourse framework for achieving this. "Healthy Lives, Healthy People" emphasises that efforts to improve public health, effect healthy behaviour changes, and to reduce health inequalities need to be integrated; this integration has been lacking in the past (Buck and Frosini 2012).

The "Healthy Lives, Healthy People" public health strategy emphasised that it is a public health priority to enable older people to remain healthy and independent in their own homes for as long as they wish. Explicit aspirations relevant to older people were as follows: promote health and wellbeing across the lifecourse and aim to prevent, or at least delay, the onset of ill health; promote active ageing and tackle health inequalities; integrate public health with health and social care, transport, leisure facilities and housing services so that older people can remain independent and socially connected with their communities. Emphasis on the importance of active ageing within the government's public health strategy is consistent with the 2001 National Service Framework (NSF) for Older People (Department of Health 2001). The overarching objective of this framework was to extend healthy life expectancy and to improve the experience of older people using health and social care services; explicit aims were to provide quality and dignity in care, joined up care and to promote healthy ageing with an emphasis on the role of health and social care in the promotion of greater physical fitness and reductions in obesity among older people. The "Healthy Lives, Healthy People" white paper also advocated abolition of the default retirement age (DRA) so that older people could choose to work longer if they wished and thereby continue to reap the financial, health and social benefits of work; the government has already acted on this recommendation and as of 1st October 2011, individuals have the choice of when to retire and cannot be compelled by their employer to retire at age 65 years (Department for Business Innovation and Skills 2011).

The final policy area which will be addressed in this section is reform of care and support for adults. Social care supports people who cannot manage the everyday activities of daily living and aims to enable them to take an active part in life. The Dilnot Commission on Funding of Care and Support (Commission on Funding of Care and Support 2011) concluded that the current system of funding and provision of adult social care is confusing, unfair and unsustainable set against the context of an ageing UK population. Dilnot recognised that the current care and support system does not allow individuals and their families to plan for care costs; the commission recommended a lifetime cap on self-funded care costs of £35,000 in conjunction with a raise in the means tested threshold for assistance with the costs of social care from £23,500 to £100,000. The government accepted the recommendations of the Dilnot report in principle in its 2012 white paper “Caring for our future: reforming care and support” but delayed decision on funding of Dilnot’s proposals to the next comprehensive spending review (Department of Health 2012a). Age UK’s response to the white paper emphasised that without commitment of funding and a clear timetable for action it is unclear whether the white paper will actually translate into the fairer, more straightforward and affordable care system which is so needed by older people and their families (Age UK 2012).

6.5.2 Implications of this thesis for current health and social care policy

To recap, this thesis has examined the evidence for social inequalities in musculoskeletal ageing among the community dwelling men and women who participated in the Hertfordshire Cohort Study and has presented evidence for social inequalities in grip strength, physical function and frailty among men and women but has not identified convincing evidence for social inequalities in osteoporosis and fracture; three explanations can be advanced for the specific nature of these results. Firstly, height and weight follow divergent social gradients such that shorter stature and increased fat mass arise with greater frequency among socially disadvantaged individuals; this would be to the detriment of muscle strength whilst affording some protection for bone. Secondly, ageing skeletal muscle remains highly responsive to variations in physical activity in a way that ageing bone does not. Thirdly, socioeconomic disadvantage is associated with poor dietary variety and quality and diets which are unlikely to provide sufficient intakes of the protein, vitamins and antioxidant nutrients which are crucial for muscle mass and strength; however, such diets may provide sufficient intakes of the key nutrients required for bone owing to wide availability of calcium rich milk and dairy products. If replicated in other studies, the results presented in this thesis have several potential implications for health and social care policy.

First, the Marmot review recommended in broad terms that “the impact of health inequalities on an ageing population with increased incidence of disability and life-long illness holds significance for future strategies and policies” (Marmot 2010). The results presented in this thesis suggest that any such future strategies and policies should be relevant to older people and to the muscle based aspects of musculoskeletal ageing which commonly affect them such as loss of muscle strength, loss of physical function and physical frailty.

Second, this thesis has demonstrated that social inequalities in grip strength are evident across the normal range of grip strength among healthy, community dwelling older men and women and well before grip strength has declined to levels which would be indicative of disability; this raises the possibility that policies designed to reduce social inequalities in mobility disability and disability free life expectancy should consider the contribution of social variation in muscle strength to these inequalities.

Third, the results from this thesis suggest that lifecourse initiatives designed to promote healthy and active ageing, and to prevent loss of muscle strength and loss of physical function with age, should be targeted proportionately across the social gradient with the twin objectives of improving muscle strength and physical function for all in later life, while also aiming to narrow the social gradient in these musculoskeletal disorders.

Fourth, any such interventions to prevent loss of muscle mass and function with age may do well to take a combined approach to modification of the health behaviours which may be inferred as being most important for muscle strength on the basis of the pattern of results presented in this thesis i.e. a combined approach which promotes maintenance of a healthy body weight, increased physical activity (particularly resistance exercise) and consumption of a varied, high quality diet which provides the vitamins and minerals required for muscle strength and function.

Fifth, consistent with the wider literature on social inequalities in osteoporosis and fracture, this thesis suggests that intervention strategies to reduce fracture and osteoporosis should continue to have a universal population focus.

Sixth, the results presented in this thesis suggest that the burden of poor muscle strength and physical function in later life is likely to be focused among a materially disadvantaged subgroup of older men and women; this has relevance for bodies such as the new CCG’s who will be responsible for commissioning health and social care services which are relevant to the local populations that they serve.

Finally, the results of this thesis suggest that there exists a socioeconomically disadvantaged subgroup of older men and women in the UK who face the multiple and contradictory jeopardy of low income and a lack of accrued lifetime personal wealth, combined with greater loss of muscle strength and physical function with older age. This loss of muscle strength and physical function in turn reduces the likelihood of individuals being able to extend their working life in order to secure the income which might have been sufficient to enable them to have maintained their standard of living and financed an appropriate level of care and support for their needs. Older men and women who are socioeconomically disadvantaged urgently need the government to commit to adopt Dilnot's recommendations on the funding of adult care and support.

Chapter 7. Conclusions

A healthy musculoskeletal system is essential for independent and active ageing; however, musculoskeletal disorders are the most frequent cause of physical disability in the developed world and are prevalent among older people. The UK population is ageing; the already substantial burden of musculoskeletal disorders on health and social care systems will only increase over time as the population ages.

Social inequalities in health are well documented for the UK in general but little is known about social inequalities in musculoskeletal ageing. This thesis has therefore explored social inequalities in a panel of musculoskeletal ageing phenotypes among the 3,225 'young-old' community dwelling men and women who participated in the Hertfordshire Cohort Study.

Paper 1 showed that having fewer cars available for household use was associated with lower grip strength and poorer PF among men and women, and increased falls among men. Not owner-occupying one's home was associated with lower grip strength in men and women and poorer PF in men. All associations were robust to adjustment for adult lifestyle and the range of co-morbidity data available in HCS.

Paper 2 demonstrated that Fried frailty is not uncommon even among community dwelling 'young-old' men and women and identified social inequalities in frailty (across age of leaving full-time education, current home ownership and car availability) which were largely mediated by co-morbidity.

Paper 3 found little strong or consistent evidence among men, or women, for social inequalities in prevalent or incident fracture, DXA bone mineral density, bone loss rates, or pQCT bone strength, with or without adjustment for age, anthropometry, lifestyle and clinical characteristics.

Overall, the three papers presented in this thesis suggest that muscle strength and physical function among community dwelling older men and women in the UK are strongly socially patterned across markers of current material deprivation (housing tenure and car availability) but there is no convincing evidence for a social gradient in fracture or bone mineral density across the range of social circumstances which are evident among the HCS participants.

Three explanations can be advanced for the specific nature of the patterns of social inequalities in grip strength and total femoral BMD which have been presented in this thesis. Firstly, height and weight follow divergent social gradients such that shorter stature and increased fat mass arise with greater frequency among socially disadvantaged individuals; this would be to the detriment of muscle strength whilst affording some protection for bone. Secondly, ageing skeletal muscle remains highly responsive to variations in physical activity in a way that ageing bone does not. Thirdly, socioeconomic disadvantage is associated with poor dietary variety and quality and diets which are unlikely to provide sufficient intakes of the protein, vitamins and antioxidant nutrients which are crucial for muscle mass and strength; however, such diets may provide sufficient intakes of the key nutrients required for bone owing to wide availability of calcium rich milk and dairy products. Variations in smoking habit and alcohol intake seem unlikely to have played an important role in the results presented in this thesis.

This thesis has many implications for further research. Future studies of social inequalities in musculoskeletal ageing should: be careful to ascertain data on a wide range of markers of socioeconomic position and material deprivation which are directly relevant to older people; examine the evidence for social inequalities in an even wider panel of musculoskeletal ageing phenotypes than have been considered in this thesis e.g. by considering osteoarthritis; collect data which enable the impact of lifecourse customary and occupational physical activity on social inequalities in musculoskeletal ageing to be fully explored and dissected; ideally collect longitudinal data which enable inferences about cause and effect to be made with greater confidence than from cross-sectional studies and which enable e.g. investigation of social inequalities in trajectories of grip strength across the lifecourse according to socioeconomic position and material deprivation throughout life; explore the evidence for social inequalities in musculoskeletal ageing in wider social and ethnic contexts than considered in this thesis; examine the cellular mechanisms underpinning social inequalities in muscle strength; and attempt to explore the mechanisms through which housing tenure exerts its influence on social inequalities in musculoskeletal ageing.

This thesis also informs development of clinical interventions which aim to delay and reduce the loss of muscle mass and function with age; health behaviour interventions which jointly promote increased levels of physical activity (particularly resistance exercise), consumption of a varied and high quality diet (which provides the nutrients required for muscle), and maintenance of a healthy body weight, may have a beneficial effect on muscle strength in later life. However, any such interventions should be targeted proportionately across the social gradient with the twin objectives of improving muscle strength and physical function for all older people, while also aiming to narrow the social gradient in these musculoskeletal disorders.

This thesis also has implications for many aspects of health and social care policy. First, strategies to reduce health inequalities should be relevant to older people and to the muscle based aspects of musculoskeletal ageing which commonly affect them. Second, policies designed to reduce social inequalities in mobility disability and disability free life expectancy should consider the contribution of social variation in muscle strength to these inequalities. Third, initiatives designed to prevent loss of muscle strength and loss of physical function with age should be targeted proportionately across the social gradient whilst intervention strategies to reduce fracture and osteoporosis should continue to have a universal population focus. Fourth, the burden of poor muscle strength and physical function in later life appears to be focused among materially disadvantaged older men and women which has relevance for commissioning of health and social care services. Finally, this thesis suggests that there exists a socioeconomically disadvantaged subgroup of older men and women in the UK who face the multiple jeopardy of low income and a lack of accrued lifetime personal wealth, combined with greater loss of muscle strength and physical function with older age; these men and women urgently need the government to commit to adopt Dilnot’s recommendations on the funding of adult care and support.

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Appendix 1. Mutually adjusted associations between socioeconomic position and material deprivation and housing tenure and car availability among HCS participants

Mutually adjusted associations between socioeconomic position and car availability and not owner-occupying one's home

Odds ratio (95%CI)	**Men (n=1528)**		**Women (n=1441)**	
Social class at birth	1.22	(1.06,1.41)	1.15	(1.00,1.32)
per lower band	*p*	*0.005*	*p*	*0.06*
Age left full-time education	0.80	(0.68,0.94)	0.77	(0.66,0.89)
per year older	*p*	*0.008*	*p*	*0.001*
Social class in adulthood	1.58	(1.39,1.80)	1.54	(1.36,1.74)
per lower band	*p*	*<0.001*	*p*	*<0.001*
Number of cars available	0.39	(0.31,0.50)	0.34	(0.27,0.42)
per extra car	*p*	*<0.001*	*p*	*<0.001*

Mutually adjusted associations between socioeconomic position and housing tenure and having two or more cars available for household use

Odds ratio (95%CI)	**Men (n=1528)**		**Women (n=1441)**	
Social class at birth	0.86	(0.78,0.96)	0.97	(0.86,1.09)
per lower band	*p*	*0.005*	*p*	*0.61*
Age left full-time education	1.12	(1.03,1.22)	1.07	(0.98,1.18)
per year older	*p*	*0.008*	*p*	*0.13*
Social class in adulthood	0.89	(0.81,0.97)	0.82	(0.74,0.92)
per lower band	*p*	*0.01*	*p*	*<0.001*
Housing tenure	0.30	(0.21,0.42)	0.38	(0.26,0.56)
not owning/mortgaging home	*p*	*<0.001*	*p*	*<0.001*

Appendix 2. Inter-relationships between musculoskeletal ageing phenotypes among HCS men

Inter-relationships between continuously distributed musculoskeletal ageing phenotypes: HCS men

Correlation (95%CI)	**Grip Strength**	**DXA Total Femoral BMD**	**Change in DXA Tot Fem BMD**	**pQCT Tibia SSI**
DXA Total Femoral BMD	0.09 (-0.00,0.17) *p=0.05, n=495*			
Change in DXA Tot Fem BMD	-0.02 (-0.13,0.10) *p=0.78, n=276*	-0.05 (-0.18,0.07) *p=0.37, n=276*		
pQCT Tibia SSI	0.17 (0.07,0.28) *p=0.001, n=304*	0.16 (0.05,0.27) *p=0.004, n=304*	0.06 (-0.06,0.18) *p=0.35, n=261*	
pQCT Radius SSI	0.26 (0.15,0.36) *p<0.001, n=295*	0.37 (0.26,0.47) *p<0.001, n=295*	-0.09 (-0.20,0.03) *p=0.13, n=254*	0.31 (0.20,0.42) *p<0.001, n=286*

Measures of association are simple, unadjusted Pearson correlation coefficients with 95% confidence intervals.
Analyses were based on the maximum available sample size for each pairwise comparison.

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Inter-relationships between binary musculoskeletal ageing phenotypes: HCS men *continued*

Odds ratio (95%CI)	**Poor SF-36 Physical Function**	**History of falls in past year**	**Fracture since 45 years of age**	**Fried Frailty**
History of falls in past year	2.14 (1.47,3.14) *p<0.001, n=940*			
Fracture since 45 years of age	1.43 (1.05,1.96) *p=0.02, n=1682*	1.37 (0.84,2.23) *p=0.20, n=941*		
Fried frailty	12.43 (3.85,40.12) *p<0.001, n=320*	1.00 (1.00,1.00) *insufficient data*	0.49 (0.06,3.82) *p=0.49, n=320*	
New fracture	1.21 (0.57,2.55) *p=0.62, n=1092*	0.88 (0.25,3.01) *p=0.83, n=625*	2.80 (1.44,5.47) *p=0.002, n=1093*	2.41 (0.28,20.87) *p=0.43, n=276*

Measures of association are unadjusted odds ratios with 95% confidence intervals.
Analyses were based on the maximum available sample size for each pairwise comparison.
Insufficient numbers of men had data available on both falls history and frailty owing to the phasing of the falls question and recruitment of participants for the East Hertfordshire follow-up study.

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Inter-relationships between continuously distributed and binary musculoskeletal ageing phenotypes: HCS men *continued*

Difference (95%CI)	**Grip Strength**	**DXA Total Femoral BMD**	**Change in DXA Tot Fem BMD**	**pQCT Tibia SSI**	**pQCT Radius SSI**
Poor SF-36 physical function	-0.40 (-0.53,-0.28) *p<0.001, n=1571*	-0.11 (-0.36,0.13) *p=0.36, n=495*	-0.20 (-0.54,0.15) *p=0.26, n=276*	0.12 (-0.21,0.44) *p=0.48, n=304*	-0.18 (-0.53,0.18) *p=0.33, n=295*
History of falls in past year	-0.33 (-0.53,-0.14) *p=0.001, n=864*	*insufficient data*	*insufficient data*	*insufficient data*	*insufficient data*
Fracture since 45 years of age	0.02 (-0.12,0.17) *p=0.75, n=1572*	-0.25 (-0.51,0.01) *p=0.06, n=495*	0.16 (-0.17,0.49) *p=0.35, n=276*	-0.16 (-0.48,0.15) *p=0.31, n=304*	-0.17 (-0.49,0.15) *p=0.30, n=295*
Fried frailty	-0.70 (-1.22,-0.17) *p=0.009, n=320*	0.02 (-0.54,0.57) *p=0.96, n=320*	-0.93 (-1.50,-0.36) *p=0.002, n=275*	-0.22 (-0.80,0.36) *p=0.46, n=302*	-0.33 (-1.00,0.34) *p=0.33, n=294*
New fracture	-0.30 (-0.59,-0.01) *p=0.05, n=1088*	-0.68 (-1.14,-0.21) *p=0.004, n=346*	0.33 (-0.16,0.83) *p=0.19, n=242*	-0.22 (-0.79,0.34) *p=0.43, n=264*	-0.11 (-0.65,0.43) *p=0.69, n=260*

Measures of association are average differences (with 95% confidence intervals) in standard deviation units of each continuous musculoskeletal phenotype (columns of the table) according to presence versus absence of each binary musculoskeletal phenotype (rows of the table).
Analyses were based on the maximum available sample size for each pairwise comparison.
Insufficient numbers of men had data available on both falls history and DXA and pQCT measures of bone owing to the phasing of the falls question and recruitment of participants for the HCS baseline DXA scan and East Hertfordshire follow-up study.

Appendix 3. Inter-relationships between musculoskeletal ageing phenotypes among HCS women

Inter-relationships between continuously distributed musculoskeletal ageing phenotypes: HCS women

Correlation (95%CI)	**Grip Strength**	**DXA Total Femoral BMD**	**Change in DXA Tot Fem BMD**	**pQCT Tibia SSI**
DXA Total Femoral BMD	0.09 (0.01,0.17) *p=0.03, n=467*			
Change in DXA Tot Fem BMD	0.02 (-0.08,0.12) *p=0.70, n=289*	-0.16 (-0.27,-0.05) *p=0.004, n=289*		
pQCT Tibia SSI	0.20 (0.10,0.30) *p<0.001, n=316*	0.33 (0.22,0.44) *p<0.001, n=315*	-0.09 (-0.21,0.03) *p=0.13, n=286*	
pQCT Radius SSI	0.16 (0.06,0.26) *p=0.003, n=298*	0.31 (0.21,0.42) *p<0.001, n=297*	-0.14 (-0.26,-0.02) *p=0.02, n=271*	0.46 (0.36,0.56) *p<0.001, n=296*

Measures of association are simple, unadjusted Pearson correlation coefficients with 95% confidence intervals.
Analyses were based on the maximum available sample size for each pairwise comparison.

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Inter-relationships between binary musculoskeletal ageing phenotypes: HCS women *continued*

Odds ratio (95%CI)	**Poor SF-36 Physical Function**	**History of falls in past year**	**Fracture since 45 years of age**	**Fried Frailty**
History of falls in past year	1.66 (1.26,2.20) *p<0.001, n=1397*			
Fracture since 45 years of age	1.12 (0.84,1.49) *p=0.44, n=1539*	1.60 (1.20,2.13) *p=0.001, n=1397*		
Fried frailty	15.28 (6.37,36.65) *p<0.001, n=318*	1.21 (0.42,3.46) *p=0.72, n=242*	1.10 (0.40,3.03) *p=0.86, n=318*	
New fracture	1.18 (0.72,1.92) *p=0.51, n=1049*	2.02 (1.31,3.13) *p=0.002, n=950*	3.55 (2.37,5.33) *p<0.001, n=1049*	1.11 (0.31,3.96) *p=0.88, n=266*

Measures of association are unadjusted odds ratios with 95% confidence intervals.
Analyses were based on the maximum available sample size for each pairwise comparison.

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Inter-relationships between continuously distributed and binary musculoskeletal ageing phenotypes: HCS women *continued*

Difference (95%CI)	**Grip Strength**	**DXA Total Femoral BMD**	**Change in DXA Tot Fem BMD**	**pQCT Tibia SSI**	**pQCT Radius SSI**
Poor SF-36 physical function	-0.68 (-0.81,-0.56) *p<0.001, n=1415*	0.14 (-0.13,0.41) *p=0.32, n=467*	0.11 (-0.27,0.48) *p=0.58, n=289*	-0.13 (-0.47,0.22) *p=0.47, n=316*	-0.06 (-0.44,0.32) *p=0.76, n=298*
History of falls in past year	-0.17 (-0.31,-0.04) *p=0.01, n=1279*	-0.01 (-0.26,0.23) *p=0.91, n=368*	0.19 (-0.15,0.52) *p=0.27, n=220*	0.01 (-0.30,0.33) *p=0.93, n=241*	0.20 (-0.12,0.51) *p=0.23, n=228*
Fracture since 45 years of age	-0.14 (-0.26,-0.01) *p=0.04, n=1414*	-0.47 (-0.72,-0.23) *p<0.001, n=467*	0.09 (-0.21,0.39) *p=0.55, n=289*	-0.41 (-0.70,-0.12) *p=0.006, n=316*	-0.17 (-0.47,0.13) *p=0.27, n=298*
Fried frailty	-0.91 (-1.25,-0.56) *p<0.001, n=318*	0.36 (-0.04,0.76) *p=0.08, n=317*	-0.03 (-0.45,0.38) *p=0.87, n=288*	-0.17 (-0.56,0.23) *p=0.41, n=315*	-0.19 (-0.63,0.24) *p=0.38, n=297*
New fracture	-0.26 (-0.45,-0.07) *p=0.01, n=1046*	-0.64 (-0.97,-0.31) *p<0.001, n=354*	0.16 (-0.23,0.55) *p=0.42, n=251*	-0.42 (-0.78,-0.06) *p=0.02, n=264*	-0.25 (-0.62,0.12) *p=0.19, n=249*

Measures of association are average differences (with 95% confidence intervals) in standard deviation units of each continuous musculoskeletal phenotype (columns of the table) according to presence versus absence of each binary musculoskeletal phenotype (rows of the table).
Analyses were based on the maximum available sample size for each pairwise comparison.

Appendix 4. Appendix for paper 2

The following detailed methodology section for paper 2 was published on the Age and Ageing website. This appendix also presents the mutually and co-morbidity adjusted results which are described in the results section of paper 2.

Methodology

In the late 1990s, 3225 men and women aged 59–72 years were recruited to the Hertfordshire Cohort Study (HCS) which has been described in detail previously (Syddall et al. 2005a). In brief, the HCS participants participated in a baseline study which included a home interview at which trained nurses collected information on medical and social history. The latter included: age left full-time education; own current or most recent full-time occupation; husband's current or most recent full-time occupation for ever married women; and housing tenure (three categories: owned/mortgaged; rented; other) and car availability for the household (three categories: none; one; two; three or more) as markers of material deprivation. Men and women who were willing, subsequently attended a clinic for a number of investigations including a 2 hour fasted oral glucose tolerance test, measurement of blood pressure, an electrocardiogram (ECG) and a clinical examination for hand osteoarthritis. A subgroup of 498 men and 468 women who were resident in East Hertfordshire also underwent dual-energy x-ray absorptiometry (DXA) scans for assessment of bone mineral content and density.

Study group

In 2004-5, a follow-up study was performed in East Hertfordshire. The family doctors of participants in the baseline survey were contacted to ask if their patients could be approached again. Of the original 498 men and 468 women who had undergone a DXA scan, 8 had died, 6 had moved away, GP permission could not be obtained to approach 4 people, 47 were no longer on family doctor lists, and 17 were unavailable. Hence, 437 men and 447 women were invited to take part in the follow-up study. Of these, 322 men (74%) and 320 women (72%) agreed to attend a follow-up clinic.

At the follow-up clinic visit, medical and social histories were updated. Information was collected on frailty status using the Fried criteria(Fried et al. 2001). Self-assessed health related quality of life was ascertained using the short-form 36 (SF-36) questionnaire. Hand grip strength was measured three times on each side using a Jamar handgrip dynamometer and participants completed a timed 3 metre walk. Intra- and inter-observer studies were carried out during the fieldwork to standardise measurement technique. The baseline and follow-up studies had ethical approval from the Hertfordshire and Bedfordshire Local Research Ethics Committee and all participants gave written informed consent.

Derived measures

Registrar General's social class was coded from the 1990 OPCS Standard Occupational Classification unit group for occupation using computer assisted standard occupational coding. Current social class was identified on the basis of own current or most recent full-time occupation for men and never-married women, and from the husband's occupation for ever-married women (Arber and Ginn 1993).

Appendix 4 continued

Mutually and co-morbidity adjusted associations between frailty and the lifestyle and social characteristics of HCS participants

Odds ratios (95%CI) for Fried frailty	MEN		WOMEN	
	Mutually adjusted	Co-morbidity* adjusted	Mutually adjusted	Co-morbidity* adjusted
Age	1.27 (0.96,1.69) *p=0.10*	1.38 (0.90,2.11) *p=0.14*		
Alcohol intake			0.72 (0.48,1.06) *p=0.10*	0.72 (0.48,1.10) *p=0.13*
Age left full-time education	0.83 (0.43,1.61) *p=0.58*	0.84 (0.33,2.16) *p=0.72*		
Housing tenure	2.24 (0.61,8.23) *p=0.23*	1.56 (0.25,9.79) *p=0.64*	2.47 (1.01,6.03) *p=0.05*	1.88 (0.70,4.99) *p=0.21*
Number of cars available	0.35 (0.11,1.04) *p=0.06*	0.16 (0.03,0.82) *p=0.03*		

Odds ratios (95%CI) and p-values estimated from mutually adjusted logistic regression models per: increased year of age; increased band of alcohol intake (categorised as in paper 2 from non-drinkers through to individuals with high weekly intakes of alcohol); per year older when left full-time education; per extra car available to the household, and for those who did not own/mortgage their home in comparison with those who did. Lifestyle and social characteristics were included in the mutually adjusted models if they were significantly associated ($p<0.05$) with frailty in the univariate analyses presented in the results section of paper 2.

*Co-morbidity adjusted models were estimated as per the mutually adjusted models with additional adjustment for ischaemic heart disease, stroke/TIA, and high blood pressure for men and ischaemic heart disease, high blood pressure and diabetes for women (see the results section of paper 2 for justification of the co-morbidities included in these models).

Appendix 5. Associations between socioeconomic position and material deprivation and height (cm) among HCS men and women

	MEN				WOMEN			
			Regression				Regression	
	Mean	SD	Coefficient (95%CI)		Mean	SD	Coefficient (95%CI)	
Social class at birth								
I	169.3	8.0	-0.89	(-3.85,2.06)	162.4	5.3	1.57	(-1.93,5.07)
II	168.2	9.6	1.38	(0.05,2.70)	161.2	6.2	0.37	(-0.81,1.54)
IIINM	169.3	9.2	1.01	(-0.29,2.31)	162.3	6.5	1.50	(0.24,2.77)
IIIM	167.6	9.0	Reference		160.8	5.6	Reference	
IV	167.5	9.2	-0.54	(-1.34,0.25)	160.4	6.1	-0.38	(-1.14,0.38)
V	168.3	8.7	-1.09	(-2.17,0.00)	160.6	5.8	-0.26	(-1.45,0.93)
			p	*0.001*			*p*	*0.03*
			*p**	*0.12*			*p**	*0.22*
Age left full-time education								
<=14 years	167.3	8.9	-1.76	(-2.56,-0.96)	160.4	6.3	-0.51	(-1.32,0.30)
>=15 years	168.0	9.1	Reference		160.9	5.8	Reference	
			p	*<0.001*			*p*	*0.005*
			*p**	*0.01*			*p**	*0.17*
Social class in adulthood								
I	169.0	9.5	1.67	(0.32,3.03)	160.9	6.0	0.27	(-1.10,1.65)
II	168.5	8.7	0.94	(0.09,1.78)	161.7	5.0	1.11	(0.30,1.92)
IIINM	167.8	9.6	2.09	(0.96,3.21)	161.2	5.0	0.55	(-0.42,1.53)
IIIM	167.5	9.0	Reference		160.6	6.0	Reference	
IV	166.7	9.3	-0.65	(-1.60,0.30)	159.9	5.0	-0.71	(-1.61,0.18)
V	167.3	8.8	0.20	(-1.61,2.01)	160.0	5.0	-0.66	(-2.40,1.09)
			p	*<0.001*			*p*	*<0.001*
			*p**	*0.07*			*p**	*0.05*
Housing tenure								
Owned/mortgaged	168.3	9.1	Reference		161.0	5.8	Reference	
Rented/other	166.2	8.8	-1.91	(-2.73,-1.10)	160.2	6.0	-0.88	(-1.61,-0.14)
			p	*<0.001*			*p*	*0.02*
			*p**	*<0.001*			*p**	*0.68*
Number of cars available								
None	163.5	8.6	-1.08	(-2.43,0.28)	159.6	5.9	-1.41	(-2.25,-0.56)
1	167.5	9.0	Reference		161.0	6.0	Reference	
2	169.6	8.7	0.51	(-0.20,1.21)	161.4	5.1	0.45	(-0.31,1.21)
3 or more	170.6	9.3	0.45	(-0.82,1.71)	160.3	7.3	-0.72	(-2.53,1.10)
			p	*0.04*			*p*	*0.004*
			*p**	*0.58*			*p**	*0.13*

p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 6. Associations between socioeconomic position and material deprivation and weight (kg) among HCS men and women

	MEN				WOMEN			
			Regression				Regression	
	Mean	SD	Coefficient (95%CI)		Mean	SD	Coefficient (95%CI)	
Social class at birth								
I	83.9	11.0	1.38	(-4.42,7.17)	68.2	7.6	-2.93	(-10.86,5.00)
II	84.0	13.6	1.46	(-1.14,4.07)	70.1	13.5	-0.97	(-3.64,1.70)
IIINM	81.5	11.8	-1.06	(-3.61,1.50)	70.0	13.3	-1.13	(-4.00,1.74)
IIIM	82.6	12.8	Reference		71.1	12.9	Reference	
IV	82.2	12.6	-0.36	(-1.92,1.20)	71.6	13.6	0.52	(-1.20,2.24)
V	81.6	12.4	-1	(-3.14,1.13)	73.9	14.6	2.74	(0.04,5.44)
			p	*0.18*			*p*	*0.02*
			*p**	*0.22*			*p**	*0.14*
Age left full-time education								
<=14 years	81.8	12.5	-0.82	(-2.40,0.77)	72.3	13.5	1.01	(-0.85,2.87)
>=15 years	82.6	12.7	Reference		71.3	13.4	Reference	
			p	*0.54*			*p*	*0.03*
			*p**	*0.21*			*p**	*0.67*
Social class in adulthood								
I	80.8	11.2	-1.47	(-4.12,1.19)	70.5	14.7	-1.12	(-4.26,2.01)
II	82.9	12.7	0.65	(-1.01,2.30)	69.8	12.2	-1.81	(-3.66,0.03)
IIINM	83.5	12.7	1.26	(-0.96,3.48)	70.8	14.3	-0.82	(-3.04,1.39)
IIIM	82.2	12.1	Reference		71.6	13.3	Reference	
IV	82.1	14.0	-0.09	(-1.95,1.77)	73.9	13.5	2.29	(0.25,4.34)
V	82.2	14.0	0.02	(-3.53,3.57)	73.6	15.0	2.02	(-1.96,6.01)
			p	*0.88*			*p*	*<0.001*
			*p**	*0.93*			*p**	*0.32*
Housing tenure								
Owned/mortgaged	82.6	12.5	Reference		70.5	13.0	Reference	
Rented/other	81.6	13.5	-0.97	(-2.58,0.63)	74.6	14.3	4.01	(2.34,5.69)
			p	*0.23*			*p*	*<0.001*
			*p**	*0.06*			*p**	*0.001*
Number of cars available								
None	80.2	12.7	-2.46	(-5.11,0.20)	73.3	14.0	1.46	(-0.46,3.39)
1	82.6	13.2	Reference		71.9	13.5	Reference	
2	82.2	11.6	-0.37	(-1.76,1.01)	69.2	12.8	-2.68	(-4.42,-0.94)
3 or more	83.9	13.3	1.24	(-1.24,3.72)	68.8	10.6	-3.04	(-7.19,1.11)
			p	*0.21*			*p*	*<0.001*
			*p**	*0.47*			*p**	*0.02*

p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home
and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 7. Associations between socioeconomic position and material deprivation and weight for height (standard deviation score) among HCS men and women

	MEN				WOMEN			
			Regression				Regression	
	Mean	SD	Coefficient (95%CI)		Mean	SD	Coefficient (95%CI)	
Social class at birth								
I	0.2	1.2	0.22	(-0.24,0.67)	-0.3	0.5	-0.27	(-0.86,0.32)
II	0.0	1.1	0.02	(-0.19,0.22)	-0.1	1.0	-0.10	(-0.30,0.09)
IIINM	-0.2	0.9	-0.16	(-0.36,0.04)	-0.2	1.0	-0.19	(-0.40,0.03)
IIIM	0.0	1.0	Reference		0.0	1.0	Reference	
IV	0.0	1.0	0.01	(-0.11,0.14)	0.0	1.0	0.07	(-0.06,0.20)
V	0.0	1.1	0	(-0.17,0.17)	0.2	1.1	0.22	(0.02,0.42)
			p	*0.85*			*p*	*0.001*
			*p**	*0.63*			*p**	*0.05*
Age left full-time education								
<=14 years	0.0	1.0	0.06	(-0.06,0.19)	0.1	1.0	0.11	(-0.03,0.24)
>=15 years	0.0	1.0	Reference		0.0	1.0	Reference	
			p	*0.001*			*p*	*0.001*
			*p**	*0.01*			*p**	*0.4*
Social class in adulthood								
I	-0.2	0.9	-0.25	(-0.46,-0.04)	-0.1	1.0	-0.12	(-0.36,0.11)
II	0.0	1.0	-0.02	(-0.15,0.11)	-0.2	0.9	-0.20	(-0.33,-0.06)
IIINM	0.0	1.0	-0.05	(-0.23,0.12)	-0.1	1.1	-0.12	(-0.28,0.05)
IIIM	0.0	0.9	Reference		0.0	1.0	Reference	
IV	0.0	1.1	0.02	(-0.13,0.16)	0.3	0.9	0.23	(0.08,0.38)
V	0.0	1.2	-0.03	(-0.31,0.25)	0.2	1.1	0.19	(-0.11,0.48)
			p	*0.11*			*p*	*<0.001*
			*p**	*0.41*			*p**	*0.06*
Housing tenure								
Owned/mortgaged	0.0	1.0	Reference		-0.1	1.0	Reference	
Rented/other	0.0	1.1	0.04	(-0.08,0.17)	0.3	1.0	0.37	(0.25,0.50)
			p	*0.51*			*p*	*<0.001*
			*p**	*0.64*			*p**	*<0.001*
Number of cars available								
None	-0.1	1.1	-0.14	(-0.35,0.07)	0.2	1.0	0.21	(0.07,0.35)
1	0.0	1.0	Reference		0.0	1.0	Reference	
2	0.0	0.9	-0.05	(-0.16,0.05)	-0.2	1.0	-0.24	(-0.37,-0.11)
3 or more	0.1	1.1	0.08	(-0.11,0.28)	-0.2	0.9	-0.18	(-0.48,0.13)
			p	*0.53*			*p*	*<0.001*
			*p**	*0.2*			*p**	*0.003*

p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 8. Associations between grip strength and anthropometry, walking speed, oily fish consumption, smoking and alcohol

		MEN : Mean (SD) grip strength (kg)	**MEN:** Regression Coefficient (95%CI)		**MEN** *p*	**MEN** *p**	**WOMEN:**Mean (SD) grip strength (kg)	**WOMEN:** Regression Coefficient (95%CI)		**WOMEN** *p*	**WOMEN** *p**
Height (SDS)		0.40**	3.02	(2.68,3.36)	*0.000*	*0.000*	0.28**	1.60	(1.31,1.89)	*0.000*	*0.000*
Weight for height (SDS)		0.07**	0.54	(0.17,0.91)	*0.004*	*0.000*	-0.02**	-0.12	(-0.42,0.18)	*0.44*	*0.001*
Self	Very slow	39.2 (9.1)	-4.92	(-6.68,-3.17)			21.4 (7.3)	-5.57	(-6.75,-4.40)		
Reported	Stroll at easy pace	42.8 (7.9)	-1.31	(-2.26,-0.37)			25.0 (6.0)	-2.01	(-2.78,-1.24)		
Walking	Normal speed	44.1 (6.9)	Reference				27.0 (5.3)	Reference			
Speed	Fairly brisk	45.6 (7.3)	1.48	(0.57,2.39)			28.0 (4.8)	0.95	(0.21,1.69)		
	Fast	45.5 (6.8)	1.38	(-0.45,3.21)			28.2 (5.1)	1.16	(-0.12,2.45)		
		test for trend	1.50	(1.11,1.89)	*0.000*	*0.000*	*test for trend*	1.64	(1.34,1.94)	*0.000*	*0.000*
Oily fish	None	42.7 (7.9)	-1.23	(-2.36,-0.10)			24.3 (6.4)	-2.01	(-3.07,-0.95)		
portions	0.1-1.0	43.9 (7.4)	Reference				26.3 (5.8)	Reference			
per week	1.1-3.0	45.3 (7.3)	1.39	(0.43,2.35)			27.4 (5.1)	1.10	(0.36,1.84)		
	>3.0	44.4 (7.5)	0.48	(-1.03,1.99)			27.5 (5.7)	1.13	(0.11,2.16)		
		test for trend	0.85	(0.35,1.34)	*0.001*	*0.02*	*test for trend*	0.99	(0.60,1.37)	*0.000*	*0.000*
Smoking	Never	44.0 (7.4)	Reference				26.7 (5.7)	Reference			
habit	Ex	44.2 (7.8)	0.19	(-0.64,1.02)			26.0 (6.1)	-0.71	(-1.39,-0.04)		
	Current	43.6 (6.9)	-0.41	(-1.57,0.74)			27.0 (5.3)	0.27	(-0.76,1.30)		
		test for trend	-0.12	(-0.68,0.43)	*0.66*	0.97	*test for trend*	-0.15	(-0.60,0.30)	*0.51*	*0.44*
Weekly	Non-drinker	42.4 (7.5)	-1.61	(-3.26,0.04)			25.7 (5.9)	-1.03	(-1.79,-0.26)		
alcohol	<10M;<8F	44.0 (7.6)	Reference				26.7 (5.7)	Reference			
units	11-21M;8-14F	44.7 (7.4)	0.75	(-0.21,1.71)			26.7 (6.1)	-0.06	(-1.04,0.93)		
	>21M;>14F	43.9 (7.3)	-0.05	(-1.01,0.90)			26.8 (5.4)	0.03	(-1.39,1.45)		
		test for trend	0.25	(-0.17,0.67)	*0.25*	*0.65*	*test for trend*	0.41	(-0.02,0.83)	*0.06*	*0.84*

SDS: sex-specific standard deviation (SD) score; M: male; F: female; 95%CI:95% confidence interval. *p*: p-values are univariate for continuously distributed SD scores for height and weight for height, and are for trend across ordinal bands of walking speed, oily fish per week, smoking habit and alcohol intake.
*p**: mutually and age adjusted p-values for association from models based on 1566 observations for men and 1413 observations for women. **Pearson correlation coefficient.

Appendix 9. Associations between total femoral DXA bone mineral density and anthropometry, physical activity score, daily dietary calcium from foods, smoking habit and alcohol intake among HCS men and women

		MEN					WOMEN				
		Mean (SD) total femoral BMD (g/cm^2)	Regression Coefficient (95%CI)		*p*	*p**	Mean (SD) total femoral BMD (g/cm^2)	Regression Coefficient (95%CI)		*p*	*p**
Height (SDS)		0.11**	0.01	(0.00,0.03)	*0.01*	*0.007*	0.12**	0.02	(0.00,0.03)	*0.01*	*0.04*
Weight for height (SDS)		0.40**	0.06	(0.04,0.07)	*<0.001*	*<0.001*	0.44**	0.06	(0.05,0.07)	*<0.001*	*<0.001*
Activity score (SDS)		-0.02**	0.00	(-0.02,0.01)	*0.71*	*0.60*	0.01**	0.00	(-0.01,0.01)	*0.89*	*0.91*
Dietary calcium from foods (SDS)		0.04**	0.01	(-0.01,0.02)	*0.35*	*0.17*	0.03**	0.00	(-0.01,0.02)	*0.56*	*0.13*
Smoking habit	Never	1.04 (0.12)	Reference				0.89 (0.13)	Reference			
	Ex	1.04 (0.14)	0.00	(-0.03,0.03)			0.91 (0.13)	0.01	(-0.01,0.04)		
	Current	1.03 (0.13)	-0.01	(-0.05,0.02)			0.91 (0.14)	0.02	(-0.02,0.06)		
		test for trend	0.00	(-0.02,0.01)	*0.60*	*0.36*	*test for trend*	0.01	(-0.01,0.03)	*0.22*	*0.92*
Weekly alcohol units	Non-drinker	1.02 (0.09)	-0.02	(-0.08,0.04)			0.89 (0.14)	-0.01	(-0.04,0.02)		
	<10M;<8F	1.04 (0.13)	Reference				0.90 (0.13)	Reference			
	11-21M;8-14F	1.02 (0.14)	-0.02	(-0.05,0.01)			0.89 (0.13)	-0.01	(-0.05,0.03)		
	>21M;>14F	1.06 (0.13)	0.02	(-0.01,0.05)			0.89 (0.14)	-0.01	(-0.09,0.06)		
		test for trend	0.01	(-0.01,0.02)	*0.26*	*0.23*	*test for trend*	0.00	(-0.02,0.02)	*1.00*	*0.93*

SDS: sex-specific standard deviation score; M: male; F: female; SD: standard deviation; BMD: bone mineral density from DXA; g: grammes; 95%CI:95% confidence interval

p: p-values are univariate for continuously distributed sex specific standard deviation score variables for height, weight for height, Dallosso physical activity score and daily calcium intake from foods in mg, and are for trend across the ordinal bands of smoking habit and weekly alcohol units.

*p**: mutually and age (and for women, also menopause and HRT) adjusted p-values for association from models based on 495 observations for men and 463 observations for women. **Pearson correlation coefficient.

Appendix 10. Associations between socioeconomic position and material deprivation and poor walking speed among HCS men and women

	MEN				WOMEN			
	n(%) poor walking speed		Odds ratio (95%CI)		n(%) poor walking speed		Odds ratio (95%CI)	
Social class at birth								
I	6	(30.0)	1.03	(0.39,2.73)	3	(25.0)	0.91	(0.24,3.38)
II	22	(20.0)	0.60	(0.37,0.99)	36	(30.0)	1.16	(0.76,1.78)
IIINM	19	(16.1)	0.46	(0.28,0.78)	22	(20.8)	0.71	(0.43,1.17)
IIIM	207	(29.3)	Reference		186	(26.9)	Reference	
IV	147	(33.7)	1.23	(0.95,1.58)	115	(29.3)	1.12	(0.85,1.48)
V	69	(37.3)	1.43	(1.02,2.01)	37	(31.4)	1.24	(0.81,1.89)
			p	*<0.001*			*p*	*0.31*
			*p**	*0.01*			*p**	*0.92*
Age left full-time education								
<=14 years	117	(35.9)	1.44	(1.11,1.85)	97	(35.3)	1.52	(1.15,2.01)
>=15 years	379	(28.1)	Reference		333	(26.4)	Reference	
			p	*<0.001*			*p*	*<0.001*
			*p**	*0.15*			*p**	*0.06*
Social class in adulthood								
I	33	(30.8)	0.95	(0.61,1.48)	19	(22.6)	0.72	(0.42,1.24)
II	91	(23.1)	0.64	(0.48,0.85)	87	(25.1)	0.83	(0.61,1.12)
IIINM	40	(24.4)	0.69	(0.46,1.02)	53	(25.4)	0.84	(0.58,1.20)
IIIM	203	(32.0)	Reference		171	(28.9)	Reference	
IV	99	(36.5)	1.22	(0.91,1.65)	78	(31.0)	1.10	(0.80,1.52)
V	18	(31.6)	0.98	(0.55,1.76)	21	(38.9)	1.57	(0.88,2.78)
			p	*0.001*			*p*	*0.01*
			*p**	*0.65*			*p**	*0.86*
Housing tenure								
Owned/mortgaged	362	(26.7)	Reference		285	(24.1)	Reference	
Rented/other	133	(41.1)	1.90	(1.48,2.45)	145	(40.9)	2.18	(1.69,2.79)
			p	*<0.001*			*p*	*<0.001*
			*p**	*0.02*			*p**	*<0.001*
Number of cars available								
None	51	(48.6)	1.86	(1.24,2.80)	99	(36.3)	1.45	(1.09,1.93)
1	301	(33.6)	Reference		251	(28.2)	Reference	
2	115	(20.9)	0.52	(0.41,0.67)	72	(21.9)	0.71	(0.53,0.96)
3 or more	26	(21.3)	0.53	(0.34,0.84)	8	(17.8)	0.55	(0.25,1.20)
			p	*<0.001*			*p*	*<0.001*
			*p**	*<0.001*			*p**	*0.21*

Poor walking speed defined as a self-reported typical walking speed of ‘very slow’ or ‘strolling at an easy pace’ as opposed to ‘normal speed’, ‘fairly brisk’ or ‘fast’.
p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home
and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 11. Associations between socioeconomic position and material deprivation and Dallosso activity score among HCS men and women

	MEN				WOMEN			
			Regression				Regression	
	Mean	SD	Coefficient (95%CI)		Mean	SD	Coefficient (95%CI)	
Social class at birth								
I	66.1	15.5	5.91	(-1.18,13.00)	61.9	15.0	3.65	(-5.85,13.15)
II	60.5	14.8	0.33	(-2.86,3.52)	58.6	15.4	0.38	(-2.85,3.60)
IIINM	61.0	14.9	0.86	(-2.25,3.96)	60.3	16.6	2.05	(-1.35,5.45)
IIIM	60.2	15.5	Reference		58.3	16.3	Reference	
IV	60.8	17.0	0.64	(-1.26,2.54)	58.1	17.0	-0.15	(-2.21,1.91)
V	59.0	16.1	-1.16	(-3.75,1.42)	54.9	18.3	-3.34	(-6.58,-0.10)
			p	*0.26*			*p*	*0.05*
			*p**	*0.73*			*p**	*0.31*
Age left full-time education								
<=14 years	59.5	16.6	-1.15	(-3.06,0.76)	56.1	16.9	-2.51	(-4.68,-0.33)
>=15 years	60.7	15.6	Reference		58.6	16.6	Reference	
			p	*0.92*			*p*	*0.03*
			*p**	*0.98*			*p**	*0.56*
Social class in adulthood								
I	59.7	13.8	-1.33	(-4.57,1.90)	61.1	13.0	1.97	(-1.84,5.77)
II	60.5	15.0	-0.57	(-2.55,1.41)	58.9	16.7	-0.18	(-2.38,2.03)
IIINM	58.5	16.0	-2.6	(-5.30,0.11)	57.7	16.6	-1.37	(-3.99,1.25)
IIIM	61.1	15.8	Reference		59.1	16.2	Reference	
IV	58.9	17.3	-2.14	(-4.38,0.10)	55.9	17.2	-3.19	(-5.64,-0.74)
V	62.8	16.0	1.7	(-2.57,5.98)	51.5	22.3	-7.62	(-12.26,-2.99)
			p	*0.79*			*p*	*0.003*
			*p**	*0.04*			*p**	*0.66*
Housing tenure								
Owned/mortgaged	61.4	15.4	Reference		59.9	15.4	Reference	
Rented/other	56.6	16.8	-4.73	(-6.63,-2.82)	52.4	19.3	-7.51	(-9.45,-5.57)
			p	*<0.001*			*p*	*<0.001*
			*p**	*<0.001*			*p**	*<0.001*
Number of cars available								
None	52.9	18.4	-6.81	(-9.95,-3.68)	52.8	18.9	-5.79	(-8.03,-3.56)
1	59.8	15.8	Reference		58.6	16.0	Reference	
2	62.6	15.1	2.82	(1.17,4.48)	60.9	15.8	2.31	(0.23,4.40)
3 or more	62.4	14.2	2.66	(-0.29,5.61)	62.9	15.0	4.29	(-0.65,9.23)
			p	*<0.001*			*p*	*<0.001*
			*p**	*<0.001*			*p**	*0.001*

The Dallosso physical activity score ranged from 0 to 100 with higher scores indicating greater self-reported typical frequency of participation in weight bearing activities comprising gardening, housework, climbing stairs and carrying loads.
p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 12. Associations between socioeconomic position and material deprivation and no weekly consumption of oily fish among HCS men and women

	MEN				WOMEN			
	n(%) no weekly oily fish intake		Odds ratio (95%CI)		n(%) no weekly oily fish intake		Odds ratio (95%CI)	
Social class at birth								
I	3	(15.8)	1.37	(0.39,4.80)	0	(0.0)	0.00	-
II	9	(8.1)	0.64	(0.31,1.32)	10	(8.3)	0.82	(0.41,1.64)
IIINM	12	(10.3)	0.83	(0.44,1.58)	9	(8.5)	0.84	(0.40,1.73)
IIIM	85	(12.0)	Reference		69	(10.0)	Reference	
IV	72	(16.5)	1.44	(1.03,2.02)	44	(11.2)	1.14	(0.76,1.70)
V	23	(12.4)	1.04	(0.63,1.70)	10	(8.5)	0.84	(0.42,1.67)
			p	*0.07*			*p*	*0.36*
			*p**	*0.79*			*p**	*0.89*
Age left full-time education								
<=14 years	53	(16.3)	1.41	(1.01,1.97)	30	(10.9)	1.16	(0.76,1.77)
>=15 years	164	(12.1)	Reference		120	(9.5)	Reference	
			p	*<0.001*			*p*	*0.01*
			*p**	*0.06*			*p**	*0.10*
Social class in adulthood								
I	1	(0.9)	0.05	(0.01,0.38)	2	(2.4)	0.19	(0.05,0.78)
II	41	(10.5)	0.66	(0.45,0.97)	19	(5.5)	0.45	(0.26,0.76)
IIINM	18	(10.9)	0.69	(0.40,1.18)	25	(12.0)	1.05	(0.64,1.71)
IIIM	96	(15.1)	Reference		68	(11.5)	Reference	
IV	41	(15.2)	1.01	(0.68,1.50)	26	(10.3)	0.88	(0.55,1.43)
V	12	(21.1)	1.5	(0.77,2.94)	10	(18.5)	1.75	(0.84,3.65)
			p	*<0.001*			*p*	*<0.001*
			*p**	*0.01*			*p**	*0.09*
Housing tenure								
Owned/mortgaged	153	(11.3)	Reference		94	(7.9)	Reference	
Rented/other	64	(19.8)	1.93	(1.40,2.66)	56	(15.7)	2.16	(1.52,3.09)
			p	*<0.001*			*p*	*<0.001*
			*p**	*0.04*			*p**	*0.05*
Number of cars available								
None	21	(19.6)	1.51	(0.91,2.53)	43	(15.8)	1.87	(1.26,2.79)
1	124	(13.9)	Reference		81	(9.1)	Reference	
2	61	(11.1)	0.77	(0.56,1.07)	23	(7.0)	0.75	(0.46,1.21)
3 or more	10	(8.2)	0.55	(0.28,1.09)	3	(6.7)	0.72	(0.22,2.36)
			p	*0.004*			*p*	*0.001*
			*p**	*0.17*			*p**	*0.04*

p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home
and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 13. Associations between socioeconomic position and material deprivation and daily dietary calcium (mg) from foods among HCS men and women

	MEN				WOMEN			
	Mean	SD	Regression Coefficient (95%CI)		Mean	SD	Regression Coefficient (95%CI)	
Social class at birth								
I	1110	1.4	0.96	(0.84,1.09)	963	1.4	0.90	(0.76,1.07)
II	1178	1.3	1.01	(0.96,1.07)	1039	1.3	0.97	(0.92,1.03)
IIINM	1198	1.4	1.03	(0.97,1.09)	1070	1.3	1.00	(0.94,1.06)
IIIM	1162	1.3	Reference		1069	1.3	Reference	
IV	1165	1.3	1.00	(0.97,1.04)	1082	1.3	1.01	(0.98,1.05)
V	1149	1.3	0.99	(0.94,1.04)	1084	1.4	1.01	(0.96,1.07)
			p	*0.52*			*p*	*0.12*
			*p**	*0.77*			*p**	*0.08*
Age left full-time education								
<=14 years	1150	1.3	0.99	(0.96,1.02)	1051	1.4	0.98	(0.94,1.02)
>=15 years	1163	1.3	Reference		1071	1.3	Reference	
			p	*0.56*			*p*	*0.74*
			*p**	*0.75*			*p**	*0.86*
Social class in adulthood								
I	1156	1.3	1.00	(0.95,1.06)	1058	1.3	0.99	(0.92,1.05)
II	1157	1.3	1.00	(0.97,1.04)	1085	1.3	1.01	(0.97,1.05)
IIINM	1165	1.3	1.01	(0.96,1.06)	1082	1.3	1.01	(0.96,1.06)
IIIM	1153	1.3	Reference		1074	1.3	Reference	
IV	1162	1.3	1.01	(0.97,1.05)	1015	1.4	0.95	(0.91,0.99)
V	1198	1.3	1.04	(0.96,1.12)	1084	1.3	1.01	(0.93,1.10)
			p	*0.74*			*p*	*0.11*
			*p**	*0.13*			*p**	*0.38*
Housing tenure								
Owned/mortgaged	1169	1.3	Reference		1075	1.3	Reference	
Rented/other	1127	1.4	0.96	(0.93,1.00)	1041	1.4	0.97	(0.93,1.00)
			p	*0.04*			*p*	*0.07*
			*p**	*0.08*			*p**	*0.11*
Number of cars available								
None	1073	1.4	0.93	(0.88,0.99)	1075	1.3	1.01	(0.97,1.06)
1	1152	1.3	Reference		1060	1.4	Reference	
2	1185	1.3	1.03	(1.00,1.06)	1077	1.3	1.02	(0.98,1.06)
3 or more	1182	1.3	1.03	(0.97,1.08)	1106	1.4	1.04	(0.96,1.14)
			p	*0.00*			*p*	*0.60*
			*p**	*0.05*			*p**	*0.82*

Daily calcium intake (mg) was $\log_e$ transformed to a normal distribution for analyses but results were back transformed for presentational purposes: means and standard deviations are therefore geometric and regression coefficients are proportional differences in average daily calcium intake. *p*: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home and per extra car available for household use. *p**: mutually and age adjusted p-values for association.

Appendix 14. Associations between socioeconomic position and material deprivation and grip strength among HCS men and women without and with adjustment for oily fish intake

	"Fully adjusted" as per paper 1*			"Fully" and also oily fish adjusted		
	b	**95%CI**	***p***	**b**	**95%CI**	***p***
Grip strength among men						
Per year older when left FT education	0.13	(-0.11,0.37)	*0.29*	0.11	(-0.13,0.36)	*0.36*
Rented/other vs owned/mortgaged	-1.12	(-2.04,-0.20)	*0.02*	-1.08	(-2.00,-0.16)	*0.02*
Per extra car available	0.56	(0.07,1.06)	*0.03*	0.56	(0.06,1.05)	*0.03*
Per extra portion of oily fish per week				0.31	(0.01,0.61)	*0.04*
Grip strength among women						
Per year older when left FT education	0.05	(-0.17,0.28)	*0.65*	0.04	(-0.19,0.26)	*0.75*
Rented/other vs owned/mortgaged	-1.06	(-1.79,-0.33)	*0.004*	-1.02	(-1.75,-0.29)	*0.01*
Per extra car available	0.68	(0.24,1.11)	*0.002*	0.64	(0.21,1.08)	*0.004*
Per extra portion of oily fish per week				0.32	(0.09,0.55)	*0.01*

b: regression coefficient in kg of grip strength per unit or category of each predictor variable as indicated; 95%CI: 95% confidence interval; *p*: p-value; FT: full-time. *"Fully adjusted" as per paper 1 means mutually adjusted and also adjusted for age at clinic, height, weight for height, smoker status, alcohol intake, marital status, walking speed and diabetes for men and women and also for hypertension, minor trauma fracture since 45 years of age and number of systems medicated (according to British National Formulary coding system) for women.

Appendix 15. Associations between socioeconomic position and material deprivation and ever smoking among HCS men and women

	MEN				WOMEN			
	n(%) ever smoker		Odds ratio (95%CI)		n(%) ever smoker		Odds ratio (95%CI)	
Social class at birth								
I	16	(80.0)	1.83	(0.61,5.54)	4	(33.3)	0.74	(0.22,2.47)
II	60	(54.1)	0.54	(0.36,0.81)	48	(40.0)	0.98	(0.66,1.46)
IIINM	68	(57.6)	0.62	(0.42,0.93)	28	(26.4)	0.53	(0.33,0.83)
IIIM	485	(68.6)	Reference		280	(40.5)	Reference	
IV	293	(66.6)	0.91	(0.71,1.18)	150	(38.2)	0.91	(0.70,1.17)
V	140	(75.7)	1.42	(0.98,2.06)	63	(52.9)	1.66	(1.12,2.45)
			p	*0.002*			*p*	*0.032*
			*p**	*0.40*			*p**	*0.36*
Age left full-time education								
<=14 years	238	(72.8)	1.35	(1.04,1.77)	117	(42.4)	1.12	(0.86,1.46)
>=15 years	900	(66.4)	Reference		501	(39.6)	Reference	
			p	*<0.001*			*p*	*0.001*
			*p**	*0.002*			*p**	*0.05*
Social class in adulthood								
I	61	(57.0)	0.52	(0.34,0.79)	25	(29.8)	0.63	(0.38,1.03)
II	230	(58.2)	0.55	(0.42,0.71)	127	(36.6)	0.86	(0.65,1.12)
IIINM	108	(65.5)	0.74	(0.52,1.07)	74	(35.4)	0.81	(0.59,1.13)
IIIM	458	(71.8)	Reference		239	(40.3)	Reference	
IV	201	(73.9)	1.11	(0.81,1.53)	129	(51.0)	1.54	(1.15,2.07)
V	44	(77.2)	1.33	(0.70,2.53)	24	(44.4	1.18	(0.68,2.08)
			p	*<0.001*			*p*	*<0.001*
			*p**	*0.01*			*p**	*0.15*
Housing tenure								
Owned/mortgaged	873	(64.3)	Reference		432	(36.5)	Reference	
Rented/other	263	(80.9)	2.35	(1.75,3.17)	186	(52.3)	1.91	(1.50,2.42)
			p	*<0.001*			*p*	*<0.001*
			*p**	*<0.001*			*p**	*0.001*
Number of cars available								
None	86	(80.4)	1.76	(1.07,2.90)	123	(45.1)	1.16	(0.88,1.52)
1	628	(69.9)	Reference		370	(41.4)	Reference	
2	352	(63.8)	0.76	(0.60,0.95)	113	(34.2)	0.74	(0.57,0.96)
3 or more	68	(55.7)	0.54	(0.37,0.80)	12	(26.7)	0.51	(0.26,1.01)
			p	*<0.001*			*p*	*0.001*
			*p**	*0.01*			*p**	*0.12*

Analyses contrast ex- and current-smokers combined with never smokers.
p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 16. Associations between socioeconomic position and material deprivation and high weekly alcohol intake among HCS men and women

	MEN				WOMEN			
	n(%) high weekly alcohol		Odds ratio (95%CI)		n(%) high weekly alcohol		Odds ratio (95%CI)	
Social class at birth								
I	6	(30.0)	1.54	(0.58,4.07)	0	(0.0)	0.00	-
II	25	(22.7)	1.06	(0.65,1.71)	5	(4.2)	0.87	(0.33,2.27)
IIINM	36	(30.5)	1.58	(1.02,2.43)	7	(6.6)	1.41	(0.61,3.28)
IIIM	154	(21.8)	Reference		33	(4.8)	Reference	
IV	78	(17.7)	0.77	(0.57,1.05)	17	(4.3)	0.91	(0.50,1.65)
V	39	(21.1)	0.96	(0.65,1.43)	6	(5.0)	1.06	(0.43,2.59)
			p	*0.04*			*p*	*0.97*
			*p**	*0.16*			*p**	*0.56*
Age left full-time education								
<=14 years	61	(18.7)	0.80	(0.59,1.09)	12	(4.4)	0.87	(0.46,1.63)
>=15 years	301	(22.2)	Reference		63	(5.0)	Reference	
			p	*0.01*			*p*	*0.49*
			*p**	*0.13*			*p**	*0.84*
Social class in adulthood								
I	17	(15.9)	0.68	(0.39,1.19)	10	(11.9)	3.86	(1.74,8.57)
II	98	(24.8)	1.19	(0.89,1.60)	24	(6.9)	2.13	(1.16,3.91)
IIINM	36	(21.8)	1.01	(0.67,1.53)	10	(4.8)	1.44	(0.66,3.12)
IIIM	138	(21.7)	Reference		20	(3.4)	Reference	
IV	52	(19.1)	0.85	(0.60,1.22)	10	(4.0)	1.18	(0.54,2.55)
V	13	(22.8)	1.07	(0.56,2.04)	1	(1.9)	0.54	(0.07,4.10)
			p	*0.58*			*p*	*0.001*
			*p**	*0.73*			*p**	*0.003*
Housing tenure								
Owned/mortgaged	300	(22.1)	Reference		61	(5.2)	Reference	
Rented/other	61	(18.8)	0.82	(0.60,1.11)	14	(3.9)	0.76	(0.42,1.37)
			p	*0.20*			*p*	*0.36*
			*p**	*0.63*			*p**	*0.88*
Number of cars available								
None	24	(22.6)	1.21	(0.75,1.96)	9	(3.3)	0.63	(0.30,1.30)
1	175	(19.5)	Reference		46	(5.2)	Reference	
2	141	(25.5)	1.42	(1.10,1.82)	16	(4.9)	0.94	(0.52,1.68)
3 or more	20	(16.4)	0.81	(0.49,1.34)	4	(8.9)	1.79	(0.62,5.22)
			p	*0.46*			*p*	*0.19*
			*p**	*1.00*			*p**	*0.76*

High weekly alcohol intake defined as ≥22 units per week for men and ≥15 units per week for women.
p: univariate p-values are for trend across lower groups of social class at birth and in adulthood, per year older when left full-time education, not owning/mortgaging one's home and per extra car available for household use.
*p**: mutually and age adjusted p-values for association.

Appendix 17. Associations between socioeconomic position and material deprivation and grip strength among the 498 men and 468 women who participated in the HCS baseline DXA scan

	MEN				WOMEN			
			Regression				Regression	
	Mean	SD	Coefficient (95%CI)		Mean	SD	Coefficient (95%CI)	
Social class at birth								
I	45.5	6.2	1.02	(-4.21,6.25)	27.3	6.7	-0.52	(-5.60,4.55)
II	44.6	6.6	0.17	(-2.54,2.88)	27.0	5.7	-0.80	(-2.50,0.91)
IIINM	44.9	7.0	0.39	(-2.23,3.01)	28.4	5.6	0.66	(-1.25,2.58)
IIIM	44.5	6.9	Reference		27.8	4.7	Reference	
IV	43.2	7.5	-1.26	(-2.87,0.35)	27.7	5.0	-0.11	(-1.23,1.02)
V	43.5	9.0	-0.95	(-3.13,1.23)	26.4	6.4	-1.34	(-3.31,0.63)
			p	*0.11*			*p*	*0.77*
Age left full-time education								
<=14 years	42.5	7.7	-1.99	(-3.59,-0.39)	27.4	5.0	-0.32	(-1.53,0.89)
>=15 years	44.5	7.2	Reference		27.7	5.1	Reference	
			p	*<0.001*			*p*	*0.60*
			*p**	*0.22*			*p**	*0.88*
Social class in adulthood								
I	45.0	5.8	1.85	(-1.17,4.88)	28.3	6.0	0.24	(-1.95,2.44)
II	45.0	6.9	1.82	(0.10,3.55)	27.3	5.1	-0.69	(-1.94,0.55)
IIINM	44.8	6.7	1.63	(-0.61,3.86)	27.5	4.8	-0.55	(-1.98,0.88)
IIIM	43.2	7.7	Reference		28.0	4.8	Reference	
IV	43.0	7.9	-0.21	(-2.15,1.73)	27.2	5.4	-0.80	(-2.17,0.57)
V	45.3	8.1	2.10	(-1.90,6.10)	28.0	6.3	-0.02	(-2.78,2.74)
			p	*0.04*			*p*	*0.88*
Housing tenure								
Owned/mortgaged	44.4	7.1	Reference		27.9	5.1	Reference	
Rented/other	41.9	8.1	-0.56	(-1.09,-0.03)	27.0	4.9	-0.89	(-2.07,0.29)
			p	*0.005*			*p*	*0.14*
			*p**	*0.16*			*p**	*0.85*
Number of cars available								
None	42.8	6.6	-0.69	(-3.82,2.44)	26.3	4.4	-1.62	(-2.97,-0.26)
1	43.5	7.3	Reference		27.9	5.3	Reference	
2	45.0	7.4	1.44	(0.04,2.84)	28.1	4.9	0.17	(-0.94,1.27)
3 or more	44.2	7.3	0.71	(-1.85,3.26)	27.6	3.8	-0.27	(-3.08,2.54)
			p	*0.08*			*p*	*0.08*
			*p**	*0.97*			*p**	*0.10*

* Mutually adjusted as in paper 1 i.e. for age left education, housing tenure, car availability, age, height, weight for height, smoking, alcohol, marital status and walking speed for men and women and also adjusted for DM for men and for DM, minor trauma fracture and number of systems medicated for women.

Appendix 18. Associations between socioeconomic position and material deprivation and self-reported physical functioning among the 498 men and 468 women who participated in the HCS baseline DXA scan

	MEN				WOMEN			
	n(%) poor PF		Odds ratio (95%CI)		n(%) poor PF		Odds ratio (95%CI)	
Social class at birth								
I	1	(12.5)	0.99	(0.12,8.46)	1	(25.0)	2.31	(0.23,23.05)
II	5	(14.7)	1.20	(0.42,3.42)	2	(4.8)	0.35	(0.08,1.52)
IIINM	3	(8.1)	0.61	(0.17,2.17)	6	(18.8)	1.60	(0.60,4.26)
IIIM	22	(12.6)	Reference		25	(12.6)	Reference	
IV	25	(16.8)	1.40	(0.75,2.61)	20	(14.9)	1.21	(0.64,2.29)
V	11	(18.6)	1.59	(0.72,3.52)	4	(13.3)	1.06	(0.34,3.31)
			p	*0.20*			*p*	*0.40*
Age left full-time education								
<=14 years	15	(14.9)	0.96	(0.52,1.77)	11	(13.4)	1.09	(0.54,2.20)
>=15 years	61	(15.4)	Reference		48	(12.4)	Reference	
			p	*0.44*			*p*	*0.45*
Social class in adulthood								
I	3	(11.5)	0.56	(0.16,1.95)	3	(13.0)	1.28	(0.35,4.67)
II	12	(10.6)	0.51	(0.25,1.02)	10	(10.5)	1	(0.45,2.22)
IIINM	7	(13.0)	0.63	(0.26,1.52)	9	(14.1)	1.39	(0.60,3.22)
IIIM	35	(19.0)	Reference		21	(10.5)	Reference	
IV	16	(20.3)	1.08	(0.56,2.09)	16	(21.0)	2.44	(1.19,4.98)
V	1	(7.1)	0.33	(0.04,2.59)	0	(0.0)	-	
			p	*0.08*			*p*	*0.48*
Housing tenure								
Owned/mortgaged	54	(12.8)	Reference		35	(9.2)	Reference	
Rented/other	22	(28.6)	2.72	(1.54,4.81)	24	(27.6)	3.77	(2.10,6.76)
			p	*0.001*			*p*	*<0.001*
			*p**	*0.19*			*p**	*0.05*
Number of cars available								
None	8	(34.8)	2.45	(0.98,6.11)	13	(19.7)	1.95	(0.95,3.97)
1	47	(17.9)	Reference		31	(11.2)	Reference	
2	18	(10.3)	0.53	(0.29,0.94)	14	(12.5)	1.13	(0.58,2.22)
3 or more	3	(8.3)	0.42	(0.12,1.42)	1	(7.7)	0.66	(0.08,5.26)
			p	*0.001*			*p*	*0.22*
			*p**	*0.03*			*p**	*0.60*

* Mutually adjusted p-values as in paper 1 i.e. for housing tenure, car availability, age, height, weight for height, smoking, alcohol, marital status and walking speed for men and women and also adjusted for IHD and number of systems medicated for men and for IHD, DM and number of systems medicated for women.