The effect of social deprivation on distal radius fracture incidence and treatment

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Aim: Socioeconomic deprivation is known to be associated with many types of fracture but the reasons for this are not clearly understood. The primary aim of this thesis is to investigate if deprivation is associated with distal radius fracture and does it influence distal radius fracture treatment.

Methods: Regression modelling techniques are used to analyse four years of Leicestershire emergency department data (n=4278) and national Hospital Episodes Statistics data (n=59,315) from a similar period. Radiographic analysis and a prospective survey is carried out to identify factors responsible for the effects of deprivation on fracture incidence. Systematic review and meta-analysis is performed to quantify the risk of hip fracture after distal radius fracture.

Results: Deprivation was strongly associated with distal radius fracture in the whole population studied. Deprived patients sustained their injuries at an earlier age. The influence of deprivation was larger in white men. Incidence rate in the least deprived quintile was a third of that in the most deprived for white men and almost half for white women. Age 50 years and over and male gender was an independent risk factor for distal radius fracture in all ethnicities. Falls risk was associated with increasing deprivation. Significant variation is identified between hospital trusts treating distal radius fractures with a higher fixation rate seen in trusts with a smaller population. Deprivation was not related to any of the parameters of hospital care studied.

Discussion: Poverty is rising which will lead to higher levels of social deprivation and an increase in distal radius fracture rate. Fracture prevention strategies are required to combat this rise. Knowing which patients are at highest risk allows interventions to be efficiently targeted. Resources should be targeted to those at-risk patients from deprived areas and preventative strategies put in place.

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Abbreviations

AP	Antero-posterior
BMD	Bone Mineral Density
CI	Confidence Interval
CT	Computed Tomography
DASH	Disabilities of the Arm, Shoulder and Hand
DRAFFT	Distal Radius Acute Fracture Fixation Trial
distal radius fracture	Distal Radius Fracture
DXA	Dual-energy X-ray Absorptiometry
FRAX	Fracture Risk Assessment tool
GAM	Generalised Additive Model
GLM	Generalised Linear Model
GLMM	Generalised Linear Mixed Model
HR	Hazard Ratio
ICC	Intraclass Correlation Coefficient
ICD	Inner Cortical Diameter
ICER	Incremental Cost Effectiveness Ratio
IMD	Index of Multiple Deprivation
IRR	Incidence Rate Ratio
LSOA	Lower Super Output Area
MCI	Metacarpal Cortical Index
NICE	National Institute of Clinical Excellence
NIHR	National Institute for Health Research
OCD	Outer Cortical Diameter
ONS	Office of National Statistics
OPCS	Office of Population Censuses and Surveys
ORIF	Open Reduction Internal Fixation
PA	Postero-anterior
PROM	Patient Reported Outcome Measure

PRWE	Patient Reported Wrist Evaluation
QALY	Quality Adjusted Life Year
RR	Relative Risk
UHL	University Hospitals of Leicester
VLP	Volar Locking Plate
WHO	World Health Organisation

Relevant publications

Risk of hip fracture following a wrist fracture-A meta-analysis.
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Johnson NA, Stirling ER, Thompson JR, Dias JJ.
British Society for Surgery of the Hand, Cardiff, October 16.

Chapter 1 Introduction

1.1 The history of deprivation and health

The adverse association between social deprivation and numerous health outcomes has been recognised for many years. In 1843 a paper was published in the Lancet describing a strong relationship between life expectancy and occupation(1). The study recommended that employers and landlords should "make alterations for the comfort and health of those comparatively helpless classes of the community, the artisans and labourers."

Socioeconomic deprivation is a difficult concept which is not just related to financial poverty. In 1987 Peter Townsend wrote an article suggesting 'people can be said to be deprived if they lack the types of diet, clothing, housing, household facilities and fuel and environmental, educational, working and social conditions, activities and facilities which are customary(2).' Therefore, deprivation can relate to a lack of different types of resources, not just money. Whereas those in poverty lack financial resources to prevent deprivation.

In the United Kingdom there is a long history of research into deprivation and social inequality. Charles Booth used both quantitative and qualitative methods to investigate poverty in London in the late 19th century(3). His report titled 'Life and Labour of the People' was published in 1889 and is seen as one of the founding texts of British sociology. He noted that 35% of people in East End London were living in abject poverty and argued for the introduction of old age pensions and free school meals.

Seebohm Rowntree was a sociological researcher who carried out comparable work in York during a similar time period. His first study involved researchers visiting and surveying resident's homes and calculating a minimum weekly amount of money required for families to live a healthy life(4). This included funds for rent, fuel, light,

food, clothing, household and personal items. He applied new scientific methods such as analysing the cost of food necessary for minimum calorie requirements.

In the twentieth century Peter Townsend's work pioneered the relative deprivation approach to poverty. This takes into account a wide variety of factors including material and social living standards. He stated that for deprived people: "their resources are so seriously below those commanded by the average individual or family that they are, in effect, excluded from ordinary patterns, customs and activities."

This approach looks at factors which indicate deprivation. These identified factors can then be used to look at other variables such as income. Deprivation occurs because of lack of income and other resources. Deprivation measures are therefore related to how individuals live and not just their income. In 1968 to 1969 Townsend performed a large UK survey using this relative deprivation methodology and reported these results in 1979(5, 6). He selected 60 indicators of standard of living covering the following broad categories:

- diet
- clothing
- fuel and light
- home amenities
- housing and housing facilities
- the immediate environment of the home
- the general conditions and security of work
- family support
- recreation
- education
- health
- social relations

Absence of indicators suggested deprivation and deprivation scores were produced and compared with household income. This work identified levels of income at which standards of living would be seen as less than acceptable for modern society.

Some critics of Townsend's work suggested that measurement of his chosen indicators would not allow for the difference in how individuals choose to live. The consensual method was later developed to address these concerns(7).

This involves looking at direct measures of standards of living with deprivation defined as an enforced lack of key "necessities". These necessities are identified by public opinion and not from the views of experts. This method also contains an option for those who do not possess the necessities due to choice rather than lack of resources. The initial step for this approach therefore involves a large amount of information gathering regarding what the public believe to be the necessities which everybody should be able to afford and not manage without. These items can include food, health, housing, relationships, possessions, hobbies and financial security.

In the next stage for this consensual method surveys are undertaken to establish who lacks these necessities and if this is due to choice. Increased number of 'enforced lack of necessities' is regarded as more deprivation. Analysis is then performed to identify a 'poverty threshold' which in most studies is related to the lack of two or three necessities. When comparing deprivation through time the lack of three necessities is used as the poverty threshold. This amount of deprivation is associated with poor physical and mental health, financial difficulties and individuals who are most likely to identify themselves as being poor. Over the past thirty years there has been a rise in this deprivation poverty from 14% in 1983 to 33% in 2012(8).

1.2 Measures of deprivation

1.2.1 Index of Multiple Deprivation

The Index of Multiple Deprivation(IMD) is the official UK government measure of deprivation. This was first used in 2000 and has been updated approximately every three years since. Multiple deprivation is measured at the small area level using seven separate recognisable and measurable dimensions of deprivation(9). Individuals living

within the area experience these dimensions. This builds on Townsend's concept of relative deprivation.

The seven domains included in the IMD are:

• Income Deprivation

• Employment Deprivation

• Health Deprivation and Disability

• Education, Skills and Training Deprivation

• Barriers to Housing and Services

• Crime

• Living Environment Deprivation.

Multiple deprivation is the cumulative effect of these domains.

A total of 38 different indicators are used to capture the deprivation data for the domains. To be included an indicator must be specific to that domain and as direct as possible a measure of that type of deprivation. It must measure the main components of that deprivation, be up-to-date, easily updated, statistically robust and available across England at a small area level.

As the IMD measures deprivation at a small area level some indicators have large standard errors due to small numbers. In these cases shrinkage methodology is used to shift scores towards local authority averages for that indicator. Following this the indicator scores are combined to form the domain scores. Units used depends on the domain characteristics. In the income and employment domains the results are presented as the proportion of households experiencing that type of deprivation by comparing households to a defined level of income or employment rate. This is not possible in the other domains were simple rates cannot be calculated. For these domains indicator measurements are ranked then transformed to a normal distribution and weightings applied to form a domain score.

The seven individual domain scores must then be combined to create the overall IMD score. As the units of measurements vary the individual scores are standardised by ranking. These ranked scores are then exponentially transformed to allow continued identification of the most deprived areas. Before the domain scores for each spatial area are added together weighting is applied as some domains are understood to contribute to deprivation more than others. Income and employment are believed to be the most important and carry a domain weight of 22.5% each.

Small spatial areas called Lower Super Output Areas (LSOAs) are used to measure and compare deprivation. LSOAs are small areas of relatively equal size, usually equating to a few postcodes and consisting of about 1,500 people. Leicestershire and Rutland contains 606 LSOAs. These spatial measures have been used since IMD2004. Previously electoral ward based geographic areas had been used. These measures have weaknesses as electoral ward boundaries are frequently altered in relation to population size change to maintain a similar rate of elected local councillors to population. Therefore, changes in deprivation over time are difficult to accurately assess.

Ten indices are provided for each LSOA.

• Total Index of Multiple Deprivation score

• The seven individual domain indices

• Supplementary Income Deprivation Affecting Children Index

• Supplementary Income Deprivation Affecting Older People Index.

A higher total IMD score reflects greater deprivation. LSOAs are ranked on each indice score from 1 to 32,482 with rank 1 being the most deprived area and highest score. These rankings are split into 5 equal quintiles.

Complicated patterns of deprivation are seen across England. All nine regions contain some of the most and least deprived LSOAs. The East Midlands is comprised of 2732 LSOAs. 53.6% of these LSOAs are within the least 50% deprived LSOAs, 7.4% are in the 10% most deprived. These most deprived areas are focused around the cities of Leicester, Nottingham and Derby.

1.2.2 Other measures of deprivation

1.2.2.1 Jarman score

The Jarman score is also known as the underprivileged area score. It was originally devised in the mid eighties from a large survey of General Practitioners about the importance of variables affecting their workload. This information is used to give weightings to eight census variables which are added together to give the score for a geographical area. The initial purpose was to then give additional payments to GPs treating deprived patients.

The eight variables included are the proportion of:

- elderly living alone
- children aged under 5
- unskilled workers
- overcrowded households
- change of address in last year
- people living in a household where the head of household was born in a New Commonwealth country or Pakistan
- unemployed
- Single parents

Mean score is 0. A higher score suggests deprivation and a higher than expected demand for primary care. An area with a score of 30 or more is classified as deprived.

1.2.2.2 Townsend Material Deprivation Score

This was developed by Peter Townsend in 1988. It is based on four census variables:

- households without a car

- overcrowded households
- households not owner-occupied
- persons unemployed (of working age)

Scores are standardised then added together. Mean score is 0 and an increasing score indicates more deprivation. They can be calculated for LSOAs or larger areas.

1.2.2.3 Carstairs score

The Carstairs score were first developed in the eighties as an alternative to the Townsend score for Scotland. It can be calculated at ward level and is based on four census variables:

- unemployed males
- households without a car
- overcrowded households
- Low social class

Similar to the Townsend method scores are standardised then added together. Mean score is 0 and an increasing score indicates more deprivation.

1.2.3 Comparison of deprivation measures

All the measures above have the strength of quantifying deprivation at relatively small geographical levels. The Jarman score includes a diverse range of measures. Data used is linked to the 2001 census so may be out of date. It has been criticised for including the elderly, single parents and some ethnic groups in its definition of deprivation and implying they are a cause of the problem. The Townsend and Carstairs score are similar to each other. They are easy to calculate and shown to correlate with health measures better than the Jarman score. Disadvantages are the small number of indicators used and they also use census data which could be outdated. The Index of

Multiple Deprivation has now largely surpassed these measures. It uses more sophisticated statistical methods and a broad range of indicators. LSOAs are used to measure deprivation at smaller geographical levels than the other scores. Almost all recent research uses the IMD and for these reasons it was chosen to be used throughout this thesis.

1.3 Social deprivation and health

Social deprivation is associated with many major health problems including cancer, cardiorespiratory disease and diabetes but the potential reasons for this remain varied and largely unclear.

Lower socioeconomic status is associated with lower cancer survival rates and with presentation at a more advanced stage in the UK(10, 11). Lung cancer treatment rates are lower in those of lower socioeconomic status and they are more likely to present initially as an emergency and to die soon after diagnosis(12-15). These findings would suggest strategies to improve earlier diagnosis in deprived patients are required and would be beneficial.

In a study of 1417 patients presenting with an acute myocardial infarction in London it was found that there was minimal variation between deprivation groups in age, sex, smoking status or type of treatment(16). More patients from deprived areas were diabetic or south Asian and these patients were more likely to suffer more significant disease. Deprived patients did have a higher risk of early recurrent ischaemic events.

Kaplan et al carried out a population based study of 2679 men in Finland and found an association between socioeconomic state in childhood and ischaemic heart disease in later life(17). Other cardiac risk factors, measured as an adult, did not explain this difference. Further work by the same group attempted to find reasons for this(18). They reported that adult behaviours detrimental to health are related to low education, 'blue collar' employment and poor childhood conditions. They

recommended that governments must understand that economic policy is directly linked to public health policy.

Asthma rates in the US vary with race, being higher in Blacks and Hispanics(19). Odds ratios of 2.1 and 2.9 are seen in adults and children respectively compared to Whites. However, when three measures of socioeconomic status; family income, level of education and area of residence, were taken into account a large proportion of the differences between ethnicity decreased. A large study in Scotland using Carstairs score to measure deprivation showed a relationship between deprivation and type 2 diabetes and obesity(20). There was no relationship with type 1 diabetes. Several studies have shown an association between acute pancreatitis incidence and mortality with deprivation(21). This is most pronounced for acute pancreatitis caused by alcohol excess.

1.3.1 Social deprivation and injury

Many authors have attempted to study the relationship between social deprivation and injury, particularly for children. Dowswell et al carried out a systematic review looking at social deprivation and the prevention of injury in childhood(22). They found 32 studies which investigated this. However, the literature covered many different types of injury and social deprivation was defined in considerably different ways. They concluded therefore that it was currently difficult to design and target interventions to address inequalities in paediatric injury rates.

Dunn et al noted differences in the mechanism and patterns of injury in adult patients presenting with a head injury in Scotland(23). Deprived patients were more likely to suffer an injury due to an assault compared to less deprived patients who were more likely to sustain an injury through a road traffic accident or fall from height. Isolated injuries, normal physiology and Glasgow coma Score were more often seen in deprived patients. It was felt that these findings were due to the mechanism of injury. There was no difference in time to treatment, rate of transfer to a specialist centre or mortality. Another Scottish study reported that victims of assault attending

emergency departments were more likely to have been drinking alcohol, have suffered previous assault, be unemployed and from an area with higher deprivation score(24).

A study of over 100,000 patients with head injury in England again showed incidence rate was associated with socioeconomic factors such as unemployment, sickness from work and lone parent families(25). Interestingly access to good public transport for travel to work was linked to significantly reduced head injury rate. Therefore, some areas of London, with very high deprivation, had much lower head injury rates than expected due to the excellent public transport network.

Severe limb injury is also more common in deprived patients. A study of 601 patents admitted to Level 1 trauma centres in the US with high energy lower extremity injuries found they were more likely to live in households below the poverty line and be less likely to have health insurance compared to the general population(26). Heavy drinking was twice as high compared to national rates. Treatment decision in terms of amputation or limb salvage were not related to patient characteristics.

1.3.2 Deprivation and trauma

Several studies have investigated the relationship between fractures and deprivation. Curtis et al analysed data from UK General Practitioners covering 11.3 million people between 1988 and 2012(27). They compared fracture incidence with IMD quintiles. When comparing regions within the UK deprivation was found to be associated with increased fracture risk after adjustment for sex and age. Rates in Scotland were almost 50% higher than those in the less deprived South-East of England.

In men, the relative risk of vertebral, wrist and hip fractures increased with deprivation. The largest association was seen in men sustaining a hip fracture with those in the most deprived quintile having a relative risk of 1.3 (95% CI 1.21 – 1.41) compared to those in the least deprived quintile. These findings were not observed in women. No increase in risk of wrist or hip fractures and a reduced vertebral fracture

risk of 0.86 (95% CI 0.79 – 0.94) was seen in the most deprived quintile compared to the least deprived for women.

They suggested that higher fracture incidence for the more deprived was due to lifestyle factors such as smoking, alcohol and poor diet which are seen more frequently in areas of lower socioeconomic status and known to have a negative effect on bone health(28-31). It was felt that these negative lifestyle factors are seen more often in men than women which may explain the difference between genders. A study from Australia also noted a noted a larger association between deprivation and fracture in men(32).

Another large study in Wales calculated fracture rates by Townsend deprivation quintiles for 60,166 people who attended an A&E department with a fracture(33). They found that fracture incidence was significantly higher in areas with higher deprivation scores. However, this effect diminished with age and they concluded that socioeconomic deprivation does not appear to be a risk factor for development of osteoporotic fractures. Their study was not intended to investigate the reason for this but they felt that adverse lifestyle factors which are likely to be seen in more deprived areas such as smoking, alcohol, poor diet and reduced HRT uptake may be offset by increased levels of physical activity in more deprived areas were people are less likely to have cars. It may be that these deprivation linked lifestyle factors are less important than falls, osteoporosis and other medical co-morbidities. Fractures occur more frequently in older people living in residential and nursing care(34). These care homes are generally in large converted houses in less deprived areas meaning there is a "socioeconomic drift" of deprived older people to care in more affluent areas. Jones et al analysed this effect in their study and found the number of cases was tiny and would not influence any relationship between deprivation and fracture(33).

Aitken et al reviewed 6,872 consecutive adult patients with fractures attending an Emergency Department in Edinburgh over a one year period. Carstairs score was used to investigate an association with deprivation deciles(35). An association with deprivation was seen in 22 of the 27 fracture types studied in men and 17 out of 27 in women. In this study the effect of deprivation was not linear and the most deprived 10% of the population had the highest fracture risk. When comparing the most

deprived deciles (9, 10) with the less deprived deciles (1-8) by calculating odds ratios, to investigate the effect of severe deprivation, only distal femur fractures in males were not associated with deprivation. In women, there were five fractures that were not associated with severe deprivation – calcaneal, talar, distal humerus, distal tibial and diaphyseal tibial fractures. Odds ratios were similar between genders for the majority of fractures. Five fractures (scapula, proximal ulna, midfoot, distal humerus, proximal tibia) in men had an odds ratio of over 7.5. The odds ratios for women with these fractures were much lower. Men in decile 9 or 10 who sustained any of those five fractures were compared to the comparable women patients. 50% of men admitted to drinking more than 28 units per week, 28% were smokers and 24% of the injuries were due to road traffic accidents. The findings for women were 0.6%, 12% and 5% respectively. This again suggests lifestyle factors may influence fracture rate in deprived patients and help to explain gender differences.

The percentage of the common osteoporotic fractures (proximal femur, proximal humerus, wrist) seen in the most deprived decile was compared with the least deprived decile. In the most deprived decile 17.7% of patients had a wrist fracture, 7.4% a proximal humerus fracture and 8.6 % a proximal femur fracture compared to 18.8%, 6.6% and 15.3% in the least deprived decile respectively. The only significant difference was the reduced incidence of proximal femur fracture in the most deprived group. Life expectancy is known to be lower in this decile and the authors felt this difference was due to the fact that more deprived patients died earlier and did not live long enough to suffer an osteoporotic proximal femur fracture.

The same authors also studied the relationship between adult tibial diaphyseal fractures and deprivation in Edinburgh(36). These injuries have a bimodal distribution and are generally due to high energy trauma in younger patients and secondary to minor trauma and osteoporosis in older patients. They demonstrated a clear relationship between tibial fractures and deprivation but the effect lessened with age. Tibial fractures in younger patients tended to occur in men from socially deprived areas after football injuries, direct blows or assaults and road traffic accidents. Overall those injured playing sport were less deprived. Football was associated with deprivation but other activities such as horse riding and skiing were associated with

affluence. These younger patients are unlikely to have reduced bone density due to alcohol, smoking or poor diet. In the older group, most injuries occurred after low energy injuries and simple falls. It was felt that the mechanism of injury was related to deprivation with falls affecting older people from all deprivation groups. This agrees with the study by Jones et al. (33).

Quah et al prospectively analysed incidence of hip fracture and deprivation in 7,511 patients using the IMD 2007(37). The study was carried out in Nottingham which has a similar population to Leicester but with slightly higher levels of deprivation. Hip fracture incidence was 1.3 times higher in the most deprived quintile compared to the least deprived. More co-morbidities were seen in the more deprived population agreeing with other findings that deprivation is associated with a less healthy lifestyle potentially leading to the development of health problems. No difference in mortality was seen at 30 days but those in the most deprived quintile had a higher mortality rate at one, three, five and seven years when compared to the least deprived quintile. These findings could be expected to occur regardless of hip fracture. The authors acknowledged the variation in the literature regarding the influence of deprivation on hip fracture. They thought the variety of measures of deprivation used in other studies could be an explanation for this.

Brennan et al performed a systematic review to attempt to address the question of whether socioeconomic status is an influence on osteoporotic fracture(38). They evaluated the evidence and found only 11 suitable studies suggesting a lack of good quality literature. There was strong evidence of an association between being married or living with someone and a reduced risk of osteoporotic fracture. Limited evidence was found for a relationship between occupation type or employment status and fracture, or for type of residence and fracture. There was conflicting evidence for the relationship between osteoporotic fracture and level of income and education. They suggested further high quality literature on the subject was required.

1.3.3 Adolescent fractures and deprivation

A further study from Edinburgh investigated the relationship between adolescent fractures and deprivation(39). They believed this was an important group to study who are often included in adult or paediatric studies despite being a separate group with specific characteristics. The population was subdivided into junior (10 – 14 years) and senior (15-19 years) adolescents. Weighted linear regression using Carstairs index as a factor demonstrated social deprivation was an independent and significant risk factor for hand fractures in senior adolescent males, upper limb fractures in junior adolescent males and upper limb and distal radius fractures in senior adolescent females. All deprivation associated injuries occurred in the upper limb. The authors hypothesised that the mode of injury is the main causative factor in the relationship between fracture and deprivation.

1.3.4 Paediatric fractures and deprivation

There is also evidence linking paediatric fractures with increased deprivation. Stark et al reviewed 2712 children's fractures in Glasgow from a population at risk of 167,972 in 1997(40). They used cluster analysis of demographic variables from census data to split postcodes into three groups; affluent, middle and deprived. Combined fracture rate was significantly higher for children from deprived areas. Prior to this Lyons et al used Townsend scores to investigate fracture rate and deprivation in 2399 children with fractures in South Wales(41). Fractures rates were similar across deprivation groups. More deprived children were more likely to sustain fractures due to assault whereas sports related fractures were more common in affluent areas. The authors commented that they thought the finding of no association with deprivation was surprising and still suggested that injury prevention strategies should be targeted towards deprived areas.

Bridgman et al studied paediatric femoral fractures in the West Midlands(42). Over a 10 year period 3272 children suffered a femoral fracture. When analysed by four year age bands and gender a significantly higher rate of fracture was seen with increasing deprivation for all age-gender groups. Fractures due to road traffic accidents and falls

were 3 times and 1.5 times more frequent respectively in the most deprived areas compared to the most affluent. Similar findings have also been reported for paediatric femoral shaft fractures in Maryland, USA(43). Fracture was associated with low household income, crowding of housing, single mother families and living below the property level.

Another study from the Edinburgh unit used the Scottish Index of Multiple Deprivation to assess for a relationship with deprivation in the 2,195 children who sustained fractures in the year 2000(44). Overall there was a correlation between increasing deprivation and rate of all fractures combined. Analysis by individual fracture types revealed an association with fractures of the metacarpal, distal humerus, clavicle, midshaft of the forearm and metatarsals when compared with more affluent children. Injuries due to falls, road traffic accidents and blow or crush injuries were more common with deprivation. Sports related fractures were more likely in the least deprived children. They felt this may be due to fewer safe areas to play, higher exposure to traffic and less adult supervision in deprived areas(45-48).

1.3.5 Distal radius fractures and deprivation

To my knowledge only one paper has specifically investigated the relationship between distal radius fracture and deprivation. In a study from Edinburgh, Clement et al sought to identify if socioeconomic status influenced the epidemiology and outcome of adult distal radius fracture(49). They identified 3,983 patients with a distal radius fracture over a seven year period and evaluated socioeconomic status with the Carstairs score, dividing the cohort into quintiles according to this. They assessed all initial radiographs and reviewed a further 770 radiographs at one year following injury. Functional assessment at one year was carried out in 644 patients. This involved measurement of range of movement, grip strength and subjective assessment by asking a standardised set of questions such as had the patient regained normal use of the hand. They found that those in the most deprived quintile were significantly younger and sustained the injury 3.1 years earlier than the most affluent

patients. They were also more likely to be male and sustain the injury by a high energy mechanism. There was no difference in functional assessment or radiographic position of the fracture between the quintiles. Interestingly those in the most affluent quintile were more likely to suffer with complex regional pain syndrome.

The authors commented that patients may sustain a fracture earlier due to reduced bone quality but also note that their radiographic findings do not support this as there was no difference in severity of fracture pattern, displacement or comminution between the groups. They conclude that it is not clear whether the age difference is related to diminished bone quality.

The study assessed the whole fracture group together by quintile and compares mean age, gender, mechanism of injury, treatment and radiographic findings. They therefore do not attempt to identify differences between the two peaks of patients seen in the bimodal distribution for distal radius fracture representing fragility fractures in older patients and higher energy injuries in younger patients. Rate of injury is not calculated and they do not make any comparison with the numbers and characteristics of fracture patients and those in the background population without a fracture.

Four other papers have reported some results regarding the association between distal radius fracture and deprivation. In their study from Edinburgh looking at a wide variety of fractures Aitken et al found distal radius fracture was associated with deprivation measured by Carstairs score, for men and women(35). Odds ratio of sustaining a fracture in the two most deprived deciles was 4.2 for men and 3.0 for women compared to those in the other eight deciles. However in a study by the same group looking at only falls related fractures there was no difference in distal radius fracture prevalence across deciles(50). Curtis et al found an association for men but not women using the IMD(27). Ong found no difference between number of patients with distal radius fracture and IMD 2010 quintile in those being treated in a fracture clinic in Nottingham(51).

1.3.6 Hand and upper limb fractures and deprivation

In their study from the Derby hand unit Horton et al reviewed data on 1,234 patients presenting over a 6 month period(52). They used the Index of Multiple Deprivation 2004 and found a significant association with hand trauma and deprivation. Odds ratio for sustaining a hand injury was 1.6 in the most deprived quintile compared to the least deprived. They found that the association was greatest in adults and older children but there was not a constant relationship between deprivation and incidence of hand trauma in older patients or young children. They felt this may be a type two error due to low incidence of trauma in the very young and old.

Sporting injuries were not associated with deprivation and were most common in the least and most deprived quintiles. The authors felt this may be due to the affluent and the unemployed having more time for these activities. Injuries in the more deprived patients required lengthier surgical time, suggesting greater complexity, and self reported physical outcome was worse.

Contrastingly Anakwe et al did not demonstrate an association between hand fractures and deprivation(53). They studied 1,569 fractures in 1,382 patients in Edinburgh and used the Carstairs score to measure socioeconomic status. Only fifth metacarpal fractures in men were associated with deprivation. They felt this was due to mechanism of injury as they were frequently sustained due to assaults, blunt trauma and crush injuries. In women, only the mechanism of injury was related to deprivation, with a significant association seen with an unclear mechanism or the patient being intoxicated when injured. Again, there was no association with deprivation and sporting injury. Rate of surgical intervention was higher in affluent patients suggesting socioeconomic status influences treatment.

Duckworth et al created a multivariate linear regression model to assess the influence of several variables on patient reported functional outcome after proximal radius fracture in 200 patients(54). Socioeconomic status, when assessed by the Scottish Index of Multiple Deprivation (IMD 2009), was a significant factor negatively influencing outcome. The other predictors were a compensation claim and severity of

fracture classification. The model took into account age, gender, mechanism of injury and co-morbidities. When reviewed separately mechanism of injury was not associated with deprivation in this group of patients.

1.4 Deprivation and osteoporosis

As mentioned previously authors of studies investigating fracture rate and deprivation have hypothesised that risk factors for poor bone health such as smoking, poor diet and alcohol would be seen more often in deprived populations. However, the evidence linking social deprivation and osteoporosis is varied. Most studies investigate the relationship between deprivation and fractures and draw conclusions from this rather than directly looking for an association between deprivation and measures of osteoporosis or bone health. In their large study Jones et al found that the risk of osteoporotic fractures in older patients was not related to socioeconomic status(33). A study of 6,160 Italian women who underwent bone mineral density assessment by DXA scan found that osteoporosis was prevalent in 28.7% of the least educated patients compared to 18.3% of the most educated(55). Four times as many women from the most educated group attended the clinic for assessment and more of these were smokers, making comparison with a UK population difficult.

A recent study from Nottingham used the IMD 2010 to assess deprivation and osteoporosis in patients that attended fracture clinic and underwent a DXA scan(51). Similar number and proportion of fracture type were seen across all quintiles. There was no difference in prevalence of osteoporosis between quintiles in those that attended for a DXA scan. There was a lower attendance for a scan in those referred from more deprived quintiles. When interpreting these results it is worth noting that only patients who could be managed as an outpatient are included. Patients were not referred for DXA scan if they did not sustain a low energy fracture, lived in a care home or were thought to be too frail, unwell or cognitively impaired to tolerate a scan, were already being treated for osteoporosis or had a DXA scan in the last three years.

Pearson et al measured heel bone mineral density of 1,187 women in Nottingham(56). Jarman score was used to measure social deprivation. Women in the two most deprived quartiles had a significantly higher prevalence of osteoporosis and lower bone mineral density. The authors felt Jarman score was likely to act as a composite surrogate for other risk factors of osteoporosis. Limitations of the study were a poor uptake of screening from those in deprived areas which led to a mean Jarman score of study participants being much higher than the average for the region. 6% of people in the health authority and 11% in the city are non white but uptake from non white participants was only 0.3%.

A study from Boston, US followed 692 men over 7 years and measured bone mineral density annually. Multivariate models were created to identify which factors influenced change in bone mineral density. Income was used as a measure of socioeconomic status. Lower income was strongly associated with higher loss of bone mineral density measured at the hip, independent of a large number of potential confounders included in the model. Decline in bone mass began relatively early and the rate did not vary with ethnicity or genetic ancestry. They concluded that early life exposures influence peak bone mass which then steadily declines, independent of ethnicity, but income related factors affect the rate of loss(57).

1.5 Deprivation and falls

A further reason for increased fracture rates in deprived patients could be a higher risk of falls. It could be expected that those from deprived communities may have living conditions with hazards like poorer lighting, cramped surroundings and unsafe stairs along with suffering from more medical problems such as visual disturbances, poor balance and postural hypotension, all of which are known falls risk factors. Evidence investigating this is scarce.

In the study by Pearson et al there was no relationship between a history of two or more falls in the past year and deprivation(56). Visual problems were significantly

higher in the three most deprived quartiles. West et al demonstrated a small but significant link between deprivation and falls requiring hospitalisation(58). Admission rate following a fall was 10% higher in the two most deprived quartiles measured by Townsend score. There was no relationship between deprivation and hip fracture. They hypothesised that deprived patients who suffer a minor fall may be more likely to require hospital admission due to medical co-morbidities or lack of social support but that falls severe enough to cause a hip fracture occur independently of deprivation.

In a further study by Court-Brown et al the association between deprivation and 3,843 falls from standing height was investigated(50). This showed an overall association between fall related fractures and deprivation but hip fracture prevalence declined with increasing deprivation. Age at fracture also reduced with increasing deprivation. The authors believed that these findings were due to reduced life expectancy in deprived patients. Gribbin et al investigated falls which occurred in 61,248 patients seen in primary care(59). Incidence of falls and recurrent falls was significantly associated with increased social deprivation measured by Townsend quintile.

1.6 Deprivation and access to health care

Understanding access to healthcare and the relationship with need and demand is complex. Need reflects the requirements for healthcare of a community. Demand is how these services are utilised. Inequality of access results from a discrepancy between need, demand and the supply of these services. Several studies have reported an association between higher levels of primary consultation and deprivation(60, 61). Higher use of inpatient services has been seen in unskilled manual workers and those without access to a car(62, 63). There is evidence that health promotion and preventative services are used less in deprived areas with manual workers 10% less likely to attend their GP for preventative interventions than non-manual workers(64, 65).

It seems likely that the vast majority of patients with an acute distal radius fracture will attend their nearest Emergency Department. A large study of General Practices in England analysed data from 4.5 million patients who had self referred to an Emergency Department and been directly discharged without hospital follow up(66). A negative binomial regression model identified that increasing deprivation quintile was associated with increased attendance at an Emergency Department. It therefore seems unlikely that deprived patients with a distal radius fracture would be less likely to present for emergency treatment.

1.7 Deprivation and health summary

From reviewing the literature investigating the relationship between social deprivation and fractures some trends have emerged. For young patients, who sustain fractures not related to osteoporosis, there appears to be good evidence that increased risk of fracture in those from socially deprived backgrounds is likely to be due to the mechanism of injury. Deprivation seems to have a larger effect on fracture risk of men of all ages. This is thought to be due to lifestyle factors which have an adverse effect on bone health and also increase risk of injury.

The overall evidence investigating the relationship between social deprivation and fragility fractures such as those of the hip is varied. It could be expected that many risk factors for osteoporosis would be more likely to be seen in more deprived areas but in some studies this is not the case. Other factors such as increased activity may offset this. There is some evidence reduced bone mineral density is associated with lower socioeconomic status but several studies do not demonstrate this translates to an increase in osteoporotic fractures. Minimal evidence is available to investigate the relationship between falls and deprivation. There is good evidence that those from deprived areas will attend the Emergency Department when felt necessary so access to acute healthcare treatment seems to be unlikely to affect fracture rate however uptake of preventative strategies is low.

It should be noted that a large proportion of studies regarding fractures and deprivation come from the same trauma unit in Edinburgh which has a well established database for collecting information on all patients who attend. This population is mostly white with a much lower proportion of other ethnicities than Leicestershire. There is also considerable variation in the measures of deprivation used with few studies using the index of multiple deprivation.

1.8 Osteoporosis

1.8.1 Definition of osteoporosis

Osteoporosis is a chronic progressive and metabolic disease. It is the most common bone disease affecting men and women(67). It is most frequently seen in older white women but effects both sexes, all ethnicities and different age groups. Establishing any relationship between osteoporosis and deprivation is one of the key components of this thesis.

Osteoporosis will often present with fragility fractures. These are fractures which occur due to forces which would not normally cause a fracture, such as falls from standing height or less. Osteoporosis is a growing health problem and a huge economic burden across the world. It often leads to ongoing pain, disability and reduced quality of life(68).

It is characterised by reduced bone mass and micro architectural loss of bone tissue(69). This causes bone fragility. There are several different causes for osteoporosis and the pathogenetic mechanisms are complex. Throughout a person's life bone is continually remodelling. Bone is resorbed and this is then followed by bone formation. Osteoclasts resorb bone and control bone remodelling, while osteoblasts form new bone. Osteoblasts also mineralise osteoid and play a role in controlling osteoclast resorption. Resorption by osteoclasts occurs quicker than production of new bone by osteoblasts. Therefore increased bone remodelling leads

to a loss of bone(70). Following increased remodelling bone is initially less densely mineralised so fracture risk is higher(71).

Osteoporosis occurs due to the imbalance between resorption and formation of bone and leads to a reduction in bone mass. This may be due to an increase in resorption or reduction in formation. Oestrogen deficiency is an important factor in the development of osteoporosis. It is important in accelerated bone loss seen after menopause in women but also influences bone loss in men. Oestrogen receptors are found on osteoblasts, osteocytes and osteoclasts. Oestrogen also affects bone through growth factors and cytokines. With increasing age, there is a progressive reduction in osteoblast proportion and bone resorption exceeds formation. Vitamin D and calcium are required for normal bone homoeostasis. Insufficient dietary intake or other problems causing reduced intake or absorption can contribute to the development of osteoporosis. Other lifestyle factors such as inactivity, smoking and excessive alcohol consumption also increase the risk of osteoporosis. These factors have been shown to be associated with deprivation and have been the reason why many researchers have hypothesised that increased fracture rate in deprived areas is related to increased incidence of osteoporosis.

In the third decade of life bone mass is at its highest. If a high peak of bone mass is not obtained by this age then osteoporosis may develop later. Diet and exercise while young are therefore important for future bone health. However, genetics are thought to be the main determinant of peak bone strength. It has been suggested they are responsible for at least 80% of bone mass variance between different people. A large Norwegian study of 7,600 participants reported that forearm bone mineral density is relatively stable up until the age of 50 years(72). After 50 years, bone mineral density in males steadily decreased. In females, there was a decline from the age of 50, with a subsequent further decline after the age of 65. Many studies therefore use the age of 50 as the distinction between fragility fractures and non-osteoporotic fractures.

1.8.2 Diagnosis and measurement of osteoporosis

Bone mineral density is the amount of bone mass per unit volume or area. It can be measured by densitometric techniques. The commonest method uses dual energy x-ray absorptiometry (DXA). This utilises the absorption of x-rays which are sensitive to calcium content of tissue, which is largely bone. Commonly measurements are taken at the lumbar spine and proximal femur.

Bone mineral density is then used for the diagnostic criteria of osteoporosis. This was defined by the World Health Organisation. A Z score compares a patient's bone density with someone of the same age and sex. T score compares their bone density with somebody at their peak BMD. A T score for a woman of 2.5 standard deviations or more below that for a young female adult is classified as osteoporosis(73). The same threshold is used for men. Osteopenia, low bone mass, is defined as a BMD 1 to 2.5 standard deviations below the mean. Fracture risk increases 1.5 to 3 times with each 1 standard deviation reduction of BMD.

1.8.3 Fragility fracture

The classical sites for fragility fracture are the hip, vertebrae and forearm although they may occur almost anywhere in someone with low bone mineral density. Fracture risk exponentially rises with age. After the age of 50 years one in two women and one in five men will sustain a fracture(74). 70% of all fractures are seen in women aged over 65 years(75). Around 300,000 fragility fractures happen every year in the UK(76). This contributes to more hospital admissions than from stroke, myocardial infarctions and heart failure combined(77). With an ageing population, these numbers are rising.

A large report from the European union in 2010 aimed to characterise the burden of osteoporosis in Europe(78). They estimated that 22 million women and 5.5 million men suffered with osteoporosis and 3.5 million fragility fractures occurred in that year. 610,000 were hip fractures, 520,000 vertebral fractures and 560,000 fractures of the forearm. The cost of fractures was estimated at €37 billion. 66% of the cost was due to acute fractures, 29% to ongoing fracture care and 5% to medical therapy. Fractures caused a loss of 1.1 million quality adjusted life years. They also noted that

most individuals at high risk of fracture were untreated and there was a reduction in the number of patients on treatment. The estimated medical care costs for osteoporosis itself in Europe were €36.3 billion in 2000. By 2050 it is thought this will reach €76.8 billion. A study from the Ipswich fracture liaison service which serves a population of 320,000 estimated the cost of treating fragility fractures to be £5.3 million over a one-year period(79).

1.8.3.1 Hip fracture

Fractures of the hip are the fragility fracture which cause the most morbidity, mortality and the largest economic burden. It is estimated that worldwide there may be 21.3 million hip fractures per year by 2050, costing €100 billion. 46,000 hip fractures occurred per year in the 1980s. 85,000 emergency admissions to hospital now occur each year in the UK for hip fractures involving 1.8 million bed days and around £1.9 billion of costs for hospital care alone(80). It is expected that by 2036 there will be an increase of 65% of admissions for hip fracture to 140,000 admissions(81). Average length of hospital stay following a hip fracture is 20.4 days and the median cost for a hospital of treating the primary hip fracture is £8,049(82). In the Ipswich study mentioned above hip fractures accounted for £4 million of the total £5.3 million spent(79). One month mortality following a hip fracture is 8% and at this period only 50% of patients will have returned home(83, 84). Up to 25% of hip fracture patients enter long-term residential care and 60% have ongoing difficulties with daily activities of living such as feeding and dressing themselves(85). 50% of patients who previously walked independently are unable to walk unaided for the first year after a hip fracture(83).

1.8.3.2 Further fractures

Distal radius fracture is an injury of particular interest as it is known to have positive predictive value for subsequent fracture at other anatomical sites including vertebrae and the hip which have high associated morbidity, mortality and management costs(86, 87). Improved understanding of the groups most at risk of distal radius fracture may therefore benefit understanding of fracture epidemiology as a whole and also allow identification of groups at risk of further fracture in whom secondary preventative treatment strategies may be of benefit.

There is mounting evidence that individuals with a previous history of fragility fracture are at an increased risk of subsequent fracture(88, 89). Several studies have demonstrated that distal radius fracture pre-disposes to future hip fracture(90, 91). Haentjens et al observed that short term and long term risk of hip fracture was increased after distal radius fracture(92) . Their findings suggested distal radius fracture is an early and sensitive marker of skeletal fragility, particularly in men. The greatest risk for hip fracture after distal radius fracture has been shown to be within the first year after the distal radius injury(93, 94). The incidence of osteoporotic fracture, including hip fracture, can be significantly reduced with appropriate treatment of high-risk groups(95-97). Evaluation of patients with a distal radius fracture, and initiation of secondary preventative strategies, represents an economically viable opportunity to reduce the incidence of subsequent, and potentially more serious fragility fractures.

1.9 Distal radius fractures

1.9.1 Epidemiology of distal radius fractures

Distal radius fracture is the commonest adult orthopaedic injury and the commonest fracture treated worldwide. It is generally defined as a fracture of the radius within 3 cm of the distal articular surface and this definition is used in this thesis. Distal radius fractureis a huge burden on health care resources and a large cause of morbidity for patients so an understanding of its epidemiology is of high importance(98).

Approximately 70,000 individuals sustain a distal radius fracture in the UK each year. Estimates for the direct medical cost alone for treatment of fractures of the forearm and wrist in the UK have been predicted to total over £35 million by 2020 and distal radius fracture accounts for the majority of these(99). $170 million was paid out in US Medicare for distal radius fracture related payments in 2007. 2.5% of all emergency department attendances in Denmark are due to distal radius fracture(100). A bimodal age distribution is well described(101, 102). Injury may result from high-energy trauma in a young patient, but most commonly follows a fall onto the outstretched hand in older patients with underlying osteoporosis. Distal radius fracture is seen more frequently in younger male patients and older women patients. Up to 18% of all fractures in patients aged over 65 years of age are distal radius fractures(103).

Many epidemiological studies of distal radius fracture have been performed in several different countries with varied incidence rates reported, these are likely to reflect the differences in those populations studied along with the methods of patient identification and data capture(101, 104-108) . In a recent prospective multi-centre UK trial incidence rates of 9/10,000 and 36.8/10,000 person-years were reported for men and women respectively(98).

Several studies have suggested distal radius fracture incidence rate is increasing. Whereas others have not shown any significant change in incidence of distal radius fracture with time. In Oslo Lofthus et al. reported no rise in fracture incidence over a 20 year period while Jaglal et al. actually described a fall in the incidence of osteoporotic hip and distal radius fracture in Ontario over a 13 year period(109, 110). It was felt this was due to a simultaneous increase in preventative strategies such as BMD testing and bone-sparing medication treatment. Fracture liaison services have continued to develop significantly over recent years with publication of specific evidence based guidelines. The benefits of these services is well known and has been clearly demonstrated in the UK(111).

Distal radius fracture rate varies with season and temperature. During the summer months Emergency departments treat the most fractures overall due to paediatric injuries when children are involved in more outdoor activities and not at school(112, 113). In winter adult distal radius fracture rate increases(114, 115). This is most likely

due to falls on slippery outdoor surfaces but evidence is limited. An increased risk of distal radius fracture has been demonstrated in studies from Finland and Rochester, Minnesota(106, 116).

The studies from Rochester reported on the effect of weather and seasonality on hip and distal radius fractures over a 38 year period(116, 117). It was noted that wintery conditions were associated with the greatest increase in incidence of distal radius fracture for women aged 35-65. Increased risk of distal radius fracture was present in older women but was less marked. The risk of hip fracture incidence in women aged over 75 was not influenced by weather. They felt the disparities were related to the mechanism and location of the falls. Compared to hip fractures, distal radius fractures more often occur due to a trip or slip outdoors in mobile patients with good neuromuscular control and who try to stop their fall using their hand(118).

1.9.2 Management of distal radius fractures

There are many management options available for fractures of the distal radius. When deciding on the optimum intervention many factors should be considered such as fracture pattern, patient factors, and cost.

Initial assessment of the fracture should involve whether any reduction is required at all. Following that the form of stabilisation, if required, must be decided upon.

Variation regarding optimum treatment for distal radius fractures is high amongst surgeons. A study in which 33 experienced trauma surgeons were shown radiographs and clinical details of 5 cases and then asked about their favoured treatment options demonstrated a lack of agreement. The most popular method of management was volar locking plate (44%), followed by K-wire (28%); manipulation with cast immobilisation (15%); non-locking plate (7%) and; external fixation (5%)(119).

1.9.2.1 Non –operative management

If the position of the fracture is satisfactory it will not require any reduction and could be stabilised in a cast or other form of splintage.

Evidence suggests that patients aged over 65 have similar functional outcomes whether treated surgically or non-operatively. This has been assessed at 12-months with the patient-rated wrist evaluation (PRWE) and disability of the arm, shoulder and hand (DASH) scores. There is some evidence that casts may not even be required or can be removed after a short period of immobilisation. A randomised trial of patients with minimally displaced fractures over the age of 55 showed that early mobilisation of the wrist without a cast ensured rapid recovery without any of the complications which may be seen with casting(120). Deformity and pain did not increase with early mobilisation.

Closed manipulation and cast application is frequently performed for displaced fractures. Fractures can be manipulated using traction into an improved position under haematoma block or with intravenous anaesthesia in the emergency department or fracture clinic, a moulded cast is then applied. This technique can also be performed under general anaesthetic.

1.9.2.2 Percutaneous Pinning (Kirschner wires)

The National Institute for Clinical Excellence (NICE) recommends the use of Kirschner wires (K-wires) for percutaneous pinning of dorsally displaced distal radius fractures if the fracture does not involve the articular surface of the radiocarpal joint or if displacement of the radiocarpal joint can be realigned by closed manipulation(121). Smooth pins are passed through the skin into the fracture fragments to stabilise them. The wires are usually removed in clinic about 4 weeks later. The technique has been used successfully for many years and is quick, easy to perform and low cost. This treatment usually requires a longer plaster cast immobilisation than with plate

fixation. Early patient rated outcome scores are generally poorer than those treated with volar locking plates but several high-quality trials have not shown a consistent significant difference.

1.9.2.3 Open Reduction and Internal Fixation

Open reduction and internal fixation(ORIF) is often utilised for fractures of the distal radius which involve the articular surface or are thought to be unstable. This technique has risen in popularity since the advent of volar locking plate (VLP) technology. Locking plates have screws which lock directly into the plate creating a rigid construct attached firmly to the bone. Non-locking plate screws rely on friction and are biomechanically inferior(122). Plating requires an incision on the volar aspect of the wrist and dissection down to the bone and fracture fragments. The fracture is then reduced and the plate applied directly to the distal radius. Fixation with a volar locking plate should provide an immediate stable construct allowing early mobilisation of the wrist. However, the increased surgical exposure and plate fixation increases the risk of infection, tendon damage, neurovascular injury and metalwork problems.

1.9.2.4 External Fixation

External fixation is used less frequently but is popular in some trauma units. Metal pins are inserted into the bone and then into an external cage or cast. This method is usually used to decrease the load at the articular surface of the radius to allow bone healing in a high energy fracture, often with significant soft tissue injuries(123). The radiocarpal joint can be spanned or left free(124). There is insufficient evidence to state which method of external fixation technique is superior(125). Complications include a high rate of pin-tract infection (14%) and stiffness.

1.9.3 DRAFFT (Distal Radius Acute Fracture Fixation Trial)

The DRAFFT (Distal Radius Acute Fracture Fixation Trial) was a UK multi-centre, National Institute for Health Research (NIHR) funded study which compared the effectiveness of K-wire fixation and volar locking plate fixation for fractures of the distal radius(126). The trial has had a measurable impact on the surgical treatment of distal radius fractures in the UK and led to a resurgence in the use of K-wires(127). The analysis is high quality and detailed so frequently referenced in this thesis. 416 patients were enrolled in the study. Patients who required surgery were randomly allocated to either treatment group and assessed using PRWE. Exclusion criteria was: fracture >3cm from the radiocarpal joint; open fracture; articular surface could not be reduced indirectly; contraindications to anaesthetic; evidence that the patient would be unable to adhere to trial procedures. 73.5% of patients in the study had an extra-articular distal radius fracture.

The outcome of DRAFFT said that volar locking plates “offered no clinically relevant advantage” over K-wire fixation which is “cheaper and quicker to perform”. Similar findings have been reported by other authors. Goehre et al. found no difference in DASH scores of 40 patients treated with either volar locking plates or K-wires in the Fritz configuration(128).

Further detailed cost-analysis of DRAFFT was performed by Tubeuf et al(129). They found that the total NHS resource cost was significantly higher in the volar-locking plate group than the K-wire group by £903 (260.43, $p<0.001$).

0.008 quality-adjusted life-years (QALYs) were gained by volar locking plate fixation over Kirschner wires, which is the equivalent of 3 days’ good health per year. These were calculated using EQ5D scores with an incremental cost-effectiveness ratio (ICER) of £89,322 per QALY. This is much higher than what is considered acceptable by NICE (£20,000 - £30,000). They concluded that volar locking plates were not cost-effective in the treatment of patients under the age of 50.

1.10 Distal radius fracture radiographic parameters

Plain radiographs of the wrist are mandatory in any patient with a possible distal radius fracture. They are used for diagnosis, prognosis, planning of appropriate treatment and subsequent radiographs can assess healing and further position of the fracture. The fact that almost every patient with a distal radius fracture should have a plain radiograph means that radiographic records can be used to capture almost all patients who sustain a fracture. A large number of radiographic parameters may be measured during the evaluation of distal radius fractures. These include radial height, ulnar variance, dorsal/ palmar tilt, carpal alignment, and intra- articular gaps and steps. These radiographs also include the carpal bones and metacarpals so other information can be gained from them. Some methods exist to estimate bone health from these plain radiographs.

There is minimal evidence to demonstrate the reproducibility and validity of radiographic measurements of distal radius fractures. Most studies were carried out before the modern digital software now commonly used to measure radiographic parameters. Kreder et al. developed a standardised method of measuring eight anatomic parameters at the distal radius to test inter-observer variation(130). Sixteen observers measured these parameters on six radiographs of healed distal radius fractures. The results showed high rater agreement in measurements of palmar/dorsal tilt, ulnar variance and radial shift, but poor inter-observer agreement of intra-articular step and gap. Johnson and Szabo reviewed inter-observer variability in assessment of radial angle and palmar tilt in a cadaver study(131). Mean standard deviation was 3.2 degrees for radial angle, 3.6 degrees for conventional lateral palmar tilt, and 2.1 degrees for 15 degrees lateral palmar tilt.

1.10.1 Radiographic parameters and outcome

A large amount of literature investigating the relationship between radiological parameters and functional outcome exists but the findings are inconsistent. The quality of evidence is low. Most studies are case series and often retrospective. Some expert groups have issued recommendations regarding how much displacement can be accepted before fixation is required but they also acknowledged that the evidence supporting this is weak(132, 133).

Poor functional outcome after malunion with radial shortening or increased ulnar variance has been reported by several authors. Restoration of length has been advocated as the most important factor. In 143 consecutive patients prospectively reviewed by Brogren et al DASH outcome score was significantly higher in those with positive ulnar variance of 1mm or greater(134). In a randomised control trial comparing different treatment methods for distal radius fracture McQueen et al noted that positive ulnar variance of greater than 3 mm, compared with the unaffected side, was associated with reduced grip strength(135). In 78 patients retrospectively assessed after 22 months by Wilcke et al radial shortening ≥2 mm, dorsal angulation >15°, and radial angulation >10° were each significantly associated with poorer DASH scores(136).

In a large study reviewing 260 patients managed non-operatively Finsen et al reviewed 260 patients treated 6 years previously(137). Bivariate regression analysis disclosed a significant relationship between displacement and adverse outcome. The variables studied only explained 23% of the variability of the clinical outcome with radiographic parameters such as dorsal angulation, ulnar variance, and radial inclination only accounting for 11%. The authors concluded that alignment following distal radius fracture only has a minimal influence on clinical outcome. Chung et al found only age and income were significantly associated with outcomes 1 year after surgery in a prospective study of 66 patients treated with volar plating(138). Plant et al recently compared PROMs and physical measures of function with the radiographic measures of palmar tilt and ulnar variance in 50 patients who were treated in DRAFFT(139). The radiographic parameters correlated poorly with physical function measures and patient rated outcome scores at every point assessed (3, 6 and 12 months). The authors felt the results raised concerns about the use of radiological

parameters to determine management and that restoration of 'normal' radiographic parameters may not be necessary to achieve a satisfactory functional outcome.

Age has also been demonstrated to influence the association between malunion and outcome. Grewal et al found that malalignment of the distal radius is associated with increased reported pain and disability in patients aged under 65 years of age(140). In patients aged 65 years and over no radiographic parameter influenced PRWE or DASH scores. There was a decreasing trend with increasing age of a poorer outcome with malalignment, with a significant reduction after 65 years. Other studies have reported similar findings in older groups of patients

A persistent intra-articular step predisposes to the development of radiocarpal degenerative change. Knirk and Jupiter showed a step of 2mm or more led to a 100% incidence of radiological arthritis in 40 young adults at mean follow up of 6.7 years(141). Catalano et al. found 76% of patients with residual intra-articular displacement 7 years after internal fixation of a distal radius fracture had evidence of arthritis(142). This had progressed when reassessed after 15 years by radiographs and CT scans(143). Cadaveric experiments have shown that an articular step affects the biomechanics of the joint with a step of 1mm causing a significant increase in contact stresses(144).

Despite the evidence that articular incongruity leads to radiologically proven arthritis the correlation with symptoms and poor outcome is debatable. Studies by Trumble et al and Chung et al showed that residual articular displacement was associated with a poorer outcome(138, 145). 93% of the patients in Knirk and Jupiter's study were symptomatic. However 61% reported a good or excellent outcome and only one patient who had bilateral fractures had to stop work due to their injury (141). The only functional limitation seen in the 15 year review of Catalano's original study was an insignificant reduction in wrist flexion(143). Kreder et al. found a 9.9-fold increase in the risk of radiological osteoarthritis with persistent articular incongruity after plate fixation but there was no functional difference at one year follow-up(146). Forward et al. retrospectively reviewed 106 young adults with intra-articular distal radius fractures at a mean of 38 years and found DASH (Disabilities of Arm, Shoulder and Hand) scores were not different to population norms and functional impairment was

less than 10% when assessed by the Patient Evaluation Measure(147). Kopylov et al. looked at patients who had sustained a wrist fracture 30 years previously(148). Radiographic osteoarthritis was related to articular incongruity but complaints were limited; 87% of patients reported no difference between their injured and uninjured sides.

1.11 Variation in surgical treatment

Optimum management of distal radius fractures, particularly which fractures require surgical fixation, can be controversial. As discussed above some studies have suggested that only a small amount of displacement can cause a poor outcome whereas others have reported that even with significant malunion long term functional outcome is satisfactory(141-143, 147, 148). Deciding when intervention is required is therefore difficult and high quality guidelines do not exist. Some clinical groups have provided guidance but the evidence to base this on is varied and often low quality(132, 133)

Variation in surgical treatment rate is known to occur in many different interventions including orthopaedic procedures. Studies from the US and the Netherlands have reported variation in distal radius fracture fixation rate(149-151). Variation can be classified as warranted or unwarranted. Some variation is inevitable and random. Warranted variation may describe high quality clinical care. Rates of treatment interventions vary due to individual needs of specific patient populations(152) . Innovation and improvement may cause initial variation. This will decrease after the spread of knowledge and effective innovative methods across trusts.

Unwarranted variation suggests low quality healthcare with activities of low value and waste of resources. There are two main problems – under use of effective interventions and over use of low value interventions. Certain groups such as those from deprived backgrounds may not utilise effective interventions. Over use of low value interventions potentially exposes patients to risk from non-essential treatment,

wastes resources and diverts funding from other patients and better treatments. Understanding the causes of variation allows these problems to be identified and action taken. In this thesis investigation is carried out to see if variation is present in the surgical treatment rate of distal radius fracture in England and to attempt to identify causes for this.

1.12 Quality of care

Measuring quality of care for surgical procedures is challenging. Donabedian et al described three domains: structure, process, and outcomes(153).

Structure relates to the systems and settings in which the care takes place such as ratio of staff to patients and utilisation of electronic records. In surgery the most common structural measure is volume of procedures performed, which is known to be linked to outcome(154). Process measures relate to care that patients receive and may be related to clinical guidelines such as the proportion of diabetics who receive retinal screening or uptake of vaccinations in high risk groups. Outcome measures are regularly used for surgical procedures. The most commonly used is operative mortality but there are many other measurable outcomes such as length of stay, complication rate, readmission rate and patient rated outcome measures.

In this thesis measures of care quality such as operative rate by hospital trust will be reviewed along with direct outcome measures such as length of stay and wait for surgery and the relationship with deprivation investigated.

1.13 Aims of thesis

The overall aim of the work described in this thesis is to improve current understanding of the association between social deprivation and distal radius fractures. Deprivation is known to be associated with many types of fracture but the

reasons for this are not clearly understood. I will attempt to establish if deprivation is a risk factor for distal radius fracture and what are the important individual factors related to this. A distal radius fracture is associated with increased risk of hip fracture. This increased risk will be quantified. Further work will investigate whether deprivation influences treatment of patients with distal radius fracture.

The key research questions addressed are:

Is distal radius fracture associated with social deprivation?

Does social deprivation influence distal radius fracture treatment?

What is the risk of hip fracture after distal radius fracture?

1.14 Overview of thesis

Chapter 2 comprises the general method for the whole thesis. This is referred to in the subsequent individual results chapters and some further specific method detail is found in these chapters. Chapter 3 then describes the reliability and reproducibility of the radiographic measurements used in the thesis. This is important information for clinicians and researchers who frequently carry out these measurements and it is crucial to ensure the radiographic measures used to draw conclusions from in the thesis can be relied upon. Chapter 4 provides a 10 year review of the epidemiology of distal radius fracture in Leicestershire to establish the incidence and burden of this injury. Chapter 5 then investigates the association between deprivation and distal radius fracture in Leicestershire and England. Chapter 6 comprises analysis of variation and care quality for surgical intervention for distal radius fracture including the effect

of deprivation. Chapter 7 reports the results of a prospective survey investigating the relationship between deprivation and mechanism of injury, falls risk and osteoporosis risk in patients aged 50 years and over. Chapter 8 contains a systematic review and meta-analysis of the literature investigating the rate of hip fracture after distal radius fracture. This further establishes the importance of distal radius fracture and its relationship with subsequent fractures. Chapter 9 includes an overarching discussion whilst a final summary and plans for future directions are included in chapters 10 and 11.

Chapter 2 Method

This thesis uses a wide variety of techniques to investigate the research questions. In this chapter the general methods used in the thesis overall and subsequent results chapters are described. Some further specific detail is then provided in the individual results chapters. The results chapters include links back to the relevant methods in this chapter so they can be easily located.

2.1 Settings and population

University Hospitals of Leicester (UHL) NHS Trust provides care to a population of approximately 1 million people living in the city of Leicester, and the surrounding counties of Leicestershire and Rutland. The three areas are grouped together for healthcare provision. In this thesis when I refer to Leicestershire this will describe all three areas unless stated otherwise. The city of Leicester itself had a population of 329,839 in the 2011 Census(155). The city is diverse with 50.6% of the population being white, 37.1% Asian (28% Indian) and 6.3% black. The surrounding County of Leicestershire has a population of 650,500 people. 89% of people are White British, the largest ethnic minority group is Indian who make up 4% of the region. Rutland is the smallest county in the United Kingdom with a population of just 37,400 with only 2.7% of people from ethnic minority backgrounds.

Almost all patients sustaining an orthopaedic injury within these areas are referred for review and follow up at UHL, allowing comprehensive capture of all such presentations within the resident population. There are three hospitals in the city but only one, Leicester Royal infirmary, has an emergency department. This is one of the biggest and busiest emergency departments in the United Kingdom. A small number of minor injuries units may see and treat distal radius fractures in the region but these numbers are very low. Most of these patients would be referred for further management at UHL and almost certainly all displaced fractures which may require

surgery would be referred. Therefore, capture of distal radius fracture data for the region is likely to be very high.

The city of Leicester is ranked as the 21st most deprived area in England in the most recent IMD 2015 report, this is within the 10% most deprived local authorities in England(156). The county of Leicestershire has low levels of deprivation with Leicestershire and Rutland being the two least deprived local authorities in the East Midlands. Comparison with other rural counties again shows Leicestershire to have low levels of deprivation.

2.2 Epidemiology of distal radius fracture in Leicestershire

2.2.1 Patient identification

Details of all patients presenting to UHL with a radiographically confirmed fracture of the distal radius between January 1st 2007 and December 31st 2014 were identified from the Emergency department database. Data is prospectively recorded for all patients that attend the Emergency department. Data was requested and obtained for all patients recorded as having an open or closed wrist fracture, distal radius fracture, Colles fracture, fracture lower end of radius or distal forearm fracture. Data on age, gender, laterality of injury, and the location and date of the injury were collected. A computer generated random sample of 100 patient's radiographs were assessed to check the accuracy of the diagnosis using radiographs and this revealed the accuracy of the ED diagnosis was 97%.

The population at risk was identified by obtaining the adult (18 years and older) population data for Leicester, Leicestershire and Rutland for 2007-16 inclusive from the United Kingdom Office of National Statistics (ONS)(157). The total population at risk was calculated by the addition of the numbers for the three regions. This was calculated for each year of study to ensure accurate incidence rates for that year.

Data were categorised primarily by gender, and age of under and over 50 years of age. Age groups were split at 50 years because bone mineral density is known to reduce after 50 years of age(72). This therefore divides the patients into those who have suffered osteoporotic fragility fractures and younger patients who generally have good bone quality and have suffered injuries from higher energy trauma. This method has been utilized in recent high-quality trials and allows comparison with those results(126). Groups of 10-year age bands were made for some analyses. Season and day of the week of fracture was determined from the date of injury. Location of fracture, when recorded, was reported as occurring at home, in a bar/pub, in the street, in a public place, in the workplace, during sporting activity, following road traffic collision (RTC), or other location.

Date of presentation to ED was used to determine the day of week and season at presentation. Poisson regression modelling was used to investigate trends in fracture incidence, day and season of injury over the study period.

Projections for the future number of distal radius fracture in the UK were made using the calculated fracture incidence rates for Leicestershire and population predictions from the ONS.

2.3 Effect of deprivation on distal radius fracture rate in Leicestershire

From the data collected above a four year sample from 2007 to 2010 was identified for further investigation of the relationship between deprivation and distal radius fracture rate. 4,355 adult patients who attended Leicester Royal Infirmary with a distal radius fracture from January 2007 to December 2010. 77 (1.8%) patients from outside Leicestershire were excluded from the study group as comparison with local data would be inaccurate leaving 4278 (98.2%) for analysis. 3481 patients were white and 797 of other ethnicities (South Asian 629, Black 51, Mixed race 30, Other 87). Patient demographics including sex, age, ethnicity, location of injury, date of presentation and postcode were recorded. Location data was available for 4054 patients (95%).

2.3.1 Index of Multiple Deprivation

The Index of Multiple Deprivation 2010 (IMD 2010) was chosen as the most appropriate measure of deprivation(158). This is the official UK government measure of deprivation and is now frequently used in most deprivation related research. The 2010 version is the most appropriate to the time period studied in this thesis. Quintiles and ranking are used for statistical analysis. Postcodes were used to link each patient to their respective LSOA with its assigned IMD 2010 score and quintile. Accurate post code data was recorded for all patients so IMD score and quintile was available for every patient in the study group.

2.3.2 Incidence rate and deprivation quintile

Population data is available for each LSOA in the studied region by gender, ethnicity, deprivation scores in the following age bands: 16-34, 36-49, 50-64, 65+(155). This data was used to calculate the total denominator of people in each deprivation quintile by gender, ethnicity and age groups.

As I wished to investigate adult fractures in those aged 18 and over estimates were calculated for the age band of 18-49 years to remove those aged 16 and 17 years. Total LSOA population by each year of age and gender is available but this does not include ethnicity or deprivation scores. The relevant LSOA total populations of men and women aged 16 and 17 was obtained. The proportion of each gender and ethnicity per quintile in the 16-34 age group was calculated. These proportions were then applied to the total number of men and women aged 16 and 17 to estimate how many people were in each group. These gender, ethnicity and quintile specific estimates were subtracted from the appropriate group. Groups were then added together to find the denominator by gender in the age groups 18-49 years and 50 years and over.

Incidence rates by quintile, ethnicity and gender were calculated by dividing the number of fractures per year by the population at risk in that quintile.

2.3.3 Surgical treatment

Identification of which patients were treated with surgery was gained using hospital theatre books. These records are kept within the operating theatre and members of staff record the exact procedure, operating surgeon, anaesthetist, patient details and the time and date of the procedure. These generally provide accurate data about surgical procedures. For this detailed four year analysis theatre books were reviewed from Leicester Royal infirmary and Glenfield General Hospital. The vast majority of trauma surgery is carried out at the Leicester Royal infirmary. However, in some very busy periods, such as during cold weather, with a large increase in patients sustaining a distal radius fracture then some additional surgical procedures were carried out at the Glenfield General Hospital. Detail of the dates of the procedure, the type of the procedure performed and patient demographics were obtained from the theatre books.

2.4 Radiographic measurements and deprivation

Radiographs of all patients with a distal radius fracture who underwent surgical intervention in Leicester(n=618) were reviewed along with a 10% computer generated random sample of those treated non-operatively (n=367). Fractures of those who had surgical treatment were classified as intra or extra-articular. Bone density was calculated from the second metacarpal cortical width using the Metacarpal Index (MCI). MCI has been demonstrated in several studies to be a successful assessment of bone mass, bone quality and a predictor of osteoporotic fracture. Dorsal tilt was chosen as a measure of initial fracture displacement. Dorsal tilt measures the angle of the joint surface on a lateral radiograph and is regarded by clinicians as one of the

most important radiographic parameters to measure. Displacement and change in dorsal tilt is most often seen with high-energy trauma and in patients who sustain a fracture with underlying bone fragility. Normal tilt is approximately 11° of volar angulation. Tilt most often become more dorsally angulated following a fracture but it occasionally displaces further volarly depending on the direction of the force causing the injury. To measure displacement the degree of tilt from the normal position of 11° was recorded for all radiographs reviewed. Displacement was measured on the first radiograph available following injury and before any intervention. 219 patients sustained intra-articular fractures. Intra-articular step was measured for these fractures using the longitudinal method. Increasing intra-articular step displacement is also more likely to be seen in fractures caused by high energy trauma or in patients with underlying fragility. Radiographs were evaluated by the primary author and two co-authors following a standardised teaching session.

The association between measures of displacement and MCI with deprivation rank and quintile was then investigated. This was repeated for gender, age and ethnicity specific sub groups.

For any meaningful observations to be taken from the radiographic analysis in this thesis it is essential that the method of measurement was reliable and reproducible. Considerable work was undertaken to ensure this and results are described in chapter 3.

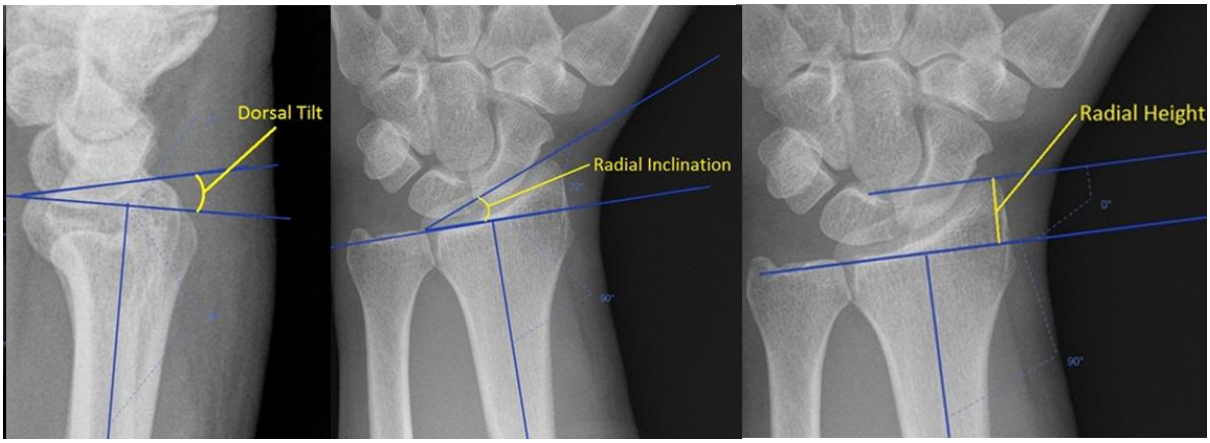
2.4.1 Reliability and reproducibility of radiographic measurements

2.4.1.1 Extra articular radiographic measurements

Two core surgical trainees, both with an interest in pursuing careers in orthopaedics, but with limited clinical experience of the specialty (4 months at the point of training) were trained to perform radiographic measures using a standardised method in a single calibration session. The four most frequently used radiological parameters in

clinical practice were chosen for investigation. Two studies have previously given a detailed description of these measurements, and the methodology used to calculate them as follows(159, 160).

Figure 1 Method of measurement for the extra-articular radiographic parameters of dorsal tilt, radial inclination and radial height



Dorsal tilt (Figure 1) is measured on the true lateral view. It is the angle created between a line drawn between the most distal points of the dorsal and volar lips of the distal radius, and a second drawn perpendicular to the long axis of the radius. Radial inclination is the angle between a line from the tip of the radial styloid to the medial edge of the articular corner of the radius and a line perpendicular to the long axis of the radius. It is measured on the PA view. Radial height is measured on the postero-anterior (PA) view and refers to the distance between a line drawn tangential to the tip of the radial styloid and another tangential to the most distal part of the ulnar head.

All measurements were made using the hospital trust online Picture Archiving and Communication System (PACS) (Agfa HealthCare IMPAX 6.5.2.657). Training involved an individual calibration session, lasting approximately 1 hour, with a senior orthopaedic registrar and a Professor of Hand and Orthopaedic Surgery. A series of ten trial radiographs were measured, with results compared with those of the tutors to check understanding and accuracy of measurements.

A random 10% sample (n= 367) of patients treated non-operatively was computer generated by an independent observer from the Leicester database. No formal power analysis was performed to determine sample size, which was guided by previous investigation of inter and intra-observer reliability of assessment of distal radius fractures(161). All radiographs were reviewed independently by the two trainees with record of each parameter made to 0.1 millimetre and 0.1 degree as appropriate. Repeat measurements of radial height, radial inclination and dorsal/palmar tilt of a further computer generated random 10% sample (n= 37) were made four weeks later to check intra-observer correlation. This was not performed for intraarticular step/gap due to a small sample size. Correlation was assessed using the intraclass correlation coefficient (ICC).

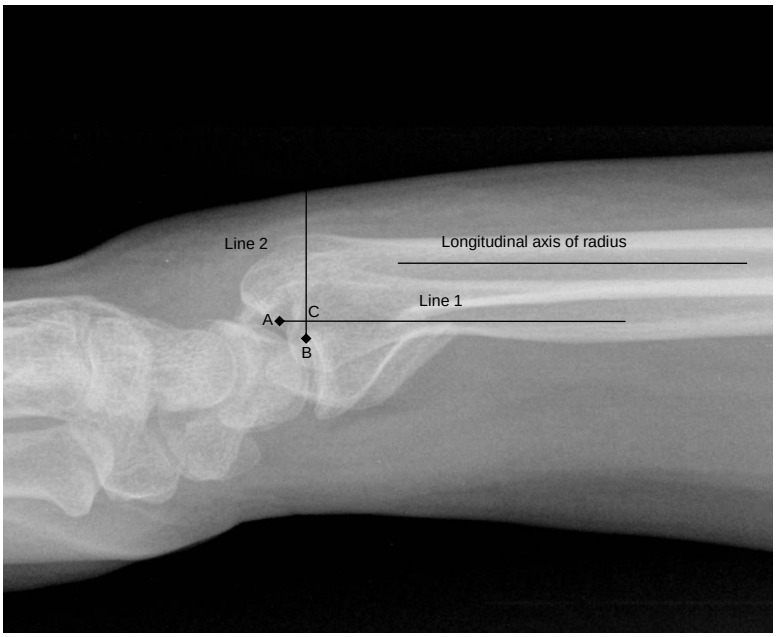
2.4.1.2 Intra articular radiographic measurement

The original sample of 367 patients used for extra-articular measurements only contained 20 patients with an intra-articular fracture. Following some initial exploratory results, it was felt important to investigate the reliability and reproducibility of the intra-articular measures of displacement further.

Two different junior orthopaedic trainees, at a similar stage of their training to the previous two observers were trained to measure intra-articular displacement in a single calibration session as previously described.

Articular step and gap (Figure 2) were measured on the true lateral view using the longitudinal axis method as described by Cole et al. as follows(160). Two points are marked at the subchondral fracture margin of the two most displaced fracture fragments (points A and B). A line (line 1) is drawn parallel with the long axis of the radius through the more central of the two marked points (point A). A second line (line 2) is drawn perpendicular to this, passing through point B. The intersection of line 1 and 2 is marked point C. Step displacement is represented by the distance between points A and C, with gap displacement the distance between points B and C.

Figure 2 Lateral radiograph showing measurement of intra-articular step-off (AC) and gap (BC) using the longitudinal axis method



A power calculation was performed to determine the sample size required. For ICC of 0.2 at 80% power with a significance level of p=0.05, 192 radiographs were required for review but slightly larger samples were used as it was expected that a small number of radiographs may not be suitable for measurement. Radiographs from 200 consecutive adult (age >18) patients presenting with an intra-articular distal radius fracture to UHL Emergency Department in 2015 were prospectively recorded. All radiographs were reviewed independently by the two trainees with record of each parameter made to 0.1 millimetre. Repeat measurements of a computer generated random 10% sample (n= 23) were made four weeks later to check intra-observer correlation. Correlation was assessed using the intraclass correlation coefficient (ICC). The ICC was calculated for all fractures, and then repeated for fractures with displacement ≥ 2mm. The value of 2mm was chosen as it is the amount of intra-articular displacement which would trigger surgical intervention for most surgeons.

2.4.2 Metacarpal Cortical Index

The Metacarpal Cortical Index (MCI) was originally developed in the 1960s for the assessment of Marfan's syndrome and other skeletal conditions associated with arachnodactyly(162). MCI is a measure of the combined width of the cortical bone in the metacarpals expressed as a ratio to the width of the shaft of the metacarpal. MCI can be thought of as the fraction of the metacarpal shaft in cross section occupied by cortical bone. It was first used by Barnett as a diagnostic tool for osteoporosis(163). Although not widely used as an assessment of BMD, MCI has been shown to be significantly associated with known risk factors for osteoporosis (high age, low BMI and smoking) and to be a strong predictor of wrist, hip and vertebral body fracture(164, 165).

In order to be diagnostically useful as a cheap and readily available measure of BMD, MCI needs to be reliable and reproducible, correlate to DXA scan results and be associated with useful clinical outcomes. This analysis aims to determine the inter-observer and intra-observer reliability of MCI, to investigate its use as a measure of BMD compared to central DXA scanning and to study its relationship to patient age and fracture displacement in distal radius fractures.

2.4.2.1 MCI measurement

The original randomly generated 10% sample of 367 patients was again used. 32 patients were excluded as they did not have an AP and lateral radiograph of the distal radius including the 2nd metacarpal available on the UHL digital image viewing software leaving 91% of the original sample (n=335).

The radiographic images for each patient were reviewed independently by two Core Surgical Trainees with no previous experience of measuring MCI. Both reviewers underwent a further standardised training session on how to measure these variables as outlined below.

Measurements were taken of the Inner Cortical Diameter (ICD) and Outer Cortical Diameter (OCD) of the narrowest part of the 2nd metacarpal shaft on an AP radiograph as demonstrated in Figure 3. Measurements were taken to 0.1 millimetre. MCI was then calculated by using the following formula and results rounded to 2 decimal places:

MCI = (OCD-ICD)/OCD

Figure 3 Plain film AP radiograph of a distal radius and hand demonstrating how ICD and OCD measurements are taken from the 2nd Metacarpal

A further random sample of 10% (n=37) of patients from the initial sample underwent repeat measurements of the MCI by the same reviewers 4 weeks after the initial measurements to assess intra-observer correlation. Inter-observer and intra-observer correlation was again assessed using the Intraclass Correlation Coefficient (ICC).

2.4.2.2 MCI and bone fragility

A search was conducted of the UHL Picture Archiving and Communication System (PACS) imaging database to identify all patients who had undergone DXA scanning of the spine and plain film imaging which included an AP radiograph of the 2nd metacarpal between June 2013 and June 2015. 104 consecutive patients who had these two investigations within 90 days of each other were identified. The BMD and the T-score of the spine from the DXA report was recorded and the MCI was calculated by both reviewers for each patient in the same way described above. The T-score was included in the analysis in addition to the BMD as T-score is used by the WHO to define osteoporosis and to guide treatment in many algorithms(166). Further models were constructed to investigate the relationship between MCI with BMD and T-score.

Radiographs were performed according to a standardised hospital protocol, which remained constant throughout the study period for all parameters. The PA view was performed with the wrist and elbow at shoulder height, aligning the joints in the transverse plane, with the hand placed on the cassette, palmar surface down. In this position the radius and ulna are parallel. The lateral view was performed with shoulder, elbow and wrist joints aligned in the sagittal plane, with the ulnar border of the wrist on the cassette.

2.4.3 Intraclass Correlation Coefficient (ICC)

Reliability describes the amount to which measurements can be replicated. This reflects correlation and agreement between measurements. Several tests are commonly used but many only measure agreement (paired t test, Bland-Altman plot) or correlation (Pearson correlation coefficient). Intraclass Correlation Coefficient (ICC) is a useful measure as it incorporates both. The Consensus-based Standards for the selection of the health status measurement instruments (COSMIN) check list was developed to assess methodological quality of studies based on measurement attributes(167). This recommends the ICC as a measurement of inter-rater reliability.

ICC is calculated by mean squares through analysis of variance. 10 forms have been described based on the model (1-way random effects, 2-way random effects, or 2-way fixed effects), type (single rater or mean of several raters) and the definition considered (consistency or absolute agreement). ICC is popular and easy to interpret. A value is obtained between zero and one. One represents perfect reliability whereas zero indicates no reliability. Problems with ICC can include errors selecting and reporting the correct form. ICC is influenced by the variance of the trait in the sample assessed. Therefore, ICC measurements from different samples may not be comparable.

In this thesis the ICC(2,1) form is used to measure reliability. Each radiographic parameter is measured by each rater, and raters are considered to represent a larger population of similar raters. The reliability is calculated from each single measurement. This method is easy to interpret, widely used and appropriate for the evaluation of radiological/clinical assessment methods that are used in routine clinical practise by other clinicians with similar expertise. Sample size was calculated based on a method by Zou which treats interval width and lower limit as random variables and includes a preferred assurance probability(168) (Appendix 7).

2.5 Risk of hip fracture after distal radius fracture

2.5.1 Study group

To identify the risk of hip fracture after distal radius fracture a systematic review and meta-analysis was performed. A multi-disciplinary advisory group was created including a senior clinical librarian, hand and wrist surgeons and a statistical expert. The protocol was reviewed by the group and after each stage of the review and

analysis process a meeting of the advisory group took place at which point any issues were resolved by consensus.

2.5.2 Search strategy and data sources

The senior clinical librarian(PD) searched Medline, Embase, Cochrane CENTRAL database and CINAHL from their inception to July 2015, using the following search terms and subject headings: distal radius or radial, or wrist or colles or smith and fracture*; recurrence or refracture or subsequent or fragility or osteoporo* or predict or future; hip* or femur* or femoral or trochant* or pertrochant* or intertrochant or subtrochant* or subcapital* or extracapsular*. These search terms were selected from previous studies and through discussion of the topic in meetings of the study advisory group.

The abstracts of articles were then screened and filtered according to the study inclusion and exclusion criteria. The authors also retrieved potentially relevant articles and reviewed their reference lists for additional articles. There were no language restrictions to the search.

2.5.3 Study selection

To be eligible studies had to meet the following inclusion criteria defined in our protocol(Appendix 1): Men or women suffering a radiographically confirmed wrist fracture and a subsequent radiographically or surgically confirmed hip fracture. The relative risk(RR), odds ratio or hazard ratio(HR) (with p value or 95% confidence intervals) must be reported or the actual number of outcome events provided. Study types for inclusion were prospective longitudinal studies or high quality retrospective studies.

2.5.4 Data extraction and quality assessment

After initial screening, full papers were obtained of those selected and assessed against the inclusion criteria by two independent reviewers (NJ, ES). Difference in assessments were resolved by consensus with the study advisory group.

Data extraction and quality assessment was performed for the studies selected following the second stage of screening. Data extraction was carried out using a modified Cochrane data collection form (Appendix 2). Data items collected included study type, source of funding, setting, start/end date, length of follow up, number of patients with distal radius fracture, method of diagnosis, number of patients with subsequent neck of femur fracture, time to hip fracture and RR, HR or odds ratio.

Quality assessment was carried out using a modified Coleman score (Appendix 3) and the Newcastle Ottawa scale for cohort studies. An assessment of bias was performed for each individual study using a modified Cochrane Risk of Bias tool (Appendix 4). Findings were reviewed at a meeting of the advisory group and studies of poor quality or high risk of bias were excluded.

2.5.5 Statistical analysis

A pooled RR with 95% confidence intervals was estimated from the RR/HRs or odds ratios and confidence intervals reported in the studies. This was calculated from the average of the logarithms of the individual relative risks weighted by the inverse of its variance. HRs and odds ratios were considered to correspond to RRs.

The I-squared and tau-squared statistics were used to evaluate the statistical heterogeneity. Random effects and fixed effects models were both calculated. With low heterogeneity a fixed effects model is appropriate. The random effects model was produced using the Der Simonian and Laird method. Analysis was performed using the meta package (version 4.1-0) in R.

2.6 National data

2.6.1 Hospital Episode Statistics data

Hospital Episode Statistics (HES) data is described as a data warehouse. It is data collected whenever a patient attends an NHS hospital in England and contains details of emergency department visits, outpatient appointments and admissions. The data is reported annually from April to March in the following year. It includes private patients treated in NHS hospitals and those resident outside of England. The data is used to pay hospitals correctly for delivering care. Each record for each period of care is stored separately. A huge amount of information is available. This includes the age of the patient, gender, ethnicity, diagnosis, comorbidities, procedures performed and the individual IMD deprivation score for that patient. Other information includes the day a patient was listed for surgery, if day case surgery was planned and if it was carried out as a day case, and length of stay in hospital. Wait for surgery can also be calculated using the operation date and date of presentation or date listed for surgery. HES data was obtained from April 2009 to March 2013. This was used to answer several research questions regarding deprivation and surgical treatment.

2.6.2 Diagnosis

HES data lists diagnoses and surgical interventions using ICD-10 and OPCS codes. The International statistical classification of diseases and related health problems (ICD-10) is a comprehensive list of codes for diseases, injuries, signs, symptoms and related social problems(169). It is created and maintained by the world health organization. The 10th revision was completed in 1992. The OPCS classification of interventions and

procedures is the national health service classification list covering procedures and interventions performed in UK NHS hospitals(170).

A search algorithm was created to filter the whole HES dataset and identify those who had an acute distal radius fracture from ICD-10 codes (International Classification of Diseases: ICD-108 codes S525 - fracture of lower end of radius - and S526 - fracture of both lower end of radius and ulna). OPCS codes were used to identify all methods of primary surgical intervention including plating, Kirschner wires and external fixation.

59,802 surgical procedures were performed in 130 hospital trusts during the four year period. This data was used to analyse rate of variation per hospital trust. Full data including ethnicity, deprivation and date of surgery was known for 59,315 procedures. This data was used for modelling the effects of deprivation and ethnicity on treatment rates and measurements of quality of care.

2.6.3 Deprivation, ethnicity and rate of fixation

To investigate the effects of deprivation and ethnicity on national fixation rate the background populations must be known. Deprivation data for England by decile is available for ethnicity and gender in age bands of 0-24, 24-49, 50-64 and 65+. Population data by IMD decile is available for 0-15 year olds, this is split by gender but not ethnicity. Number of people aged 16 and 17 years old by gender and ethnicity is available for England. A similar method as previously described in section 2.3.2 was used to create gender, ethnicity, deprivation group estimates for those aged under 18 and subtracted from the 0-24 group.

The proportion of each ethnic group by decile and gender was calculated for the 0-24 age group and these proportions applied to the 0-15 years population data and estimates for each deprivation and gender group calculated. These proportions were then applied to the population data for 16 and 17 year olds. These ethnicity, age and gender specific estimates were subtracted from the 0-24 group to give a 18-24 group. This was then used to create ethnicity gender specific quintiles for 18-49 year olds and

50 years and over by combining deciles and the age groups. Number of procedures performed in each subgroup was gained from the HES dataset. 59,315 patients were included in this part of the analysis. 95% (56,372) of patients were white, 2.5% (1,482) Asian, 1.7% (1,017) other named ethnic group and 0.7% (444) black.

2.6.4 Analysis of variation

The NHS atlas of variation series provides reports on national variation of important health treatments and investigations in the UK with the aim to reduce unwarranted variation. The first report was published in November 2013 and demonstrated clear geographical variation in health care access and service provision levels. The methodology used involves excluding the seven trusts with the highest and lowest rates to remove outliers(152). The magnitude of the difference between the remaining highest and lowest rates is then reported. The method is used in this thesis to investigate variation in distal radius fracture surgical intervention. A negative binomial model is also produced to assess the influence of deprivation, hospital trust, hand specialist unit and trust population characteristics on surgical intervention rate.

2.6.5 Temperature

Weather is known to affect the incidence of injuries and low temperatures increase the risk of falls and distal radius fracture. Minimum daily temperature was gained from the Centre for Environmental Data Analysis for each day of the study period(171). This was then linked to each patient's date of presentation with a distal radius fracture and used as a variable for the statistical modelling.

2.6.6 Hospital trust data

Summary data for each hospital trust was obtained(172). This provided a mean patient IMD score for the trust and the total population of the trust split by gender and age groups. Number of women and number of patients aged over 65 years are included in some models as fragility fracture is seen more frequently in these groups.

2.6.7 Comorbidities and Charlson index

ICD codes were also used to identify medical co-morbidities. Diabetes was included as a separate variable in some models as it was felt it may directly influence type of treatment, wait for surgery and whether the patient is suitable for day case surgery. The Charlson co-morbidity index predicts 10 year mortality based on medical co-morbidities(173). Scores are given for certain significant co-morbidities and increasing age. A higher score indicates increased mortality rate. An algorithm was used to calculate the Charlson score for each patient from the HES data.

2.6.8 Semi-elective trauma surgery

2.6.8.1 NICE guidance

The National Institute for clinical excellence is a non-departmental body of the Department of Health which aims to improve health and social care through evidence-based guidance. High-quality reviews of evidence are produced from expert multidisciplinary groups to provide recommendations and clinical guidelines. Adherence to the guidelines may influence funding which a hospital trust receives.

Recent NICE guidance has recommended that intra-articular fractures undergo surgery within 72 hours and extra-articular fractures undergo surgery within one week(121). The rationale for this is that within 72 hours organised haematoma may form which will prevent accurate reduction of intra-articular fragments. A significant portion of distal radius fractures requiring surgery will have intra-articular

displacement. These complex fractures will often require treatment by an experienced trauma or hand surgeon. To ensure these guidelines are met hospitals must therefore have experienced specialist surgeons available at almost all times.

Day case surgery is safe, cost efficient and popular with patients. With new anaesthetic techniques, the use of day case surgery for fracture fixation is becoming increasingly popular. Fractures of the upper limb can often be safely treated in this manner. This frees up hospital beds and saves resources. Some concern does exist that if patients are sent home to wait for this "semi-elective" trauma surgery that they may end up having their surgery delayed if patients are admitted with more serious injuries or injuries which necessitate hospital admission such as a fractured neck of femur. As they are not occupying a bed then they are more likely to be cancelled or delayed in times of many acute admissions.

2.6.9 Hospital Episode Statistics analysis

Using the data described above a series of regression models were designed to investigate the relationship between several measures of the quality of treatment with IMD score along with a large number of independent variables in patients who required surgical fixation for a displaced distal radius fracture (Kirschner wires, plating, external fixation).

Independent variables included:

Patient details: age, gender, ethnicity, comorbidities, Charlson index, patient IMD score, procedure

Hospital trust details: total population, population aged 65 or over, population of women, cases performed per year, cases performed that month

Date/seasonal details: year, day of week, month, cases performed per year per trust, cases performed that month per trust, minimum temperature

Treatment factors investigated were:

Rate of variation of surgical fixation

Pre-operative wait for surgery

Rate of daycase surgery

Post-operative hospital stay

Wait for semi-elective surgery

2.7 Prospective investigation of fracture risk

The primary aim of this part of the study was to identify if deprivation was associated with falls risk, mechanism of injury or osteoporosis in patients with a distal radius fracture.

2.7.1 Survey method

Using the same emergency department database all patients with a distal radius fracture were prospectively identified following attendance at the Emergency Department. This component of the study was carried out for a 12 month period from April 2015 to March 2016. All radiographs were analysed to ensure only patients with a confirmed distal radius fracture were included in the study. Patients from outside the region or of no fixed abode were excluded as deprivation data would not be available. Death checks were carried out and any patients who died were removed from the study.

Following identification of suitable patients, a questionnaire was posted to them with a stamped addressed envelope for return. Non-responders were sent up to 2 further questionnaires.

2.7.2 Survey design

A survey was designed specifically for the study. It included questions regarding place and mechanism of injury, a falls risk assessment tool, FRAX assessment of bone health and fracture risk, EQ5D, comorbidity assessment and patient rated wrist evaluation (PRWE) (Appendix 5).

2.7.2.1 Patient-Reported Wrist Evaluation (PRWE)

PRWE is a patient rated outcome measure for wrist problems(174). It is a questionnaire which contains two scales of pain and function. There are five pain questions in which patients are asked to provide scores between 0 and 10 (0 = no pain, 10 = worst pain ever). There are 10 functional questions which contain four questions about everyday activities and six questions regarding specific activities. They are scored by the patient between 0 and 10 (0 = no difficulty, 10 = unable to do). An overall score out of 100 is calculated with a higher score indicating poorer functional outcome. The optimum PROM for distal radius outcome evaluation has yet to be established but the PRWE is relatively quick and easy to use and has been favoured in recent multi-centre trials investigating outcome after distal radius fracture. In this study, it is collected to provide a baseline for future follow up studies.

2.7.2.2 EuroQol EQ-5D-5L

The EuroQol EQ-5D-5L health questionnaire is a generic patient-reported outcome measurement of well-being(175). Responders are asked to select one of five options (eg; no problems, slight problems, moderate problems, severe problems, unable to) for five different domains (mobility, self-care, usual activities, pain/discomfort, anxiety/depression. They are also asked to rate their overall health on a scale of 0 (worst imaginable health) to 100 (best imaginable health). The EQ-5D-5L is not specific for acute distal radius fracture but can be a useful tool in long-term patient management and is frequently used in high quality studies.

2.7.2.3 FRAX®

FRAX® is a freely available online tool which calculates the 10-year probability of hip fracture or a major osteoporotic fracture(176). A major osteoporotic fracture is defined as a clinical spine, hip, forearm or humerus fracture. It was developed by the University of Sheffield and launched in 2008. It is used for around 2.8 million fracture calculations each year and has been shown to be robust, effective and is approved by NICE. It can be used with or without femoral neck bone mineral density measurements.

Age, gender and height and weight measurements are required for each patient. The following risk factors are assessed with a simple yes or no response:

Previous fracture

Parental hip fracture

Current smoker

Glucocorticoid use (for more than 3 months)

Rheumatoid arthritis

Secondary osteoporosis

Alcohol (3 or more units per day)

After inputting the data, the tool calculates percentage scores for 10 year risk of a hip fracture and 10 year risk of other major osteoporotic fracture. Both FRAX scores were calculated for all patients in the study.

2.7.2.4 Falls risk assessment

NICE recommend a falls risk assessment for people who have had one or more falls or are considered to be at risk of a fall(177). They also acknowledge that there is a lack of

evidence about which assessment tool is most predictive and useful. Most assessment scales were developed for the elderly in hospital settings or nursing homes(178). Rubenstein et al developed and validated a falls risk self assessment questionnaire following rigorous qualitative analysis(179). The work was commissioned by the US Centre for Disease Control and Prevention and required to meet the American and British Geriatric Society Guidelines. It was designed to be used in a falls risk self-assessment brochure that could be used as a screening tool and for public health education. It is now widely used in falls prevention initiatives in the US such as the national STEADI (Stopping elderly accidents, deaths and injuries) and the Ohio U Steady falls prevention programs(180, 181). It was chosen to be used in this study as it is appropriate to be used by community dwelling individuals and is designed to be a quick and simple checklist which is suitable for a postal survey (Appendix 6). Respondents circle yes or no regarding twelve statements about falls risk factors. Two of the statements ("I have fallen in the past year", "I have been advised to use a cane or walker to get around safely") score 2 points while all others score 1 point. A total of 4 points or more suggests the respondent is at risk of falling.

2.7.2.5 Analysis

Comparison of responders with non-responders is performed to ensure the results are applicable to the underlying population. Categorical results of quintiles 1 and 2 are compared with quintiles 3 to 5 using the Chi squared test. Linear regression analysis is performed to investigate the association between FRAX scores and falls risk with IMD rank. This is then repeated for each individual risk factor.

2.8 Statistical analysis

All statistical analysis was performed using R. A list detailing which packages were used is included as appendix 7.

2.8.1 Modelling

Many regression models are used throughout this thesis. Each model was chosen independently as the most appropriate model for the specific research question. In this section an overall review is provided of the models used, their interpretation and the reasons why they were chosen. In the subsequent chapters the results are linked back to the appropriate text in this section.

2.8.1.1 Linear regression

Linear regression is used to describe the relationship between a dependent variable(Y) and an independent or explanatory variable(X). An equation is given for the straight line that describes the change in the Y variable with an increase in the X variable. This is the equation of the regression line. It includes an intercept and the slope of the line. These values are calculated to minimize the sum of the squared vertical distances of the points from the line. This is known as a least-squares fit. The slope can also be known as the regression coefficient. A significant positive coefficient means that the Y variable increases with an increase in X. Multivariate regression investigates the relationship with multiple explanatory variables. This dependent variable must be continuous. Multivariate regression is used to analyse the relationship between osteoporosis and falls risk factors with deprivation, age and gender.

2.8.1.2 Generalised linear models

Generalised linear models are an extension of linear regression. They can be used with continuous dependent variables and the distribution does not have to be normal but should be a member of the exponential family.

Covariates are included which act through a linear predictor along with a link function. The linear predictors influence the mean of the dependent variable through the link function. This enables the dependent variables to have a non-linear relationship with the independent variables without forcing a linear relationship. GLMs were popularized in the 1980s by McCullagh and Nelder assisted by the development of new computer software(182).

2.8.1.3 Poisson regression

Poisson distribution occurs with events that can only be counted in whole numbers and cannot be negative, they occur independently and the average frequency of occurrence is known for a given time period. It is often used for relatively rare events such as an injury like a fracture. A poisson distribution curve will always show skew to the right but this will decrease with an increasing number of events. It was famously described in 1898 for the chance of a soldier in the Prussian army being killed by a horse kick(183).

Poisson regression is therefore appropriate for modelling count variables. It is used extensively in this thesis as it is suitable for modelling the relatively rare event of a distal radius fracture occurring during a given time period. It is assumed that the response variable demonstrates a poisson distribution. The link function is the log which means all parameter estimates must be exponentiated to aid interpretation.

2.8.1.4 Robust standard errors

Robust standard errors are calculated to control for inaccuracies due to assuming that variance equals the mean(184). These were calculated using the sandwich method.

This calculates standard errors for the coefficients without assuming that the variance of the residual errors is constant. Confidence intervals were calculated from these robust standard errors.

2.8.1.5 Offset

Poisson regression involves the modelling of counts of data. In clinical practice, it is more likely that we are wanting to compare rates of a disease or condition. We therefore need to know the population at risk and include it in the model. This is dealt with by adding an offset parameter to the model. In this thesis, this is frequently the specific group at risk by age, gender, ethnicity and deprivation quintile.

A simplified example of the code for the poisson regression deprivation models is provided below;

Number of fractures~ethnicity+deprivation quintile+age group+gender+offset (log (population at risk))

2.8.1.6 Logistic regression

Logistic regression is another generalised linear model. This is used for data with a binary response outcome. This is used in this thesis for investigating the factors associated with day case surgery. The dependent variables are binary ie surgery as a day case or surgery not as a day case.

2.8.1.7 Negative binomial regression

Negative binomial regression is a variation of poisson regression. It is based on a poisson gamma distribution mixture. In contrast to poisson regression the variance is larger than its mean. It can be used for over dispersed count data. In these cases, the

variance exceeds the mean. It contains an extra parameter to model the over dispersion. This type of model is used for the analysis of variation in surgical treatment rate between hospitals. Over dispersion was present when other models were initially tested and this could not be reduced with forward selection.

2.8.1.8 Generalised linear models interpretation

GLM output can be interpreted in several ways. Coefficients for poisson, negative binomial and logistic regression are given on the log scale. Therefore, the expected log count of the rate decreases or increases by the coefficient value for each one-unit change in coefficient. They can also be thought of as the percentage change in the dependent variable with a one unit change in the covariate ie if modelling rate against population gives a significant coefficient of -0.2 then rate will decrease by 20% with each one unit increase in population. When categorical factors are included in the model the results will show coefficents in relation to one of the factors, the reference group, ie if gender is used in the model the output would show a result for one gender only such as male = 0.2. If this is significant it means that men have a significantly higher effect on the dependent variable and an increase in the dependent variable of one unit would see a 20% higher increase for men than women. Exponentiating these results gives an incidence rate ratio of 1.22 meaning the effect of men is 1.22 times that of women. Incidence rate ratios are frequently used for the deprivation quintile regression results to compare incidence rate of patients in the most deprived quintile with those in the other quintiles.

2.8.1.9 Random effects

Data is frequently structured in a hierarchical fashion. This may occur due to many reasons but in medicine may be due to treatment by different clinicians or at different hospital trusts. Assumptions of independence may therefore not be accurate. An

effect is being caused by a factor who's specific value may not be of interest. This is the case when investigating the relationship between measures of treatment, such as wait to surgery, and other patient related factors. Initial testing revealed large differences dependent on hospital trust. Whilst this was interesting information I wish to investigate the other specific factors such as deprivation and ethnicity whilst also acknowledging the effect of the hospital trust in the model. A solution to this is to include the hospital trust in the model as a random effect term. The random effects are treated as variables with a mean of zero and an unknown variance.

A generalised linear mixed model is a further extension to a generalised linear model which also includes a random effects term. These were created for a logistic regression model and several linear regression models investigating the relationship between measures of quality of treatment with deprivation and other patient factors by adding the hospital trust as a random effect.

P values were estimated using the Kenward Rogers method. P values are not part of the initial output of the random effects mixed model as it is unclear about the degrees of freedom of the t statistic. The Kenward Rogers approximation is reported to obtain the most accurate significant tests from a multi-level model(185). The method involves adjusting both the F statistic and its degrees of freedom to calculate an approximate p value.

2.8.1.10 Overdispersion

Over dispersion occurs when the variance is larger than the mean. It means that there is more variation seen within the data than one would expect. Reasons for this may include that certain important explanatory variables have not been included in the model. Over dispersion is common as data from populations is often heterogeneous whereas common models make simple assumptions. It does indicate that the model is not appropriate. Over dispersion was initially seen in some of the deprivation models but after identifying and adding interactions to the model this was corrected. Over dispersion remained present with regression analysis of variation in surgical treatment

between hospital trusts despite addition of interactions. That data was being compared between hospital trusts and this was an important factor which needed to be included in the model. In this case a different method was chosen for analysis. Options include a negative binomial model or quasi likelihood estimation.

2.8.1.11 Under dispersion

Under dispersion is rare and occurs when less variation is seen between data than expected. This was not seen in any of the models tested or used in this thesis.

2.8.1.12 Generalised additive models

Generalised additive models are another extension of the GLMs. They were invented by Trevor Hastie and Robert Tibshirani in the 1980s(186). They are a technique where the effect of predictive variables is captured using smooth functions. These may be non-linear and can be used for non-parametric data. The relationships between the dependent variable and the predictors follow smooth patterns. They can demonstrate a non-linear pattern that a classic linear model would not identify. The smoothness is determined by smoothing functions which are estimated from the data. They are used to investigate the relationship between IMD rank and continuous variables of radiographic measurements.

The model was chosen using the Bayesian Information criterion model selection tool. This attempts to reduce the risk of error using a penalty term. This increases with the number of parameters. It therefore penalizes complicated models which have too many parameters for accurate estimates of that sized dataset. A smaller score indicates a better model.

2.8.1.13 Model selection

Models were selected using forward selection. An initial model was created using only one variable then other variables added one at a time. The deviance is checked and those that add the largest significant drop in deviance are added to the model. This process is repeated until the model cannot be improved or no variables can be added. Interactions were tested and added if they would reduce the deviance. In some cases, variables were noted to significantly interact with all other variables so separate models were created.

2.8.2 Multiple imputation

Multiple imputation is a strategy for dealing with missing values in datasets. A set of plausible values are given for each missing value. The datasets created can then be analysed with standard methods and the results combined. A classification and regression tree method of imputation was used in this thesis. Missing height and weight survey data was imputed using the already known data of gender, age, deprivation rank, number of comorbidities, falls risk factors and other osteoporosis risk factors

2.8.3 Prediction intervals

The relationship between hospital trust population and surgical treatment rate is presented as a scatter plot with 95% prediction intervals. These differ from confidence intervals which describe how well the mean is determined ie 95% confidence intervals should contain the true value of the mean 95% of the time. The prediction interval states where the next observation, not the mean, is likely to fall. It describes the distribution of values rather than the uncertainty in establishing the mean.

2.8.4 Other tests

Deprivation quintiles were analysed in two ways. Deprivation population data was non-parametric. With large samples the kruskal-wallis test was used to identify any difference between the five groups. When sample size was smaller quintiles 1 and 2 were combined, and compared with the combined quintiles of 3 to 5 to produce a simpler deprived versus non-deprived analysis. Mann whitney U test was then used for non-parametric and t-test for parametric data. Chi squared test was used to compare categorical data such as mechanism or place of injury.

2.9 Permissions

Full permission was granted to access and use HES data for the study purposes from the Health & Social Care Information Centre. Local audit approval was granted to review patient demographics, radiographs and contact patients by survey. Permission was given to access census data and historical climate data for academic purposes by UK data service, census support and the Centre for Environmental Data Analysis respectively.

Chapter 3 Reliability and reproducibility of radiographic measurements

To allow significant findings to be gained from radiographs the methods used to measure the parameters must be reliable and reproducible. Results are presented investigating this for the commonly measured radiographic parameters of distal radius fracture displacement along with metacarpal cortical index and its relationship with bone mineral density. Intraclass correlation coefficient was used to measure inter-observer and intra-observer correlation between measurements (section 2.4.1.1 & 2.4.1.2). A generalised additive model was used to investigate the relationship between MCI and BMD, T-score, age and fracture displacement (section 2.4.2 & 2.8.1.12).

3.1 Extra-articular radiographic measurements

A random sample of 367 patients was computer generated by an independent observer. 341 patients had postero-anterior radiographs suitable for measurement of radial height and radial inclination. Measurement of dorsal tilt was possible on lateral radiographs from 338 patients**.**

Inter-observer correlation was excellent (> 0.8) for radial height, radial inclination and dorsal tilt between the two observers (Table 1). Intra-observer correlation was also excellent when repeat measurements of 10% of the sample were repeated four weeks after the original measurements.

Table 1 Measurement of inter-observer correlation between the two observers with 95% confidence intervals for common extra-articular radiographic parameters

	ICC	**CI - high**	**CI - low**	**N**
Radial height	0.9	0.88	0.92	341
Radial inclination	0.86	0.83	0.88	341
Dorsal Tilt	0.93	0.92	0.95	338

Table 2 Intra-observer correlation between the two observers with a 10% retest sample 4 weeks after initial measurements for common extra-articular radiographic parameters

	ICC	**CI - high**	**CI - low**	**N**
Observer 1				
Radial height	0.95	0.97	0.91	37
Radial inclination	0.87	0.93	0.77	37
Dorsal Tilt	0.99	0.99	0.98	37
Observer 2				
Radial height	0.98	0.99	0.96	37
Radial inclination	0.88	0.94	0.78	37
Dorsal Tilt	0.99	0.99	0.97	37

3.2 Intra-articular radiographic measurements

200 patients with intra-articular fractures were identified, 193 had satisfactory lateral radiographs suitable for measurement of intra-articular step and gap**.** Radiographs were deemed unsuitable for inclusion if incorrect positioning of the wrist had resulted in rotational distortion preventing appropriate visualisation of the longitudinal axis and true volar and dorsal lips of the distal radius required for accurate measurement.

Inter-observer correlation was poor (< 0.4) for articular step and gap measurements of the whole sample (Table 3).

Measurements were then repeated for fractures with displacement ≥ 2mm. This value was chosen as this displacement is likely to cause functional impairment and would be most surgeons threshold for surgical intervention. Correlation was also poor in this group. (Table 4).

Table 3 Measurement of inter-observer correlation between the two observers with 95% confidence intervals (whole sample) for intra-articular radiographic parameters

	ICC	**CI - high**	**CI - low**	**N**
Intra-articular step	0.030	-0.111	0.17	193
Intra-articular gap	0.37	0.24	0.48	193

Table 4 Inter-observer correlation between the two observers with 95% confidence intervals (fractures with displacement ≥ 2mm) for intra-articular radiographic parameters

	ICC	**CI - high**	**CI - low**	**N**
Intra-articular step	-0.4174	-0.595	-0.20	68
Intra-articular gap	-0.049	-0.314	0.22	52

Intra-observer correlation (Table 5) was poor for both parameters assessed by observer 2. Correlation was good (0.6 – 0.74) for assessment of gap but poor for step measurement by observer 1.

Table 5 Intra-observer correlation between the two observers with a 10% re-test sample four weeks after initial measurements for intra-articular radiographic parameters

	ICC	**CI - high**	**CI - low**	**N**
Observer 1				
Intra-articular gap	0.69	0.4	0.85	23
Intra-articular step	0.18	-0.23	0.54	23
Observer 2				
Intra-articular gap	0.04	-0.36	0.44	23
Intra-articular step	0.12	-0.29	0.50	23

3.3 Metacarpal Cortical Index (MCI)

3.3.1 MCI measurement

From the same sample used for extra-articular measurements 335 AP radiographs demonstrated the 2nd metacarpal allowing measurement of MCI. Inter-observer correlation for MCI measurements was high between the two observers with an ICC value of 0.85 (95% confidence interval 0.82-0.88).

In the 37 patients that were retested by both reviewers 4 weeks after the initial data collection to determine intra-observer reliability, ICC values also remained high at 0.93 and 0.91 for each reviewer respectively (See Table 6).

Table 6*:* Intra-observer Correlation with 95% Confidence Intervals (CI) for MCI measurement

	ICC	95% CI high	95% CI low	N
MCI (Reviewer 1 retest)	0.93	0.96	0.86	37
MCI (Reviewer 2 retest)	0.91	0.95	0.84	37

3.3.2 MCI and age and fracture displacement

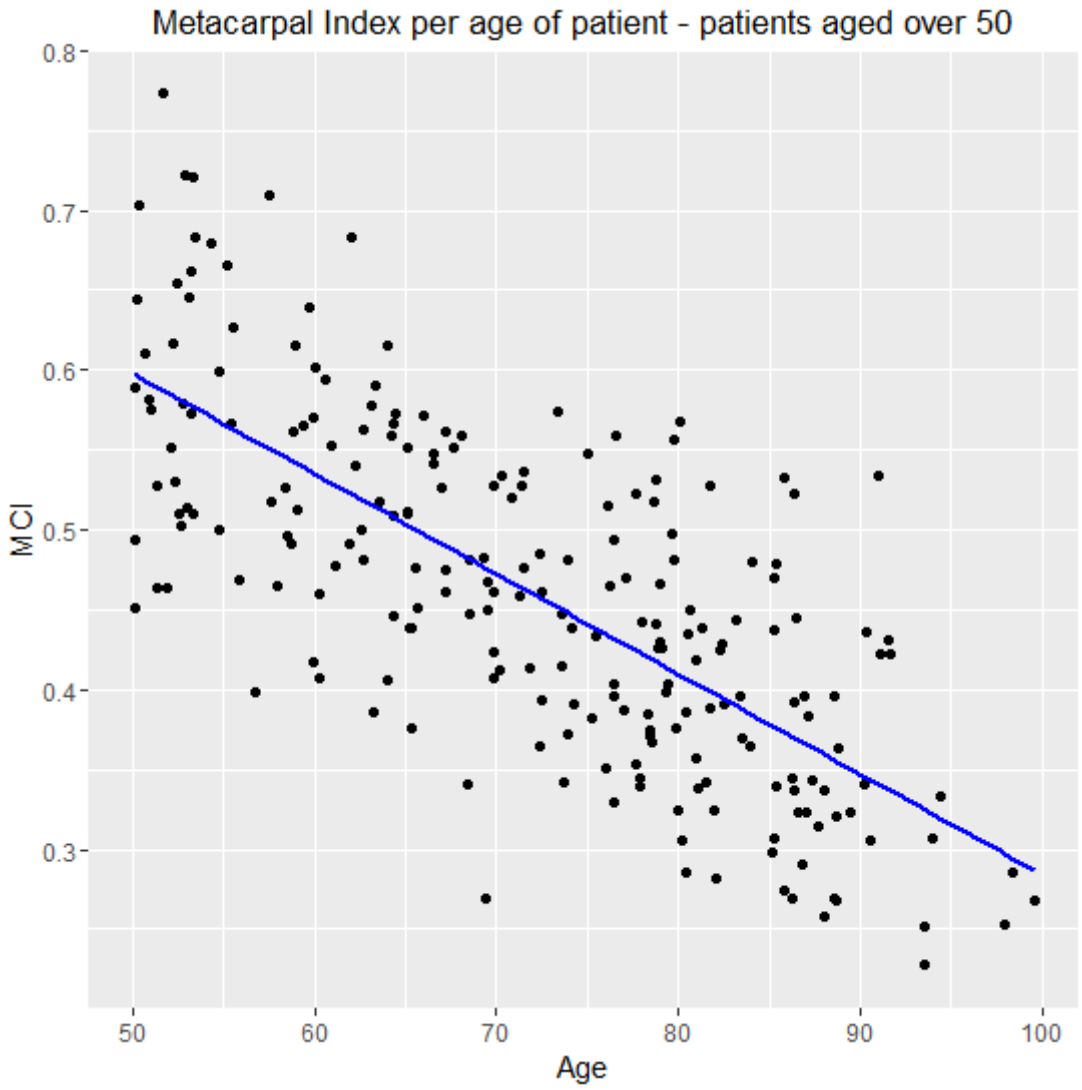
Data was non-parametric and non-linear so a generalised additive model (GAM) was used to investigate the relationship between MCI and age, gender and dorsal displacement (section 2.8.1.12). This model was chosen after comparison with other non-linear regression techniques using cross validation and Bayesian information criterion.

MCI inversely correlated with patient age ($p<0.0001$, $r^2=0.56$)(Figure 4). The decline in MCI was most noticeable in patients over 50 years old and steeper in women (women; $p<0.0001$, $r^2=0.62$, men; $p<0.0001$, $r^2=0.32$) (Figure 5). In patients over 50 MCI decreased in a steep linear fashion with increasing age ($p<0.0001$, $r^2=0.53$) (Figure 6).

Figure 4: Relationship between MCI and age in patients with distal radius fracture

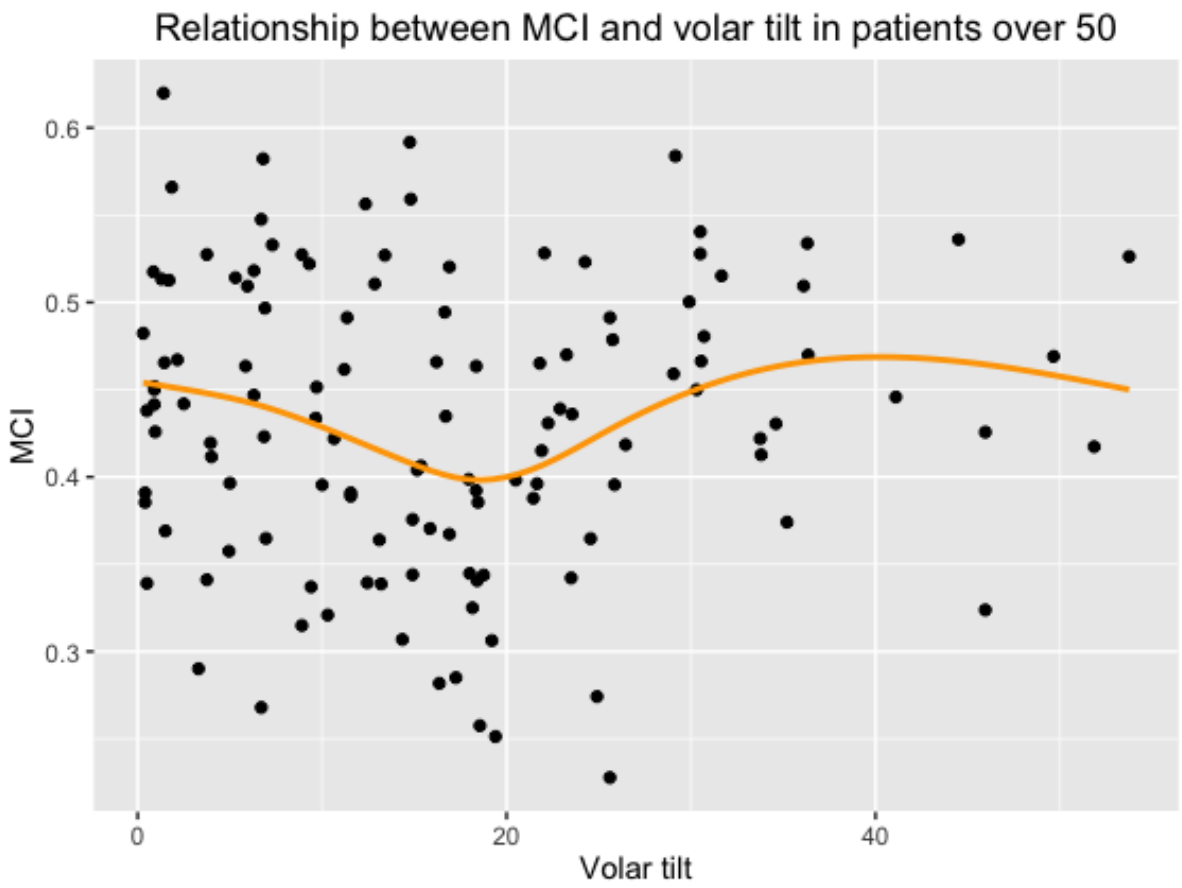
Figure 5: Relationship between MCI and age by gender in patients with distal radius fracture

Figure 6: Association between age and decreasing MCI in patients over 50 years of age with distal radius fracture



No significant relationship was seen between MCI and the degree of dorsal angulation of distal radius fractures on the lateral radiograph ($p=0.17$, $r^2=0.02$). Only dorsally angulated fractures were included in this analysis (n=175). When the model was repeated for patients aged over 50 years only (n=124) who are likely to have suffered fractures due to fragility no significant relationship was again found ($p=0.06$, $r=0.07$)(Figure 7).

Figure 7: MCI and dorsal angulation of distal radius fractures in patients aged 50 years and over



3.3.3 MCI and bone fragility

From a separate sample of consecutive patients who had undergone DXA scanning and imaging of the 2nd metacarpal within 90 days of each other (n=104) GAM modelling revealed a significant correlation between MCI and BMD ($p<0.0001$, $r^2=0.22$) (Figure 8) and MCI and T-score ($p<0.0001$, $r^2=0.22$) (Figure 9). A sharp decline in BMD and T-score was seen in patients with an MCI of <0.5.

Figure 8: Relationship between MCI and BMD in consecutive patients who had undergone radiographs demonstrating the 2nd metacarpal and a DXA scan

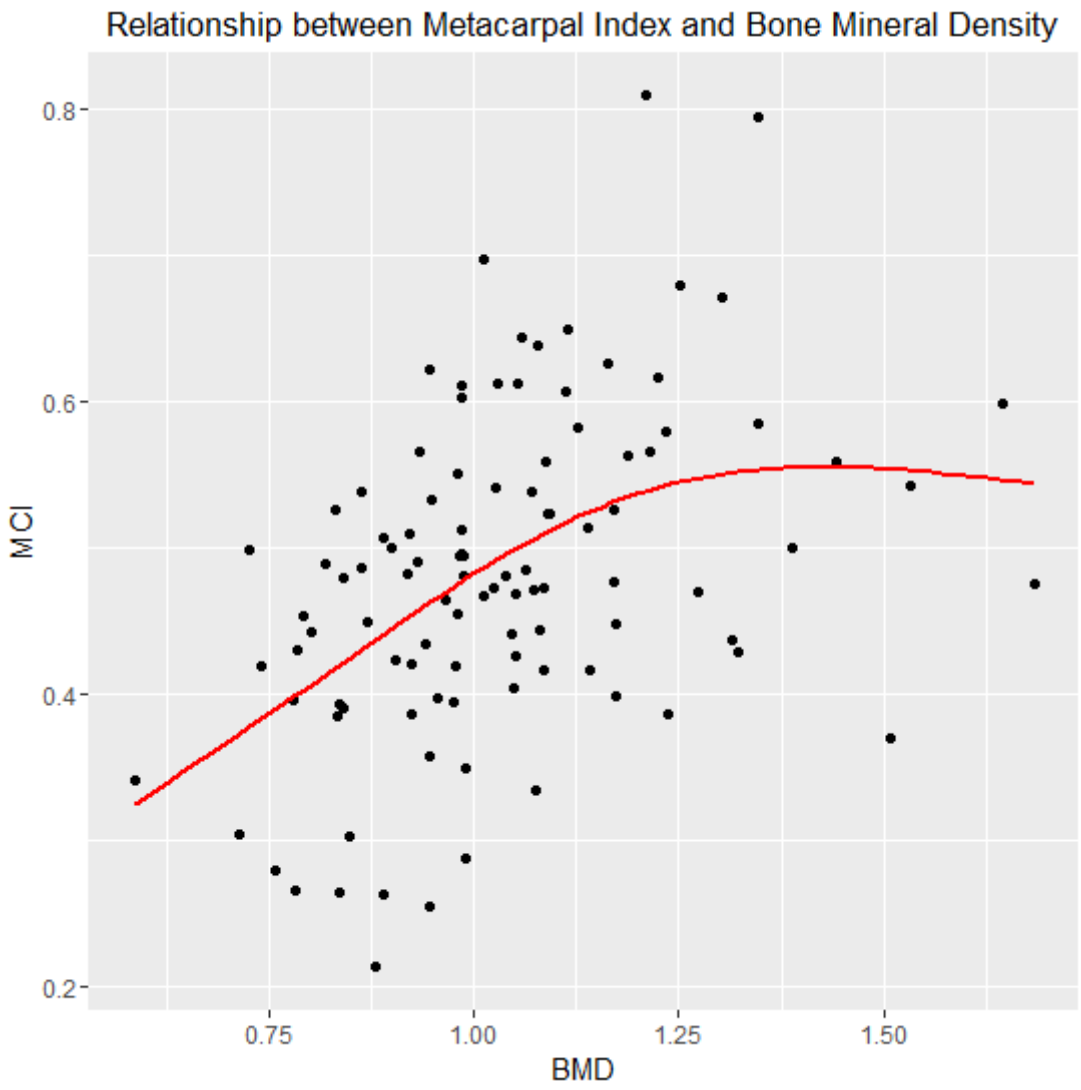
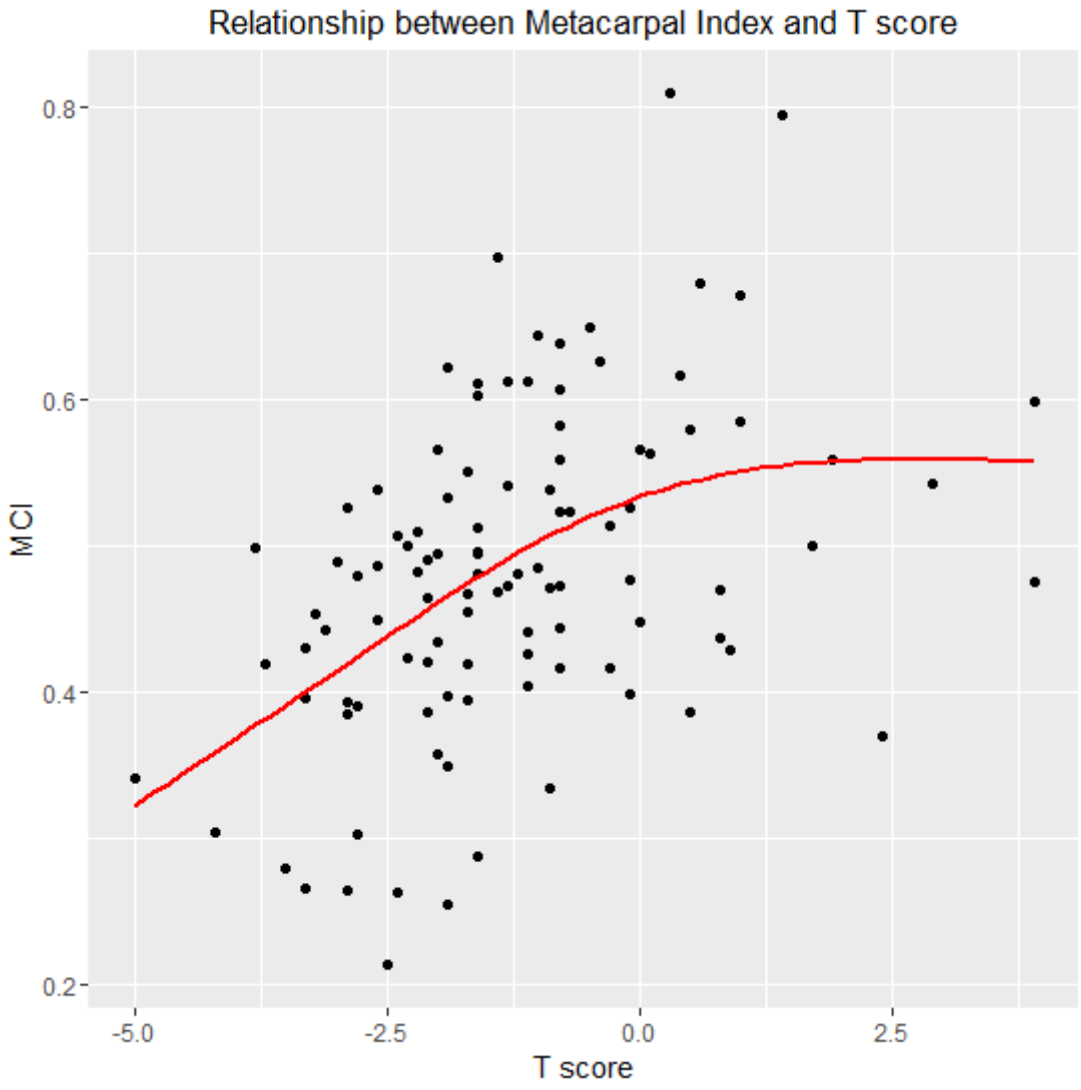


Figure 9: Relationship between MCI and T-score in consecutive patients who had undergone radiographs demonstrating the 2nd metacarpal and a DXA scan



3.4 Summary of radiographic measurement results

These results confirm that the extra-articular measurements of distal radius fracture displacement are reliable and reproducible (section 9.2.1). Dorsal tilt is used frequently in the thesis for further radiographic analysis. Dorsal tilt was chosen as it is believed to be the most important parameter influencing final functional outcome and

is also likely to significantly change with poor bone health and osteoporosis. Intra-articular step is used in only a small number of tests due to poor intra and inter-observer correlation (section 9.2.2). Step is chosen over gap as it is felt to be more important for functional outcome by clinicians.

MCI is shown to be reliable and reproducible and to correlate well with bone health (section 9.3). MCI provides a rapid, low cost assessment of bone frailty which can be conducted in most patients who present with a distal radius fracture. It is used throughout the thesis as a measure of bone fragility.

Chapter 4 Epidemiology of distal radius fracture in Leicestershire

A 10 year review was carried out of all patients who attended the UHL Emergency Department with a distal radius fracture (section 2.1). Poisson regression analysis was carried out to investigate gender and age specific trends (section 2.8.1.3). Prediction of future fracture prevalence is made based on projected population profile changes. This will assist with healthcare planning and delivery by allowing estimation of expected number of injuries. Understanding the total expected number of distal radius fractures along with the influence of deprivation on fracture rate allows accurate predictions to be made for at risk deprived groups.

4.1 Population changes

From 2007 to 2016 there was a 9.8% increase in total population in the region. This has primarily resulted from an 18.2% increase in the over 50-age group, whilst only a 3.5% increase was seen in the 18-50 population. The percentage of the total adult population made up of the over 50 age group has also increased, confirming an aging population in this geographical area. Review of the UK population profile for the 10 year period studied in this section revealed close correlation with that of our geographical region (Table 7). The gender make-up of our study population and that of the UK as a whole remained stable at 51% female for all years studied.

Table 7 Comparative adult population profiles of Leicestershire and the whole United Kingdom

	Leicestershire		UK	
Year	**18-50 (%)**	**>50 (%)**	**18-50 (%)**	**>50 (%)**
2007	57.7	42.3	56.8	43.2
2016	54.5	45.5	53.5	46.5

4.2 Trends in distal radius fracture incidence

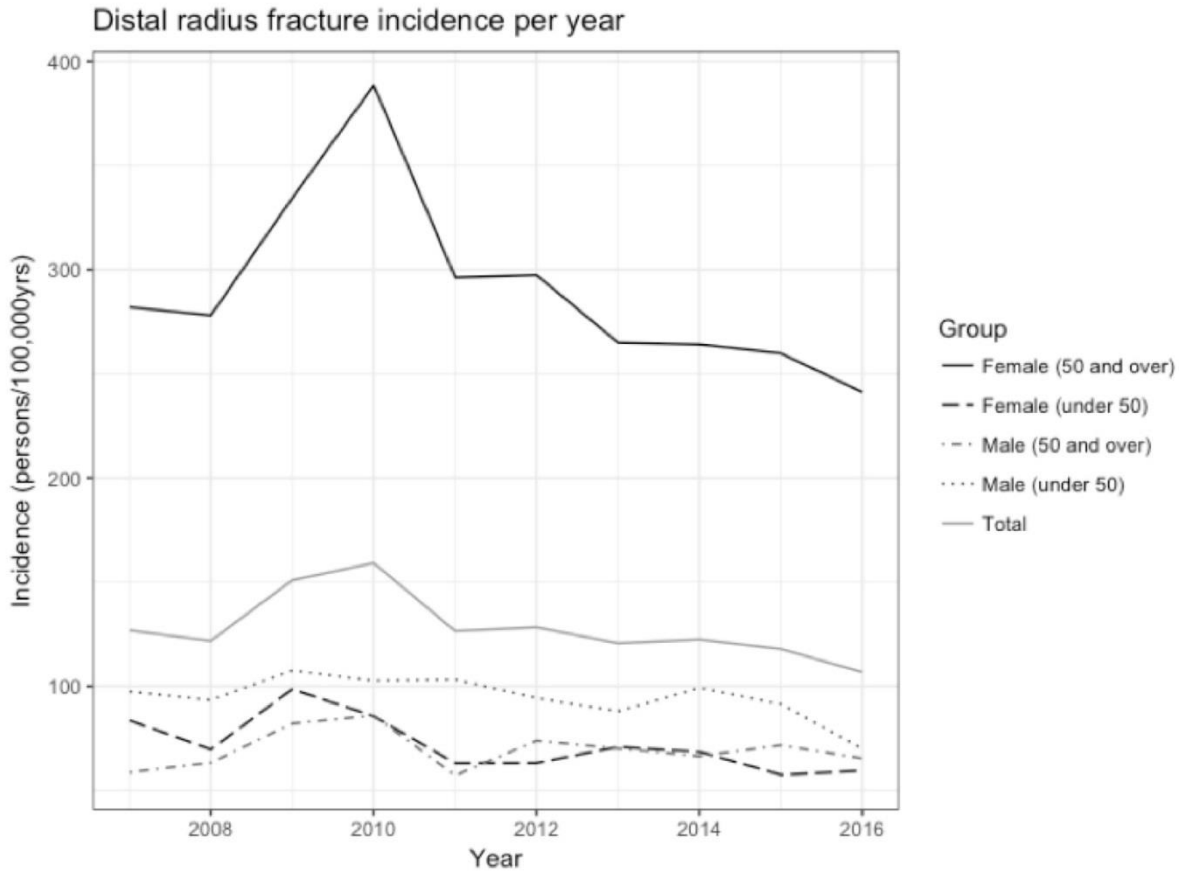
4.2.1 Overall Fracture Incidence

Between 2007 and 2016, 10,259 adult patients presented to the Emergency Department with fractures of the distal radius. The mean annual number of fractures during the 10 year period was 1,026 (range 899 – 1258). Mean incidence was calculated from the total number of fractures and total population at risk during the study period. Poisson regression modelling revealed no overall change in the number of fractures or fracture incidence in any of the subgroups studied when compared to 2007 as the reference year (Table 8). There were significant increases in fracture incidence in specific years (Figure 10). In 2009 and 2010, fracture incidence increased overall ($p<0.0001$ both years), for men ($p=0.0141$ and $p=0.0046$) and women aged 50 years and over($p= 0.0055$ and $p<0.0001$). There were significant reductions in incidence for women under 50 in 2011 ($p=0.0116$), 2012 ($p=0.0118$), 2015 ($p=0.0011$) and 2016 ($p=0.0026$), women 50 and over in 2016 ($p=0.0153$), men under 50 in 2016 ($p=0.0014$) and overall in 2016 ($p<0.0001$).

Table 8: Total number of distal radius fractures and incidence (expressed per 100,000 person/years) in Leicestershire from 2007 to 2016

Year	All Patients		Men		Women	
	No. of Fractures	**Incidence (/100,000 person years)**	**No. of Fractures**	**Incidence (/100,000 person years)**	**No. of Fractures**	**Incidence (/100,000 person years)**
2007	973	126.8	306	81.6	667	170.1
2008	944	121.8	307	81.0	637	160.9
2009	1180	150.9	371	97.0	809	202.6
2010	1258	159.2	370	95.6	888	220.1
2011	1010	126.5	327	83.7	683	167.5
2012	1032	128.3	337	85.6	695	169.2
2013	979	120.7	319	80.2	660	159.7
2014	1005	122.5	342	84.9	663	158.8
2015	979	117.9	338	82.8	641	151.8
2016	899	106.8	282	67.9	617	144.5

Figure 10: Annual distal radius fracture incidence in Leicestershire from 2007 to 2016 by gender and age group



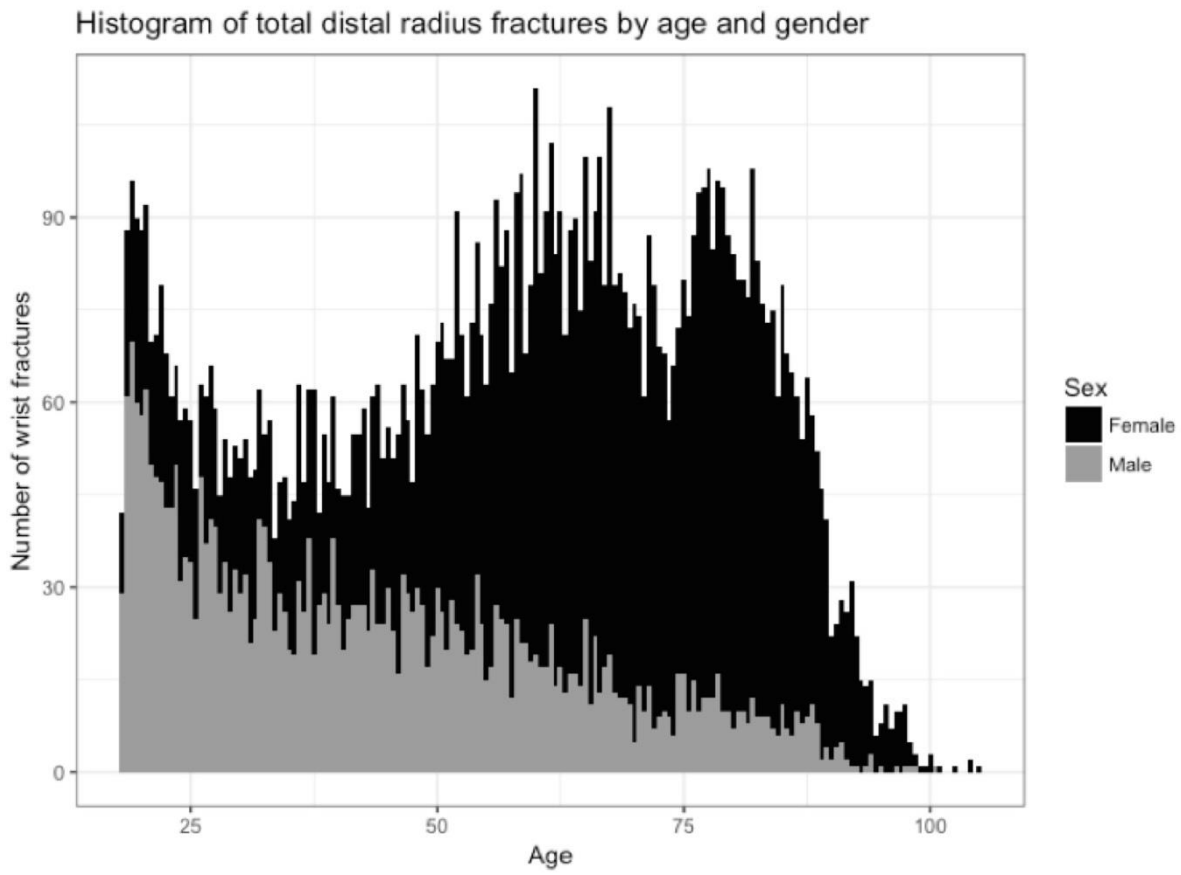
The overall male: female ratio of fractures was 32%: 68% with no significant variation over the study period. Mean age at fracture was 43.8 (range 18-98) in male patients and 62.9 (range 18-105) in female patients. Within the young (<50 years) population, fractures were more common in men, but older (50 years and over) females were by far the commonest group overall to present with a fracture (Table 9). Figure 11 demonstrates the age and gender distribution.

Table 9 Mean (10-year) distal radius fracture incidence rates in Leicestershire by

	Male	**Female**	**All**
<50 age group	94.6	72.0	83.3
>50 age group	69.5	289.6	184.7
All	83.9	170.2	127.9

gender and age group (expressed per 100,000 person/years)

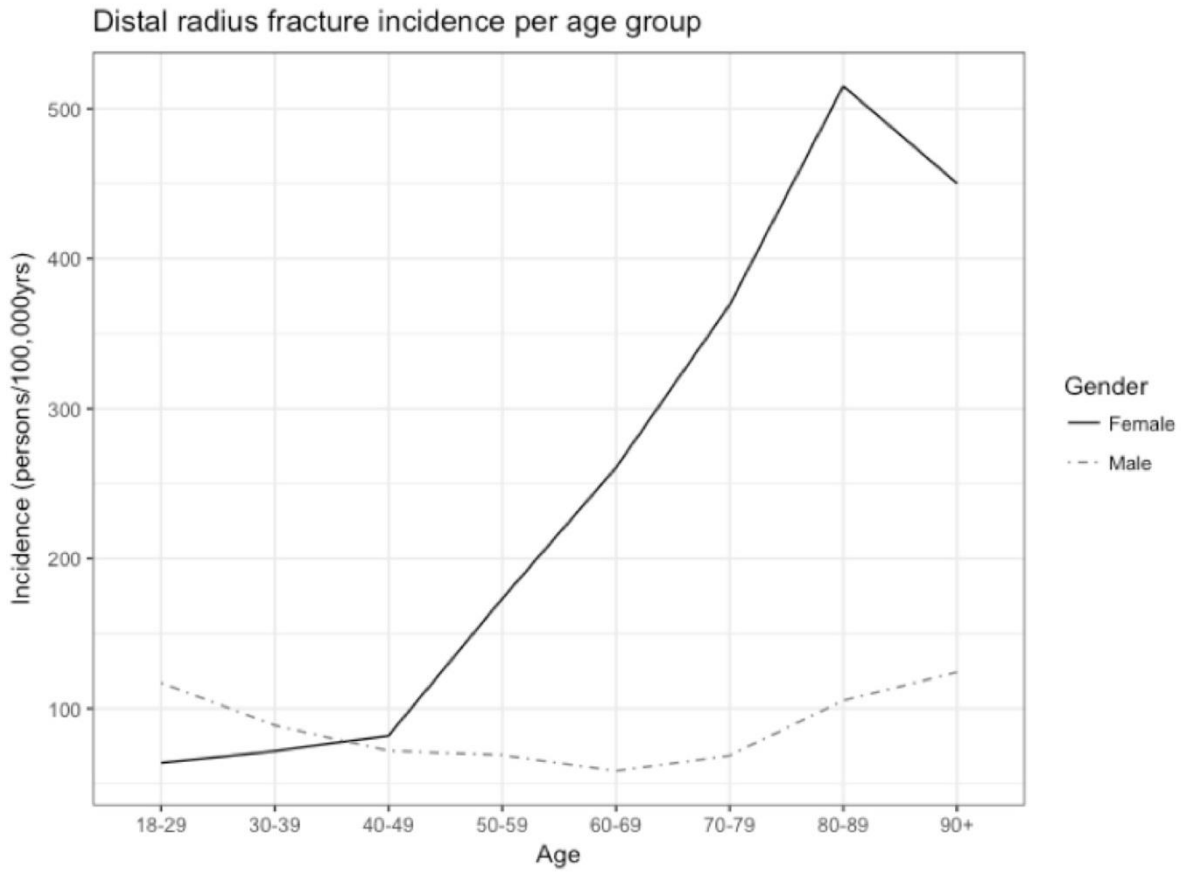
Figure 11 Total number of distal radius fracture in Leicestershire stratified cumulatively by gender and age from 2007 to 2016



4.2.2 Age and Gender Specific Incidence

Age and gender specific incidence rates of distal radius fracture were calculated and are presented in Figure 12. In women the incidence of fracture increased steadily from the fifth decade to reach a peak of 515/100,000 person years in the 80-89 age group before declining. In male patients, incidence remained low until the eighth decade from which point it rose to a peak of 124/100,000 person years in the over 90 age group.

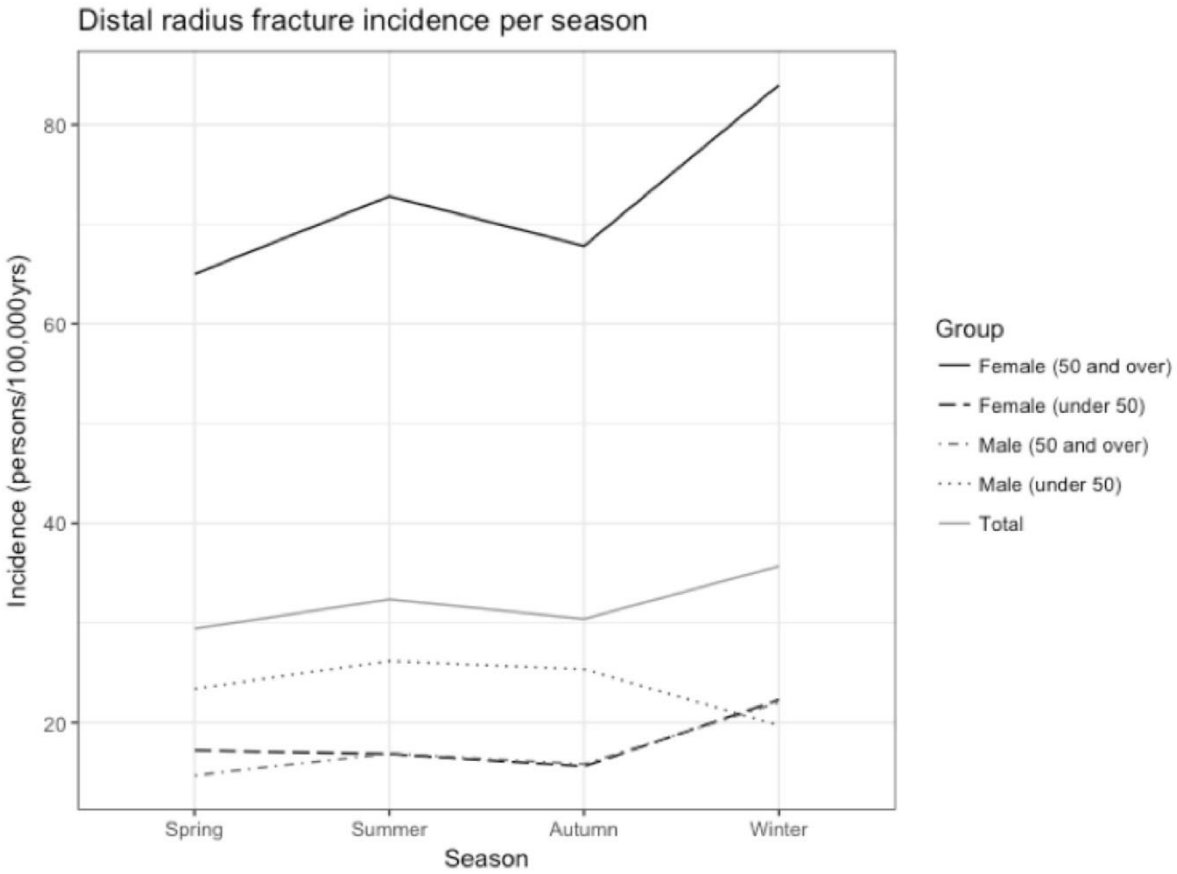
Figure 12 Gender and age specific distal radius fracture incidence rates in Leicestershire from 2007 to 2016



4.2.3 Seasonal Variation of Fracture Incidence

Poisson regression analysis of the cumulative data demonstrated a statistically significant increase ($p<0.0001$) in fracture incidence in winter for all groups except for young males (Figure 13), where a statistically significant fall ($p<0.0001$) was recorded. Across the ten-year period, 28% of fractures occurred in winter compared with 23%, 25% and 24% in spring, summer and autumn respectively (section 2.8.1.3).

Figure 13 Seasonal variation of distal radius fracture incidence by gender and age group in Leicestershire from 2007 to 2016



4.2.4 Weekly Variation in Fracture Incidence

The data reveals a notable pattern of rate of distal radius fracture in association with day of the week. In the under 50 population there is a higher incidence of fracture on or immediately after the weekend, with 52% of total fractures occurring on Saturdays, Sundays and Mondays. This was statistically significant for both men ($p<0.0001$ for all 3 days) and women ($p=0.0075$ on Mondays, and $p<0.0001$ for Saturday and Sunday) aged under 50 years when compared to Tuesdays using poisson regression (Figure 14). Tuesday was chosen for comparison as it is in the working week and unlikely to be influenced by weekend activities. There was no significant difference in incidence amongst the over 50 population across the week, but the magnitude of change in the young population was sufficient to affect a significantly increased incidence of injury at the weekend overall, accounting for 45% of total fractures ($p=0.0022$ on Mondays, $p=0.0129$ on Saturdays and $p<0.0001$ and Sundays).

The increased incidence of fracture amongst the young population over the weekend affects a reduction in the mean age of patients presenting with distal radius fracture at this period of a week ($p<0.0001$) (Figure 15).

Figure 14 Weekly variation of distal radius fracture incidence by gender and age group in Leicestershire from 2007 to 2016

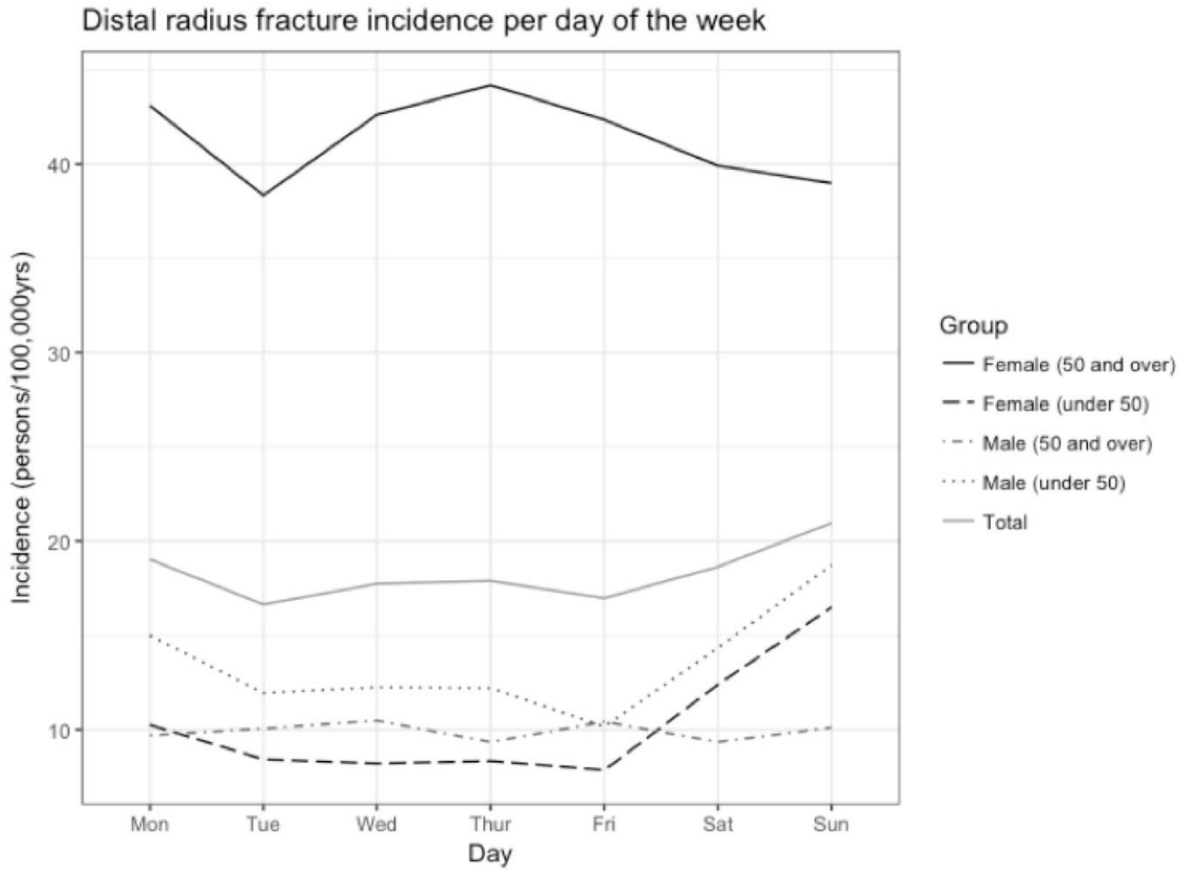
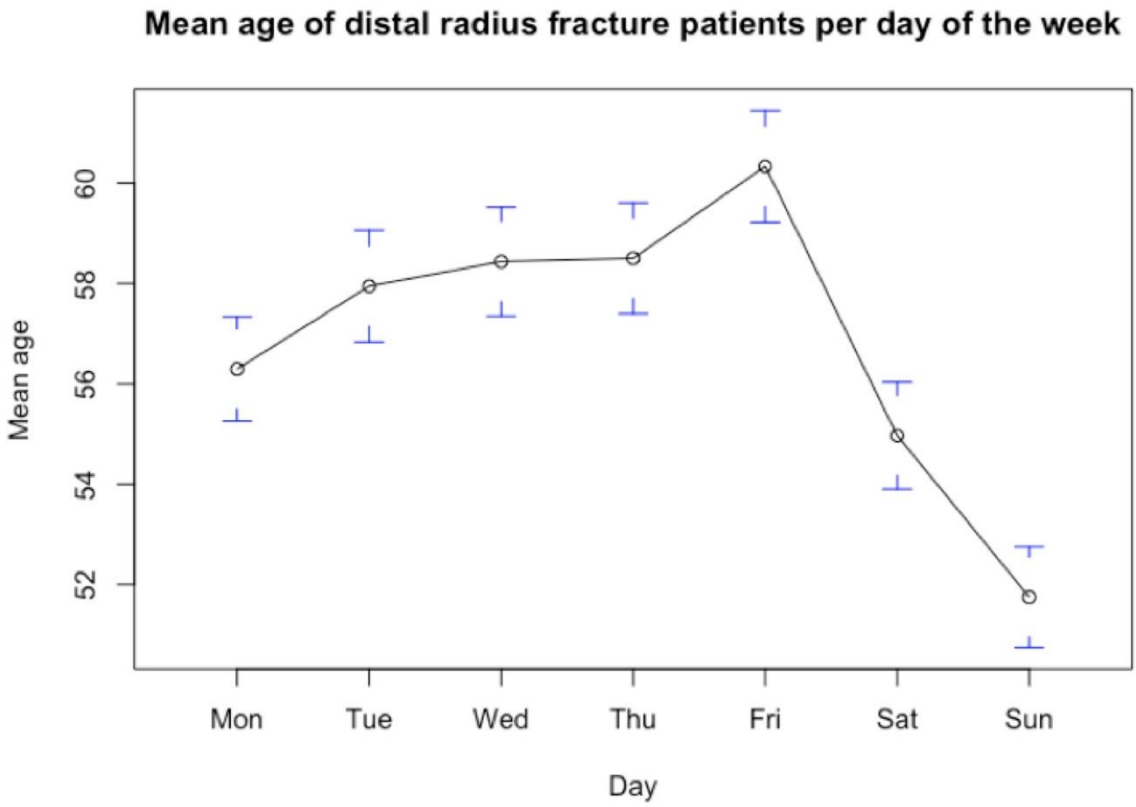


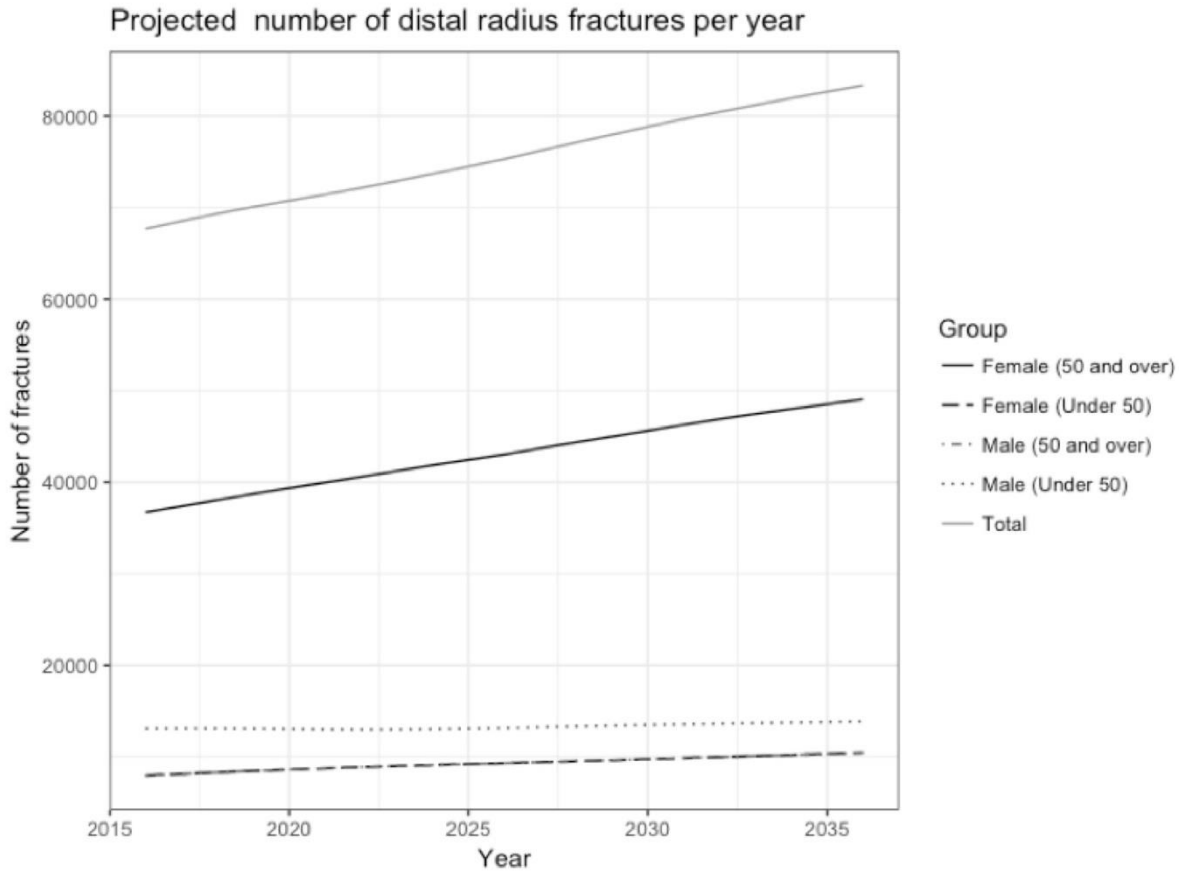
Figure 15 Mean age of distal radius fracture patients each weekday in Leicestershire from 2007 to 2016



4.3 Fracture Projection Analysis

Figure 16 shows the expected trend for the projected number of distal radius fracture in the next 20 years in the UK. Our data suggest there will be 11.2% and 23.1% increases in total fractures in the next ten and twenty years respectively. This results primarily from more fractures in the over 50 male and female age groups as a consequence of the predicted changing population structure.

Figure 16 Projected number of distal radius fracture per year in the United Kingdom by gender and age group from 2016 to 2036



4.4 Summary of the epidemiology of distal radius fracture in Leicestershire

Despite an aging population, the incidence of distal radius fracture does not appear to be changing (section 9.5). Weekly and seasonal trends are apparent which may assist with resource planning and allocation. A significant rise in the number of distal radius fracture is expected in the UK in the next two decades which will require suitable planning of resource allocation to ensure appropriate treatment of patients. The population profile in the Leicestershire study region closely matches that of the UK as a whole so these results should be generalisable to the rest of the UK. Further

understanding of how deprivation affects fracture rates allows identification of at risk groups and enables resources to be targeted appropriately.

Chapter 5 Effect of deprivation on distal radius fracture rate in Leicestershire

The aim of this chapter was to establish if distal radius fracture rate is associated with deprivation in Leicestershire and nationally. Age specific rates are calculated by deprivation quintile and compared with expected rates. Poisson regression modelling is performed investigating the effect of age, gender, ethnicity and deprivation on fracture rate (section 2.6.3 & 2.8.1.3). Analysis of the relationship between deprivation and radiographic measures of fracture displacement and bone fragility is performed using GAM models to try and establish reasons for differences in fracture rate (section 2.4 & 2.8.1.12).

5.1 Total numbers of fractures

4,278 consecutive patients with a Leicestershire postcode attended the emergency department with a distal radius fracture during the four year period and were included in the analysis.

There was a clear trend of distal radius fracture rate increasing with higher deprivation quintile for male and female patients (Table 10).

Table 10 Mean number and rate of distal radius fracture in Leicestershire (expressed per 100,000 person/years) by gender and deprivation quintile from 2007 to 2010

	Men		**Women**		**All**	
Deprivation	#/yr	Rate	#/yr	Rate	#/yr	Rate
Q1 (most deprived)	73.5	143.57	128.75	242.38	202.25	193.88
Q2	73.25	106.15	135.75	190.67	209	149.07
Q3	49	76.88	121.75	184.36	170.75	131.58
Q4	56.75	59.79	161	161.74	217.75	111.98
Q5 (least deprived)	66.25	59.49	205.75	174.77	272	118.73

5.1.1 Observed and expected fracture rate

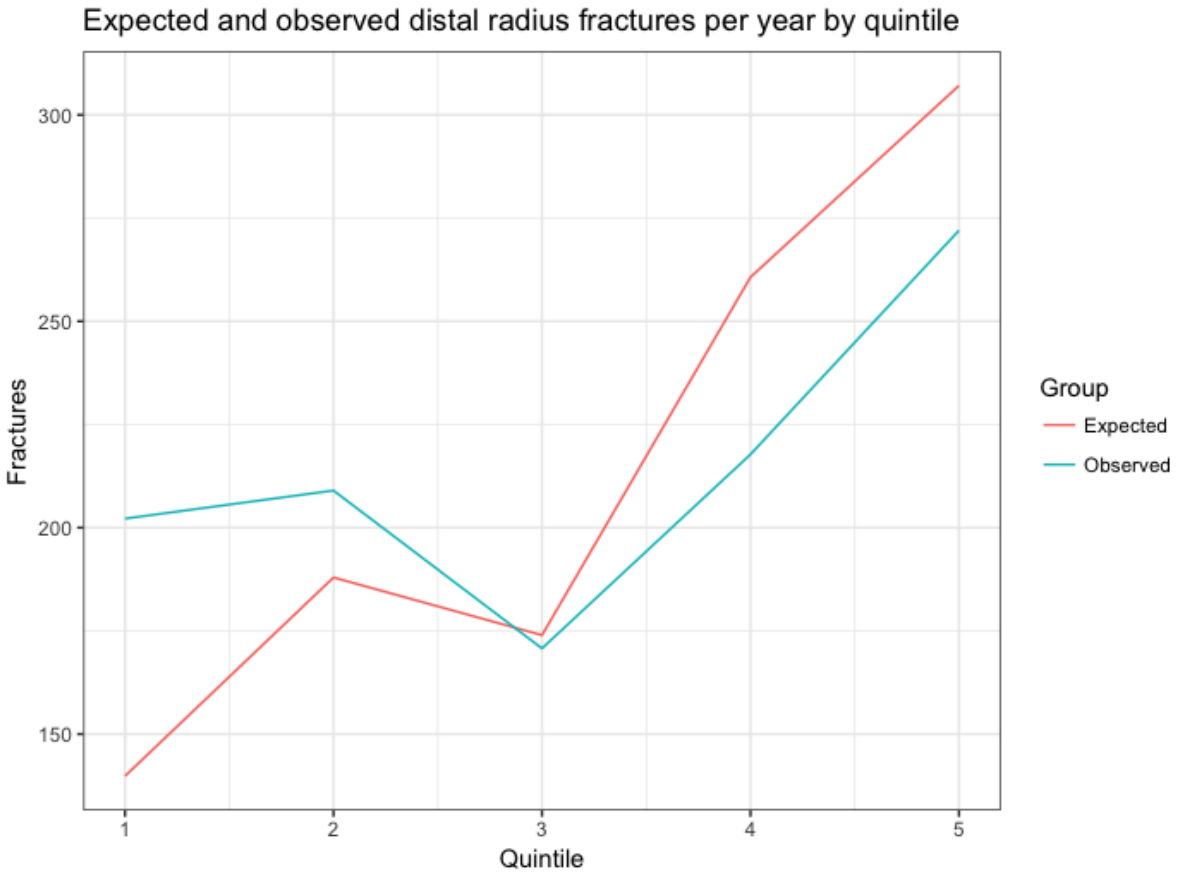
Higher than expected numbers of fractures were seen in the most deprived two quintiles and less than expected in the two least deprived quintiles. Similar numbers of observed and expected fractures were seen in quintile three, the median quintile.

Table 11 Observed number of distal radius fracture seen in Leicestershire and expected number of distal radius fracture in the region for each deprivation quintile from 2007 to 2010

Expected number of fractures is calculated from the proportion of the population in each quintile

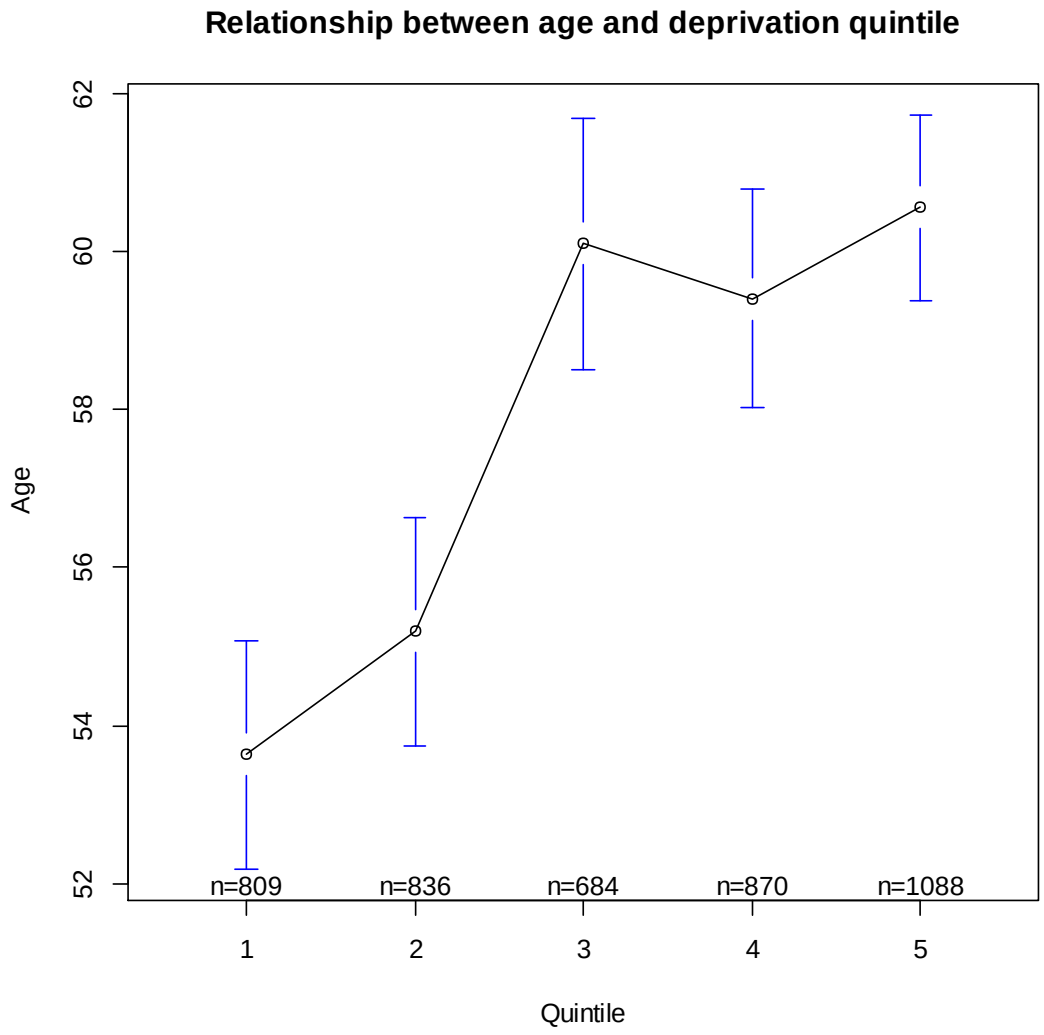
Quintile	Population	% of population	Fractures expected	Fractures observed
1	104315	13.1	140	202
2	140203	17.6	188	209
3	129772	16.3	174	171
4	194460	24.4	261	218
5	229094	28.7	307	272

Figure 17 Comparison of the expected and observed number of distal radius fracture seen in Leicestershire in each deprivation quintile from 2007 to 2010



5.1.2 Deprivation and age of distal radius fracture patients

Figure 18 Mean age of distal radius fracture patients in Leicestershire in each quintile with 95% confidence intervals from 2007 to 2010



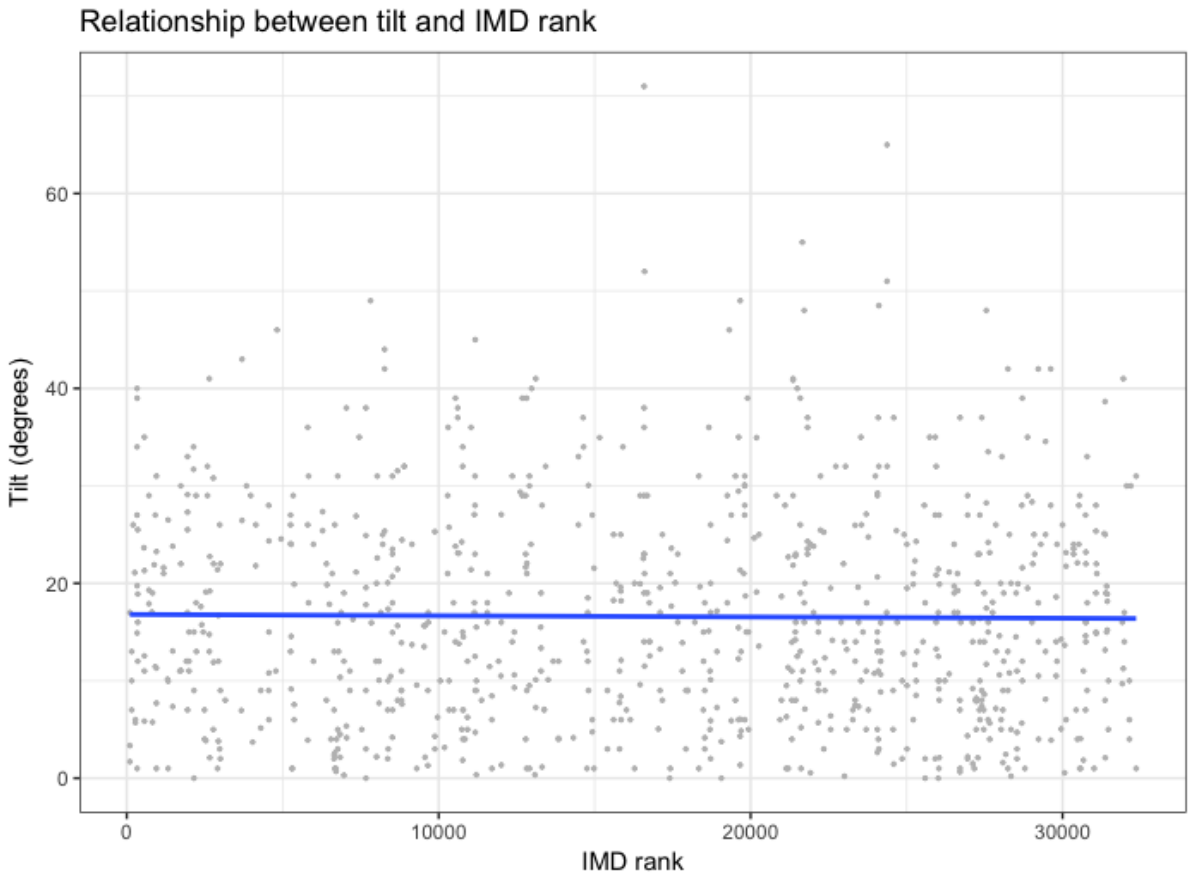
Mean age of patients in the most deprived two quintiles was 54.4 years. This was significantly lower than the mean age of 60.1 years in the least deprived three quintiles ($p<0.001$).

5.2 Relationship between deprivation and radiographic parameters

Analysis of the relationship between deprivation, measured by IMD rank, and dorsal tilt, intra-articular step and metacarpal cortical index was performed using GAM models (section 2.8.1.12).

5.2.1 Dorsal tilt

Figure 19 Relationship between dorsal tilt and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model

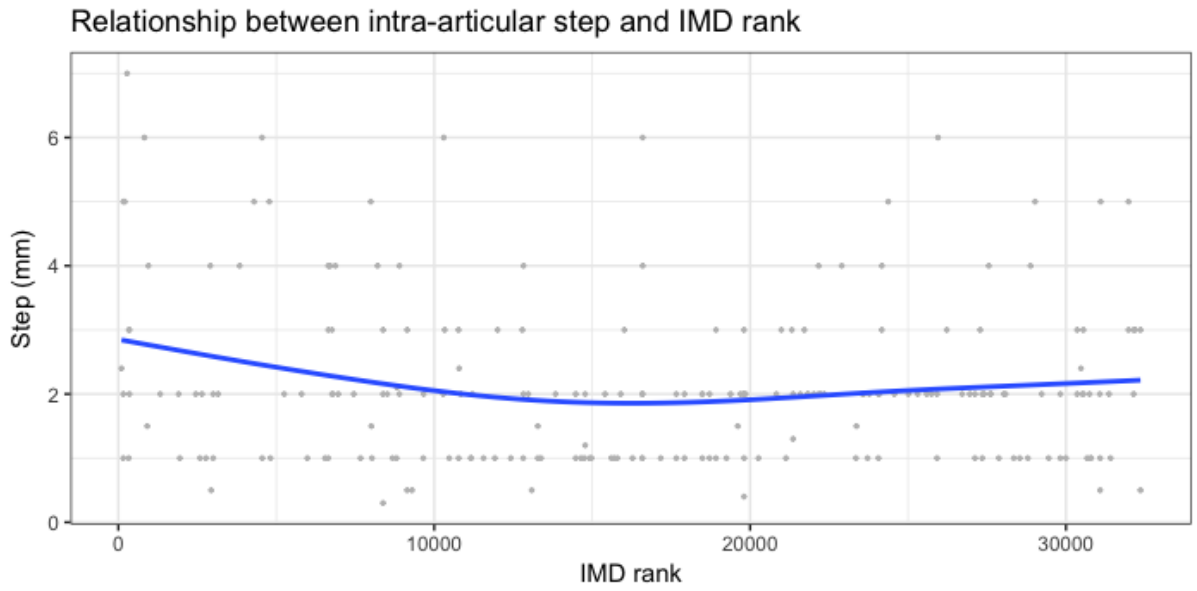


865 patients of the group who underwent radiographic measurement had lateral radiographs which allowed measurement of dorsal tilt. No relationship was demonstrated between tilt and deprivation measured by IMD rank (p=0.741).

5.2.2 Intra-articular step

219 patients had sustained a fracture with a displaced intra-articular step. There was no association with IMD rank (p=0.102).

Figure 20 Relationship between intra-articular step and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model



5.2.3 Metacarpal Cortical Index

There was no significant relationship seen between MCI and IMD rank in 888 patients (p=0.097). Further analysis by quintile revealed that MCI was higher in patients from

quintiles 1 and 2 (mean = 0.50) than those in the more deprived quintiles (mean =0.49) but this did not reach significance (p=0.07)

Figure 21 Relationship between MCI and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model

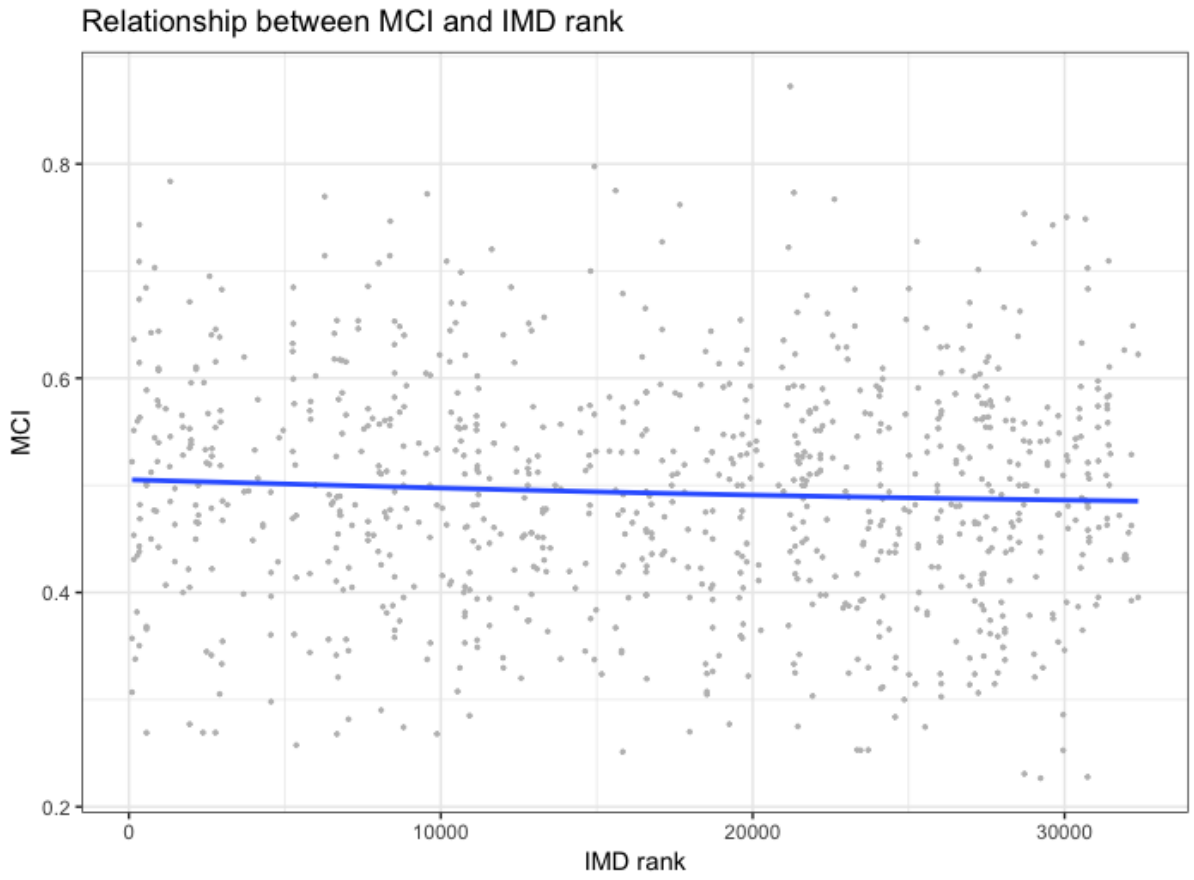
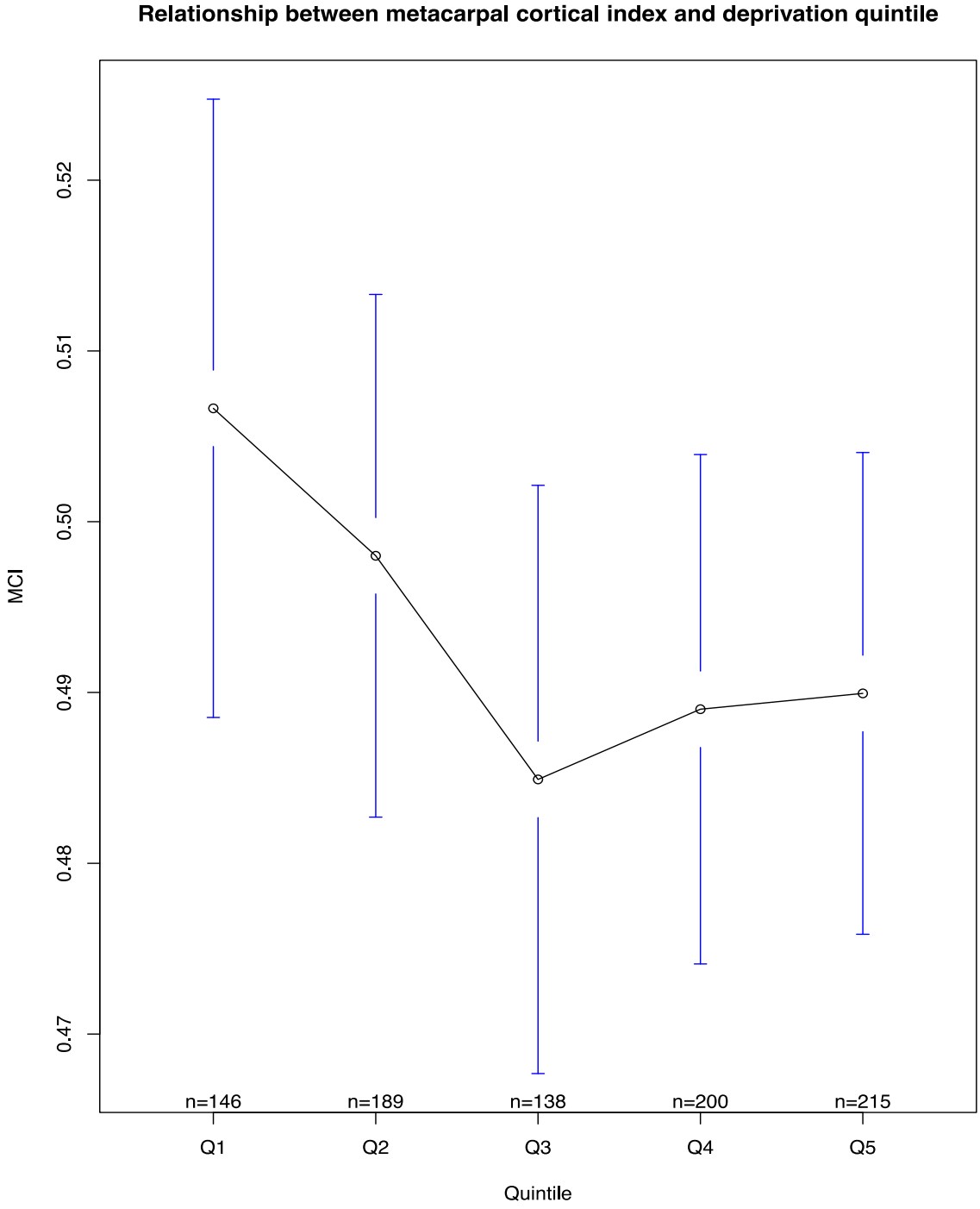


Figure 22 Mean MCI of distal radius fracture patients in Leicestershire from 2007 to 2010 in each deprivation quintile with 95% confidence intervals



5.3 Patients with distal radius fracture aged 50 years and over

2,803 patients from Leicestershire aged 50 years and over sustained distal radius fractures during the four year period studied. As with the overall results a clear trend was seen of the distal radius fracture rate increasing with higher deprivation quintile. More than expected numbers of fractures were seen in the most deprived two quintiles and less than expected in the two least deprived quintiles.

Table 12 Mean number of fractures per year and rate per deprivation quintile (expressed per 100,000 person/years) in patients in Leicestershire aged 50 years and over from 2007 to 2010

Deprivation	#/yr	Rate
Q1	115.5	335.06
Q2	124	236.28
Q3	117	206.27
Q4	148	160.83
Q5	197.75	178.25

Table 13 Observed number of distal radius fracture seen in Leicestershire and expected number of distal radius fracture in the region for each deprivation quintile from 2007 to 2010 in patients aged 50 years and over

Quintile	Population	% of population	Fractures expected	Fractures observed
1	34471	9.9	69.84	115.5
2	52480	15.1	106.32	124
3	56723	16.4	114.92	117
4	92021	26.5	186.43	148
5	110938	32.0	224.75	197.75

Figure 23 Comparison of the expected and observed number of fractures seen in Leicestershire in each deprivation quintile from 2007 to 2010 in patients aged 50 years and over

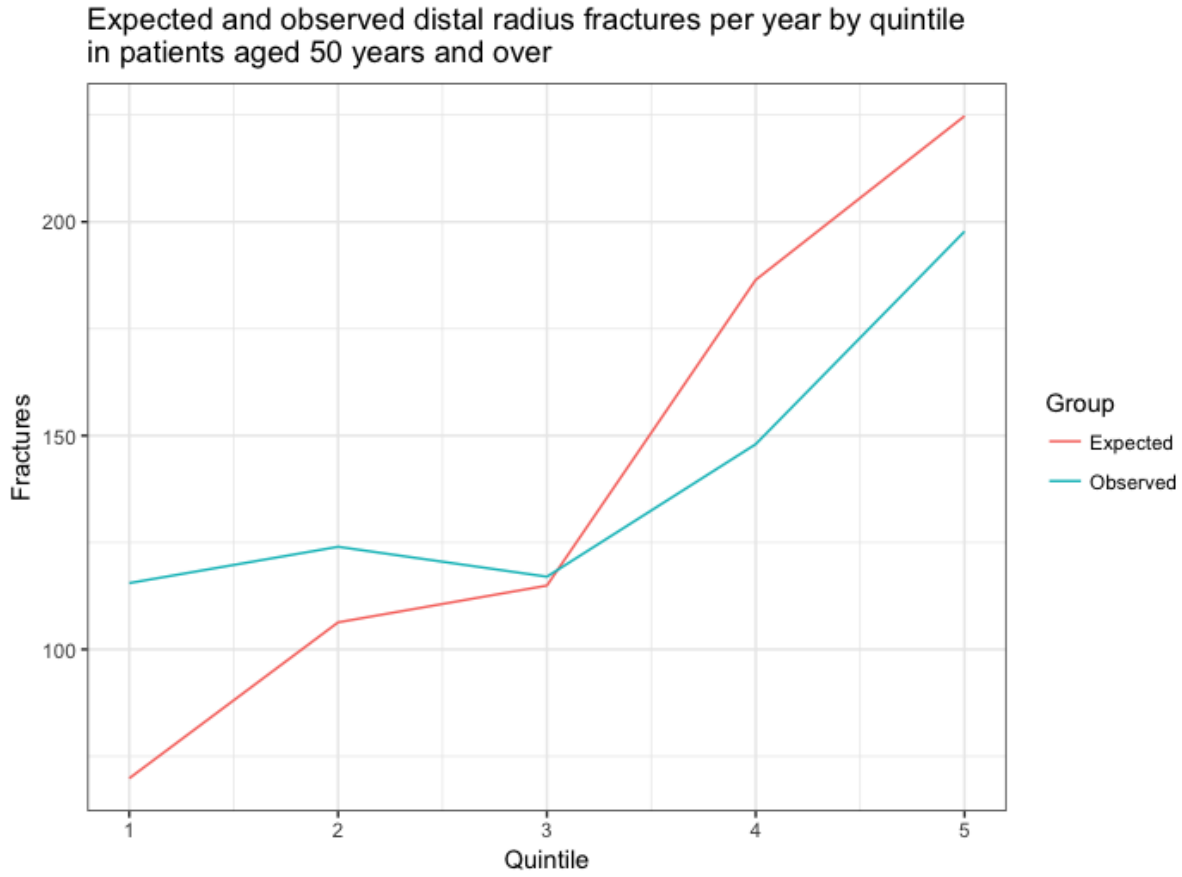
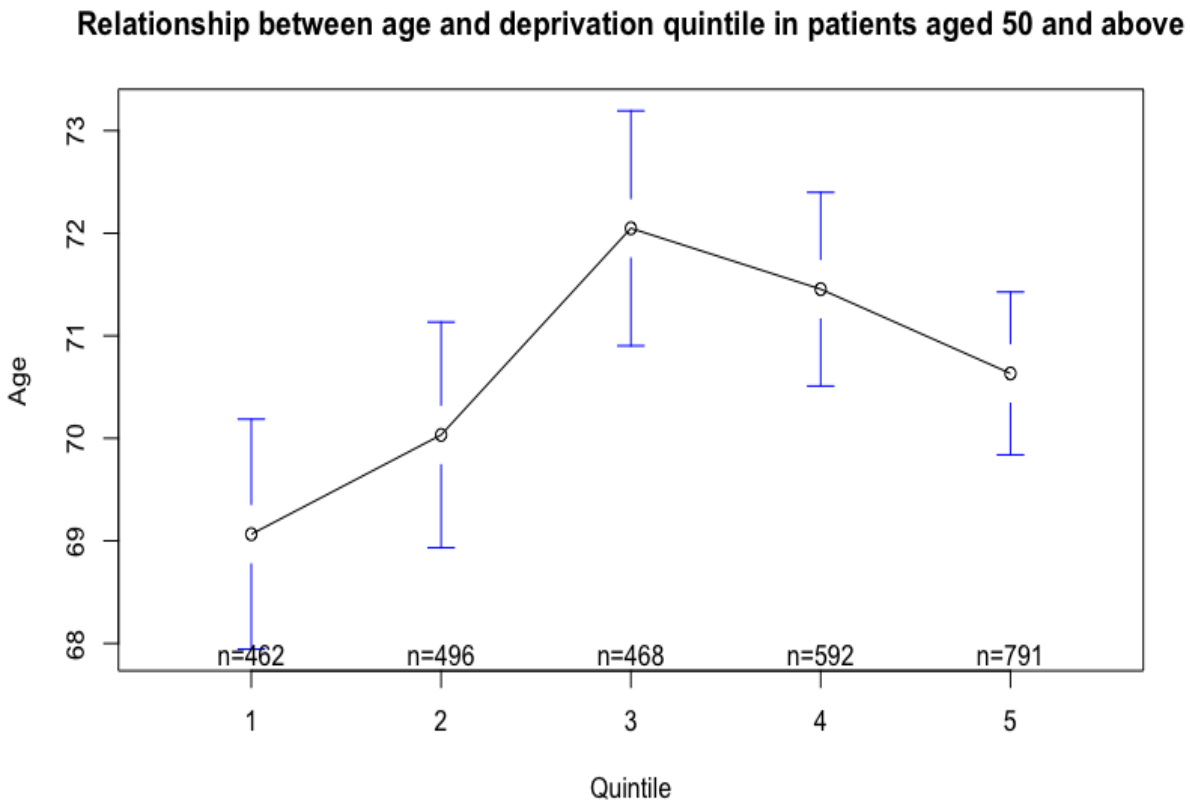


Figure 24 Mean age of distal radius fracture patients in Leicestershire from 2007 to 2010 aged 50 years and over in each deprivation quintile with 95% confidence intervals

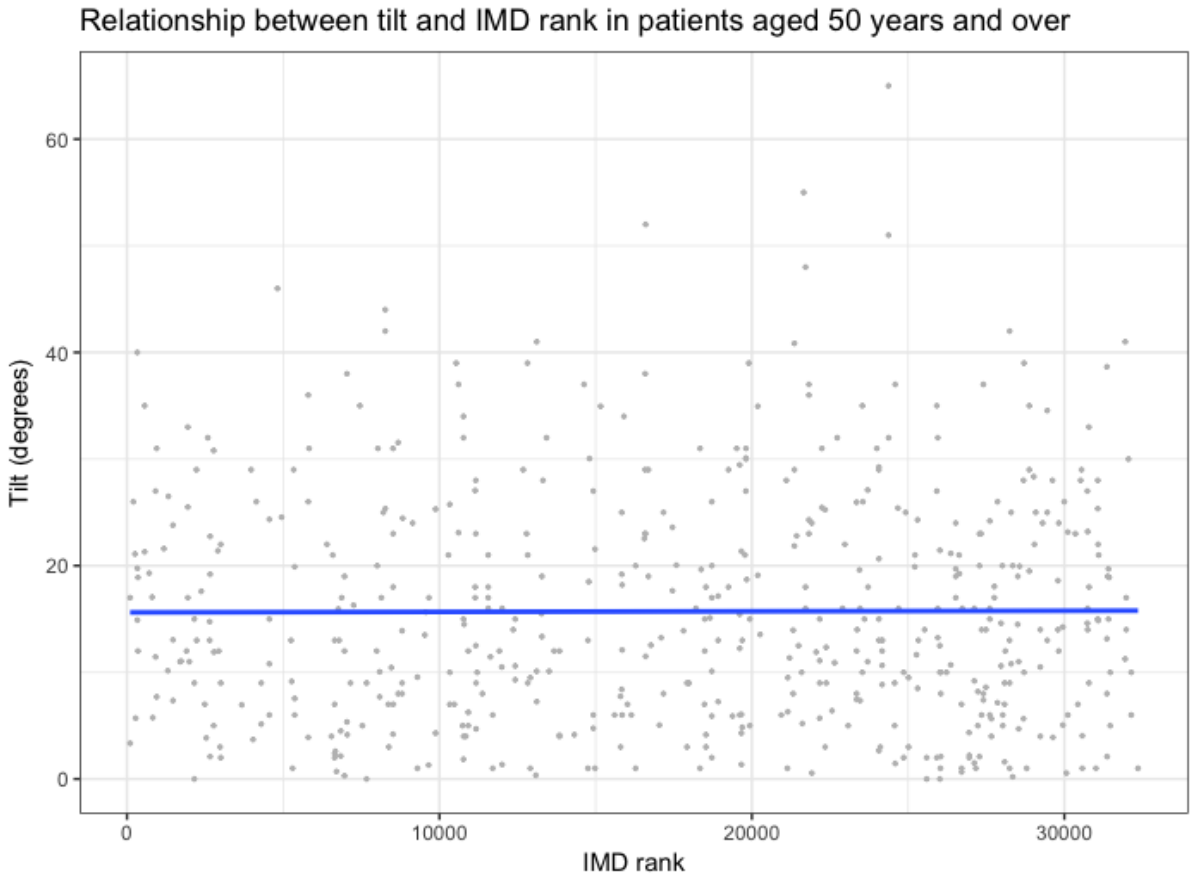


A significant difference in mean age was seen across the deprivation quintiles ($p=0.001$). Mean age of patients in the most deprived to quintiles was 69.6. This was significantly lower than the mean age of 71.2 in the least deprived three quintiles ($p<0.001$).

5.3.1 Relationship between deprivation and radiographic parameters in patients aged 50 years and over

5.3.1.1 Dorsal tilt

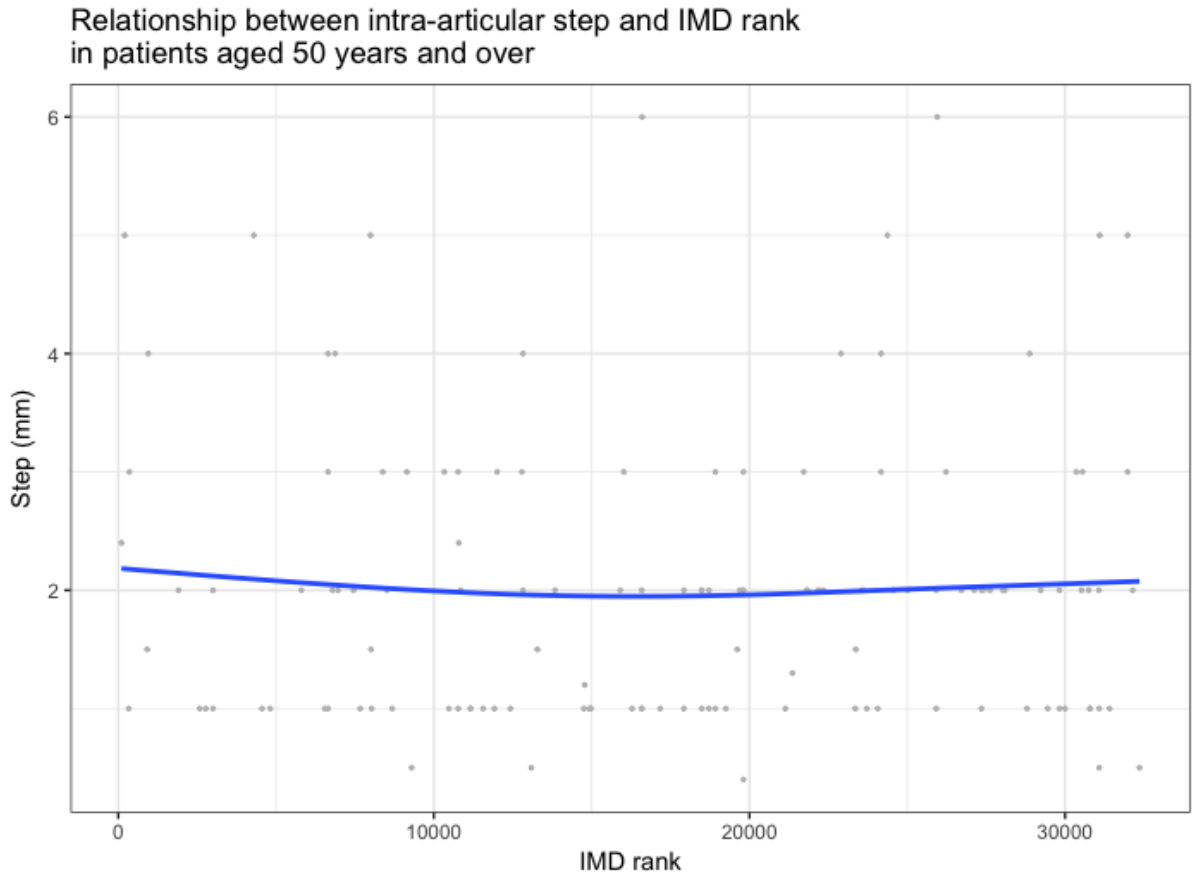
Figure 25 Relationship between dorsal tilt and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model in patients aged 50 years and over



537 patients in this age group had measurement of dorsal tilt performed. No relationship was seen between dorsal tilt and IMD rank (p=0.919).

5.3.1.2 Intra-articular step

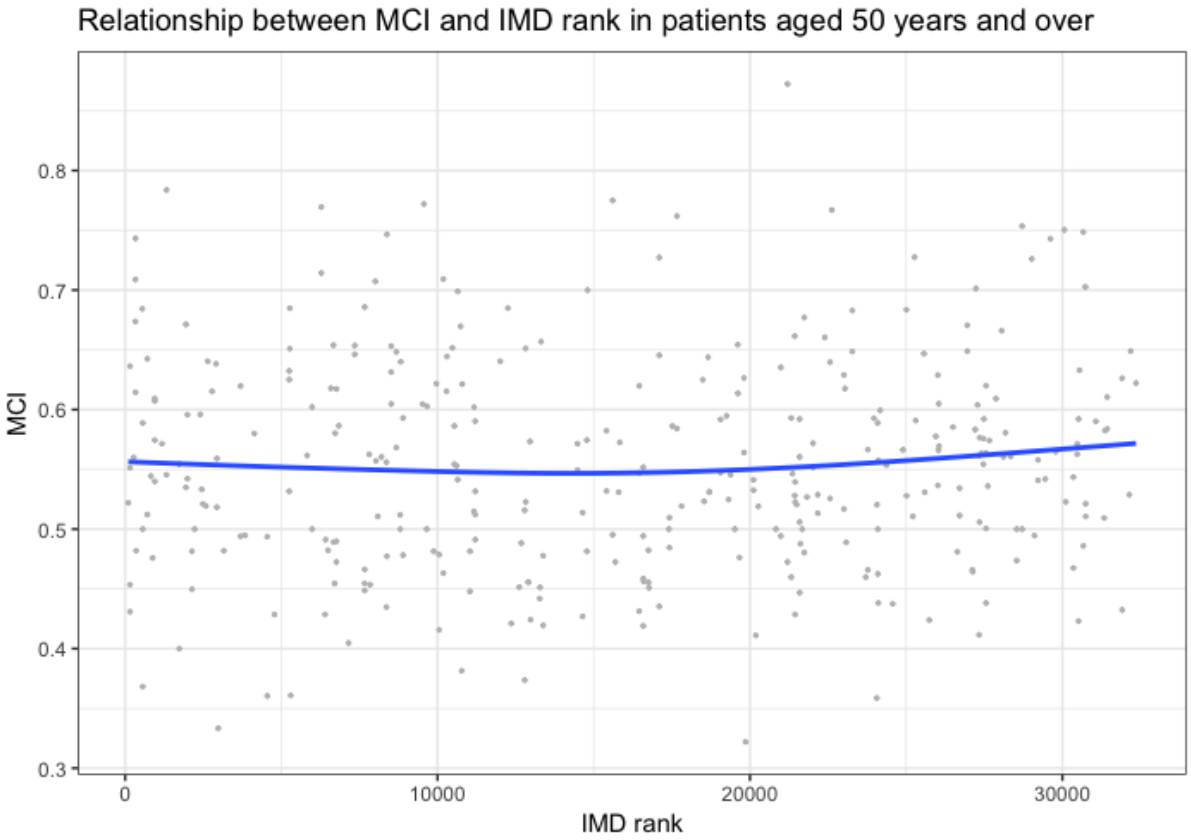
Figure 26 Relationship between intra-articular step and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model in patients aged 50 years and over



133 patients had sustained a fracture with a displaced intra-articular step. No association was seen with IMD rank (p=0.96).

5.3.1.3 Metacarpal Cortical Index

Figure 27 Relationship between MCI and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model aged 50 years and over



No relationship was seen between MCI and IMD rank in the 551 patients in which it was measured (p=0.248).

5.4 Patients with distal radius fracture aged between 18 and 49 years

1,475 Leicestershire residents suffered a distal radius fracture in the four-year study period who were aged between 18 and 49 years of age inclusive. Again, a clear trend was seen of an increased fracture rate in more deprived quintiles. More fractures than expected were seen in quintiles one and two and less fractures than expected were seen in quintiles four and five.

Table 14 Mean number of fractures per year and rate per deprivation quintile (expressed per 100,000 person/years) in adult patients in Leicestershire aged under 50 from 2007 to 2010

Deprivation	#/yr	Rate
Q1	115.5	335.06
Q2	124	236.28
Q3	117	206.27
Q4	148	160.83
Q5	197.75	178.25

Figure 28 Comparison of the expected and observed number of fractures seen in Leicestershire in each deprivation quintile from 2007 to 2010 in adult patients aged under 50 years

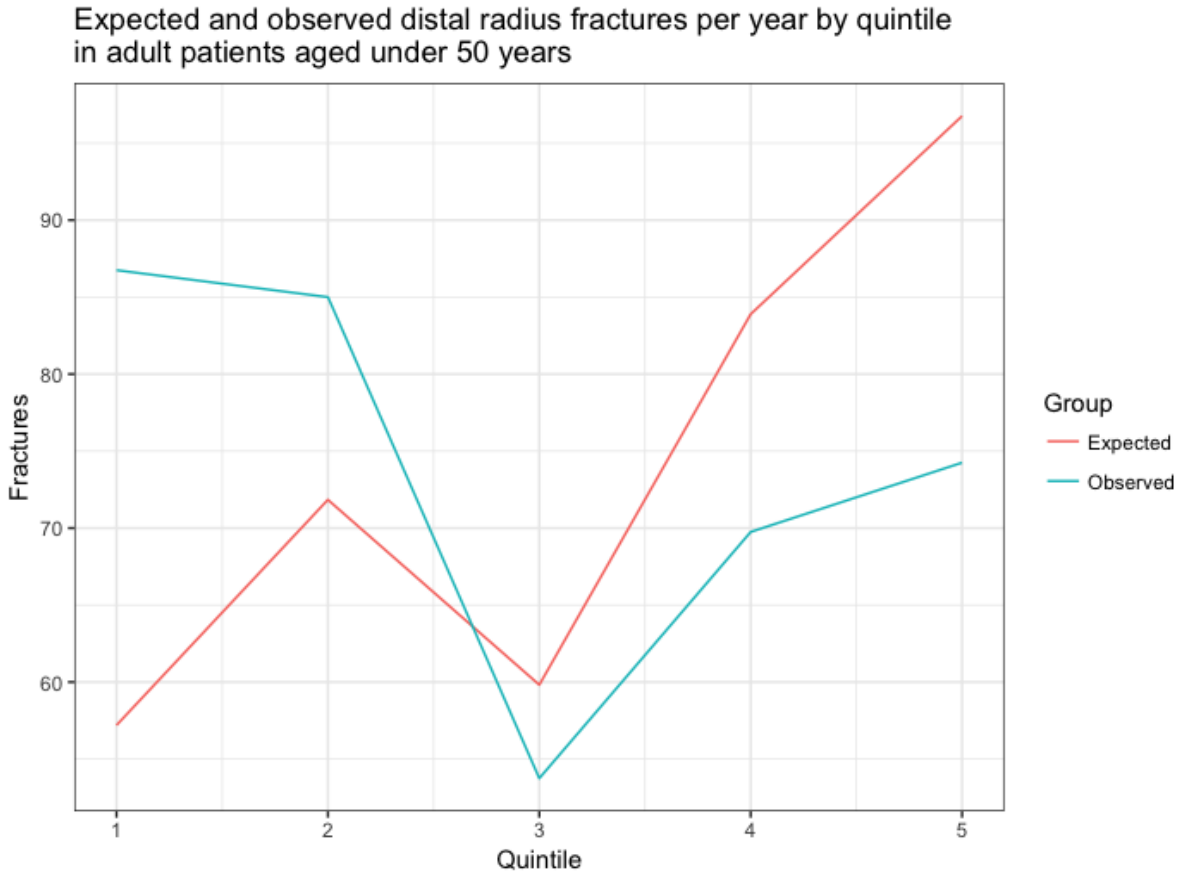
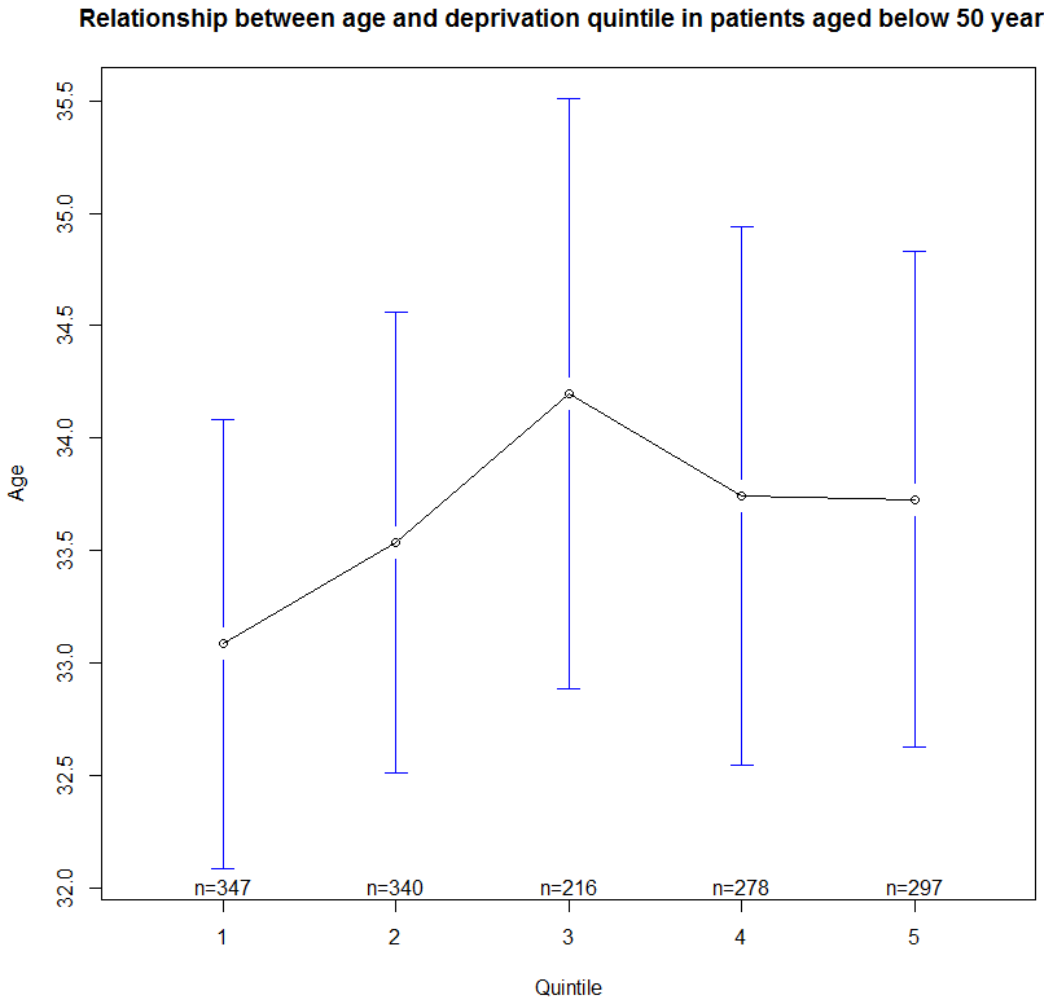


Table 15 Observed number of distal radius fracture seen in Leicestershire and expected number of distal radius fracture in the region for each deprivation quintile from 2007 to 2010 in adult patients aged under 50 years

Quintile	Population	% of population	Fractures expected	Fractures observed
1	69844	15.5	57.20	86.75
2	87723	19.4	71.84	85
3	73048	16.2	59.82	53.75
4	102439	22.7	83.89	69.75
5	118156	26.2	96.76	74.25

Figure 29 Mean age of distal radius fracture patients in Leicestershire from 2007 to 2010 in adult patients aged under 50 years in each deprivation quintile with 95% confidence intervals

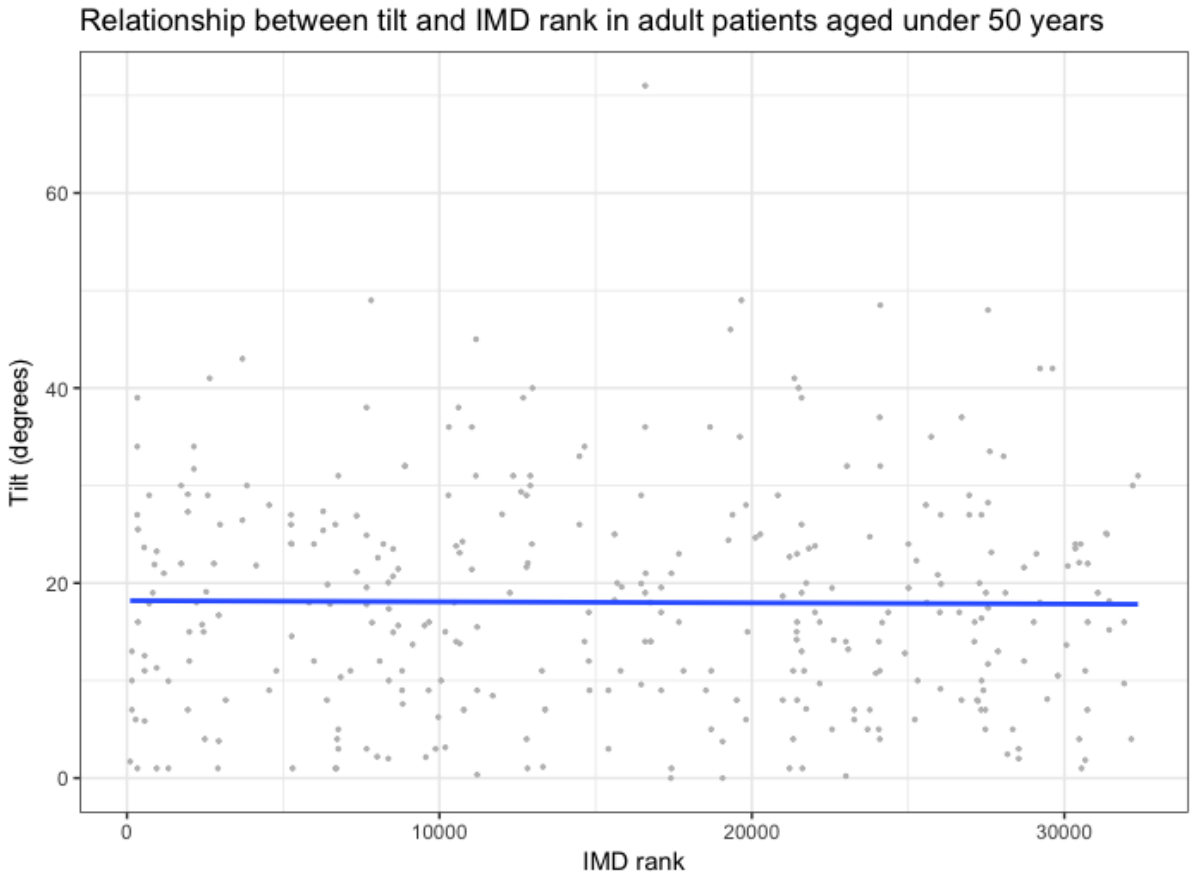


No significant relationship was seen between age and deprivation quintile across the groups (0.784) or when quintiles 1 and 2 were compared with quintiles 3-5 (0.274). Mean age of patients in the two most deprived quintiles was 33.3 years compared to 33.9 in the least three deprived quintiles.

5.4.1 Relationship between deprivation and radiographic parameters in adult patients aged between 18 and 49 years

5.4.1.1 Dorsal tilt

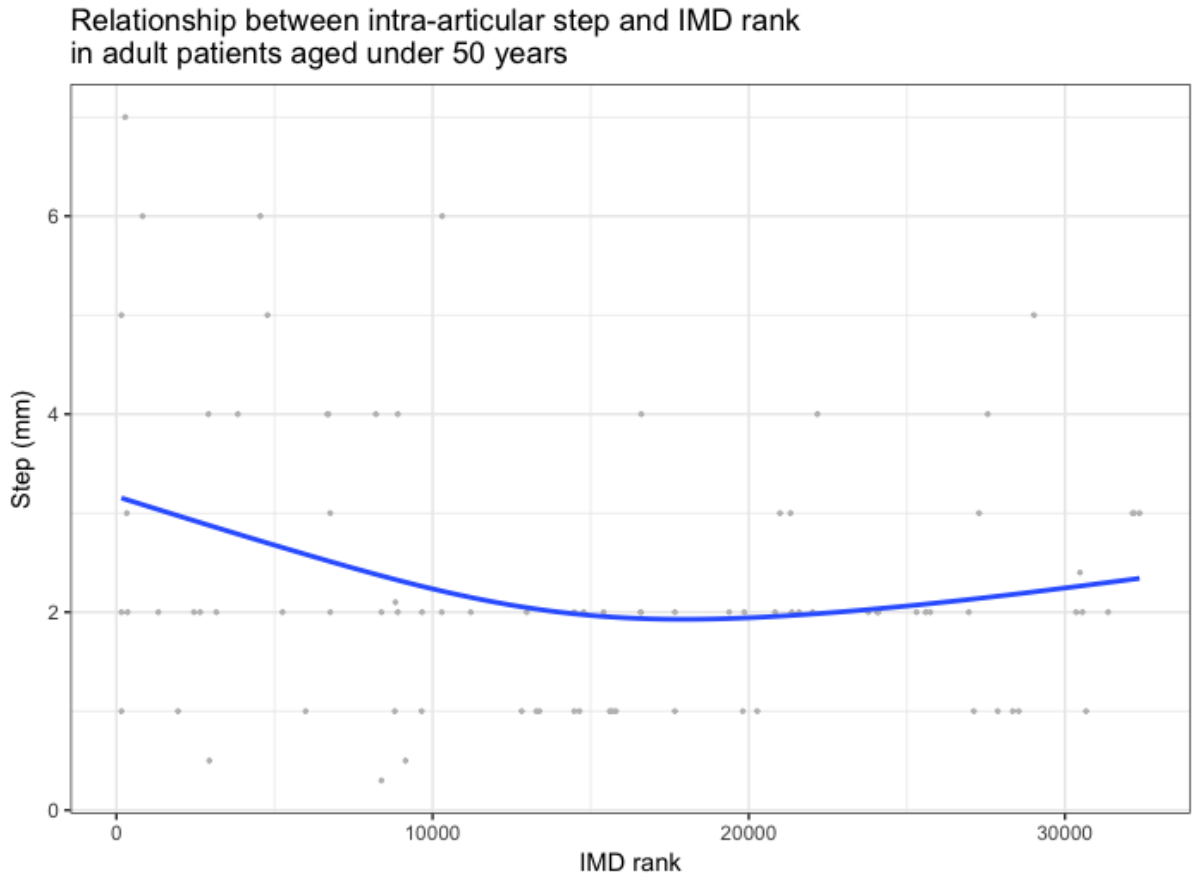
Figure 30 Relationship between dorsal tilt and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model in adult patients aged below 50 years



No relationship was seen between dorsal tilt and IMD rank in the 392 patients studied (p=0.862).

5.4.1.2 Intra-articular step

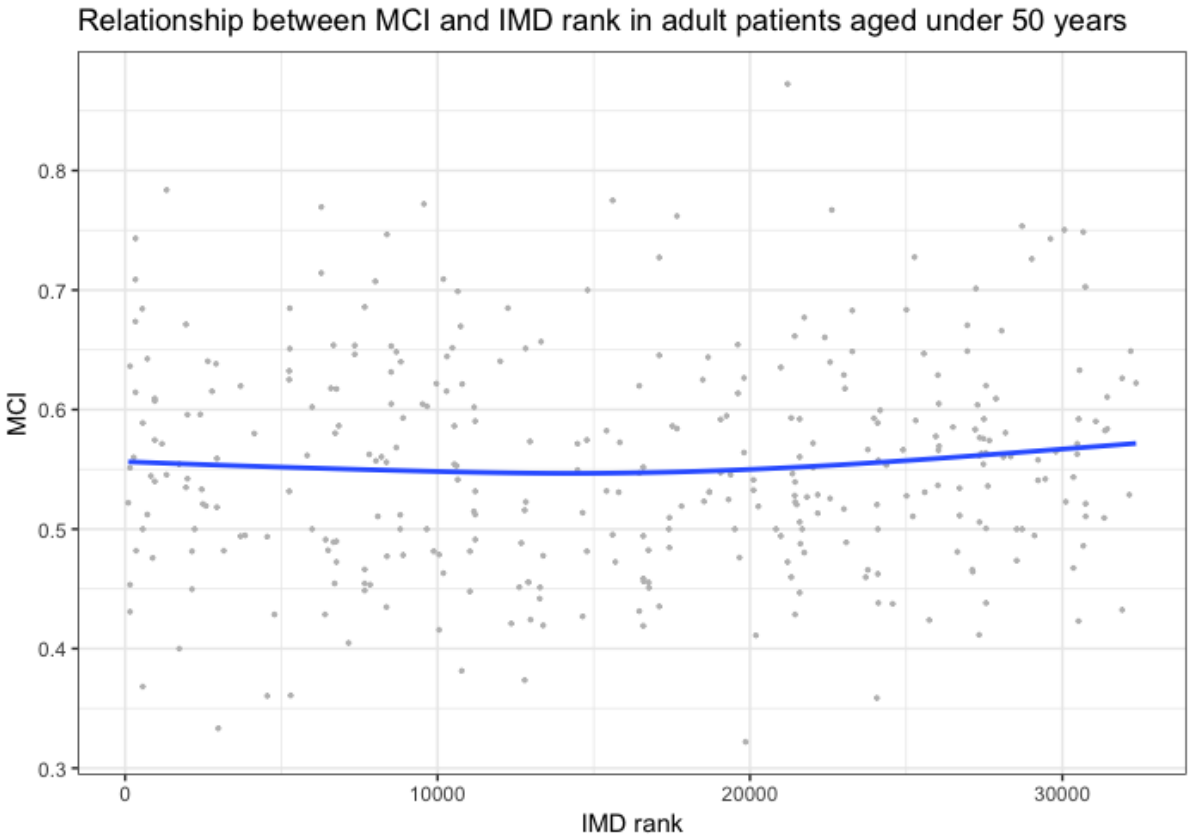
Figure 31 Relationship between intra-articular step and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model in adult patients aged below 50 years



86 patients in this age group had measurement of a displaced intra-articular step performed. A relationship between increasing step size and increased deprivation came close to statistical significance (p=0.052).

5.4.1.3 Metacarpal Cortical Index

Figure 32 Relationship between MCI and IMD rank of distal radius fracture patients in Leicestershire from 2007 to 2010 investigated using a generalised additive model in adult patients aged below 50 years



No significant relationship was seen between MCI and IMD rank in 337 patients (p=0.353).

5.5 Regression model results

Further analysis was performed investigating the effect of age, gender, ethnicity and deprivation on fracture rate. Poisson regression modelling showed a significant difference between ethnicity and all other factors (age<0.001, gender<0.001, deprivation<0.001) indicating important differences between the ethnic groups.

Further regression was therefore carried out separately for the ethnic groups (section 2.8.1.3).

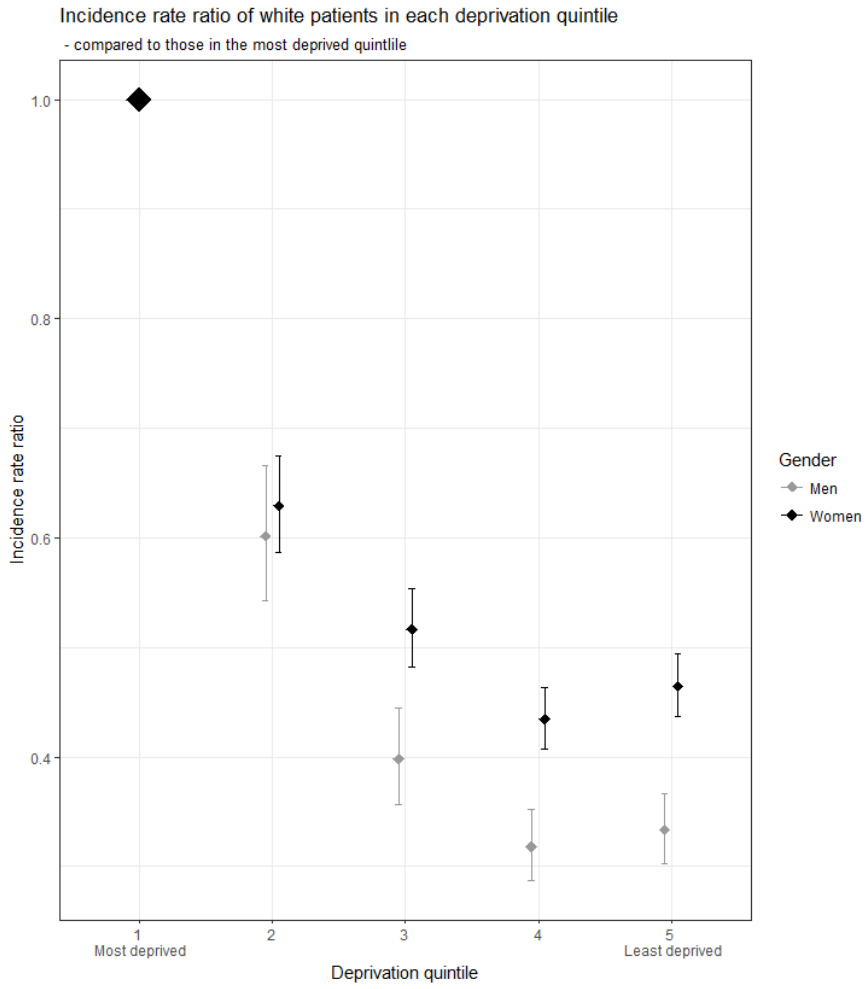
Regression modelling of white patients only (n=3481) showed fracture rate was associated with increased deprivation, age 50 years and over (p<0.001) and male gender (p=0.010) (Table 16). Model testing revealed a significant interaction between deprivation quintile and gender (p<0.001) This interaction was therefore added to the final model and separate results produced for men and women per quintile. Incidence rate ratio of the least deprived quintile compared to the most deprived was 0.33 (95% CI : 0.30 – 0.37) for men and 0.47 (95% CI : 0.44 – 0.49) for women.

Table 16 Regression results for white patients demonstrating the relationship between fracture rate and deprivation quintile, gender and age

IRR of fracture rate for deprivation quintiles are compared with quintile 1 (most deprived), Age 50 years and over is compared with patients below 50 years and male gender with female gender

Factor	IRR	95% CI lower limit	95% CI upper limit	P value
Quintile 2 - women	0.63	0.59	0.68	p<0.001
Quintile 3 - women	0.52	0.48	0.55	p<0.001
Quintile 4 - women	0.43	0.41	0.46	p<0.001
Quintile 5 - women	0.47	0.44	0.49	p<0.001
Quintile 2 - men	0.60	0.53	0.68	0.716
Quintile 3 - men	0.40	0.35	0.45	0.045
Quintile 4 - men	0.32	0.28	0.36	0.01
Quintile 5 - men	0.33	0.30	0.37	0.004
Age 50+	4.18	3.98	4.39	p<0.001
Male	1.28	1.16	1.40	0.01

Figure 33 distal radius fracture incidence rate ratio of white patients in each deprivation quintile compared to the most deprived quintile in Leicestershire from 2007 to 2010



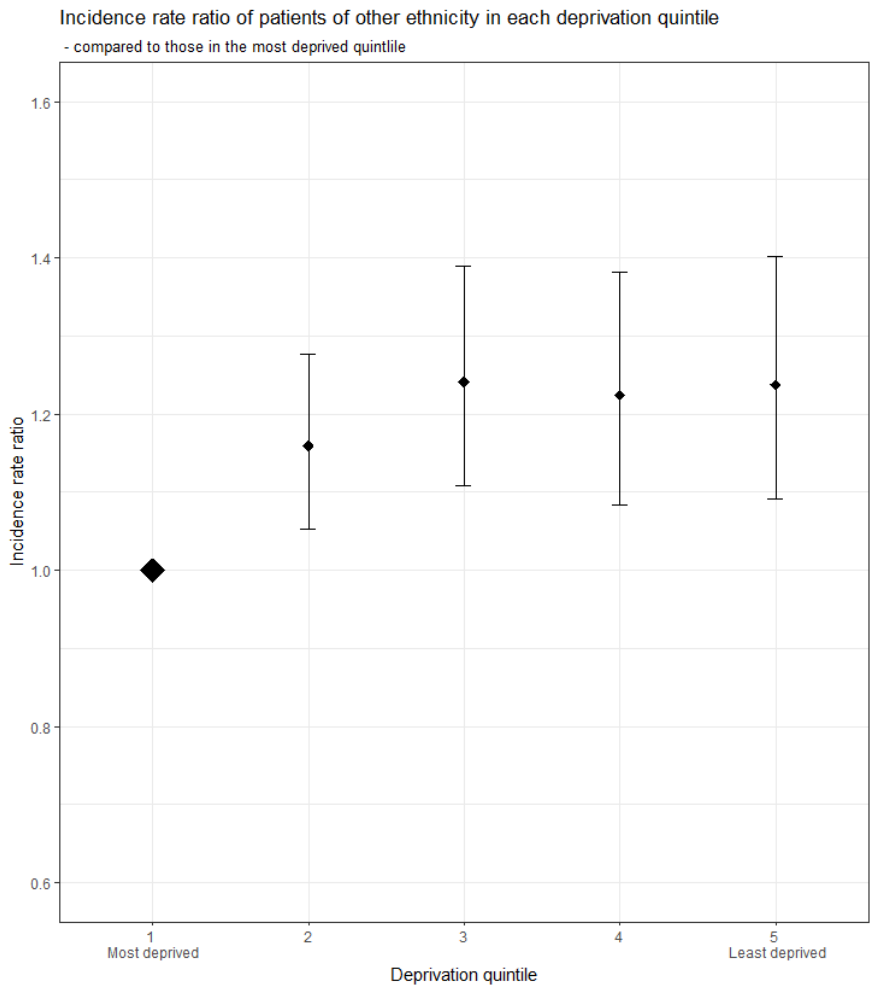
The regression model demonstrated no association with fracture and deprivation for patients of other ethnicities (n=797). There was no interaction between gender and deprivation (p=0.743) suggesting similar results for men and women. Fracture risk was higher in males (p<0.001) and patients aged 50 years and over (p<0.001) (Table 17).

Table 17 Regression results for patients of other ethnicity demonstrating the relationship between fracture rate and deprivation quintile, gender and age

IRR of fracture rate for deprivation quintiles are compared with quintile 1 (most deprived), Age 50 years and over is compared with patients below 50 years and male gender with female gender

Factor	IRR	95% CI lower limit	95% CI upper limit	P value
Quintile 2	1.16	1.05	1.28	0.125
Quintile 3	1.24	1.11	1.39	0.056
Quintile 4	1.22	1.08	1.38	0.097
Quintile 5	1.24	1.09	1.40	0.088
Age 50+	5.09	4.54	5.72	p<0.001
Male	2.62	2.36	2.91	p<0.001

Figure 34 distal radius fracture incidence rate ratio of patients of other ethnicity in each deprivation quintile compared to the most deprived quintile in Leicestershire from 2007 to 2010



5.6 Ethnicity, age and radiographic findings

Following the significant findings regarding the importance of age group, gender and ethnicity in the regression analysis further exploratory sub analysis was performed on the radiographic measurement data by gender, age and ethnicity using GAM. Some sub analysis groups, particularly other ethnicity, were small. This leads to the irregular

plots seen. Further analysis was therefore carried out comparing those in the two most deprived quintiles with the three least deprived quintiles.

5.6.1 Patients aged 50 years and over

5.6.1.1 Dorsal tilt

No relationship between dorsal tilt and IMD rank was seen in any of the gender/ethnicity subgroups in older patients.

Figure 35 Generalised additive model analysis comparing dorsal tilt and IMD rank by gender and ethnicity in distal radius fracture patients in Leicestershire from 2007 to 2010 aged 50 years and over

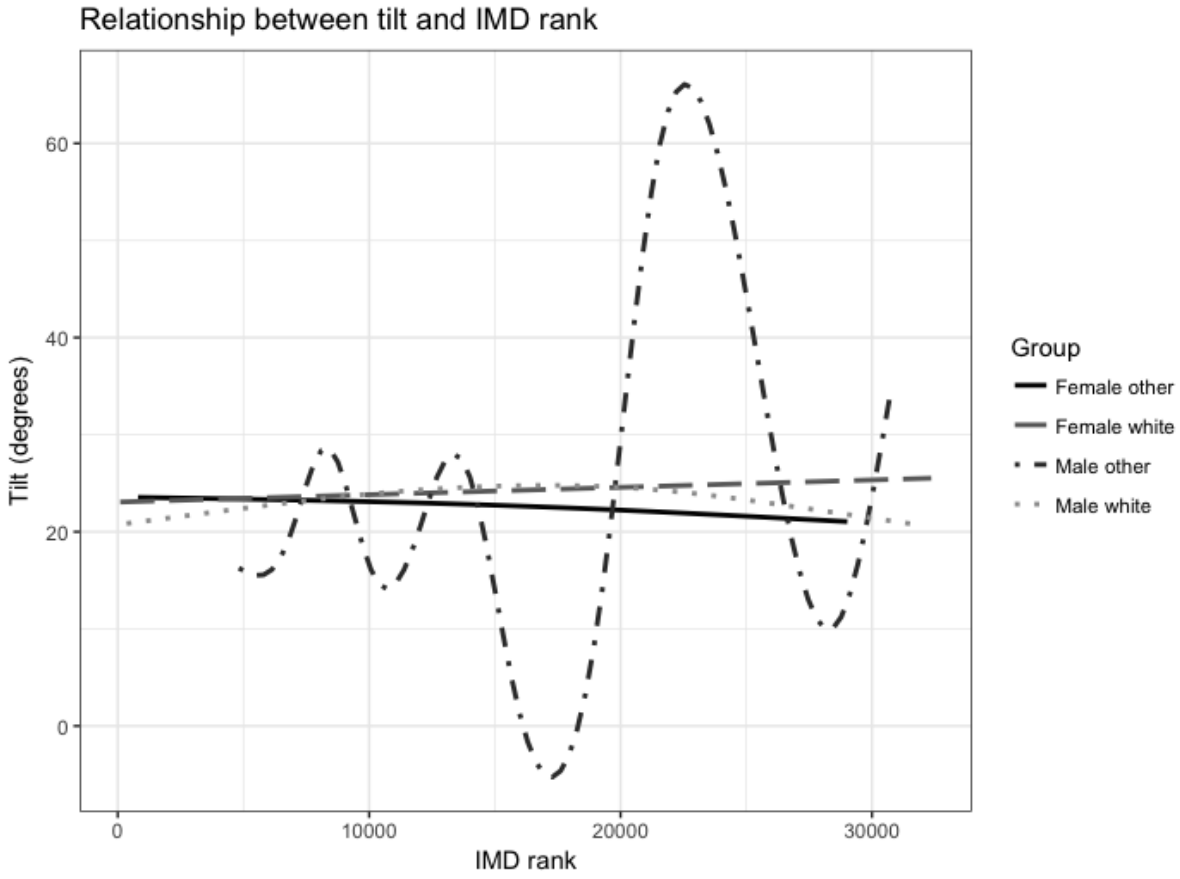


Table 18 P values obtained for each gender ethnicity subgroup from the generalized additive model investigating relationship between IMD rank and dorsal tilt

Group	N	P value
Female other	50	0.543
Female white	375	0.402
Male other	25	0.732
Male white	94	0.916

Table 19 Results of the comparison of mean dorsal tilt between the two most deprived quintiles (Q1-2) and the three least deprived quintiles (Q3-5) for each gender ethnicity subgroup

Tilt	**Q1-2 mean**	**N**	**Q3-5 mean**	**N**	**P**
female other	24.36	31	20.52	19	0.377
female white	24.10	115	24.65	260	0.747
male other	22.09	16	21.36	9	0.916
male white	22.98	26	23.17	68	0.962

5.6.1.2 MCI

Significant trends were seen in females of other ethnicity and white males. Females of other ethnicity had higher MCI in more deprived areas. In deprived areas, their MCI was higher than white females.

White males had lower MCI in more deprived areas. In the most deprived two quintiles MCI of white males was significantly less than the MCI of males of other ethnicity.

Figure 36 Generalised additive model analysis comparing MCI and IMD rank by gender and ethnicity in distal radius fracture patients in Leicestershire from 2007 to 2010 aged 50 years and over

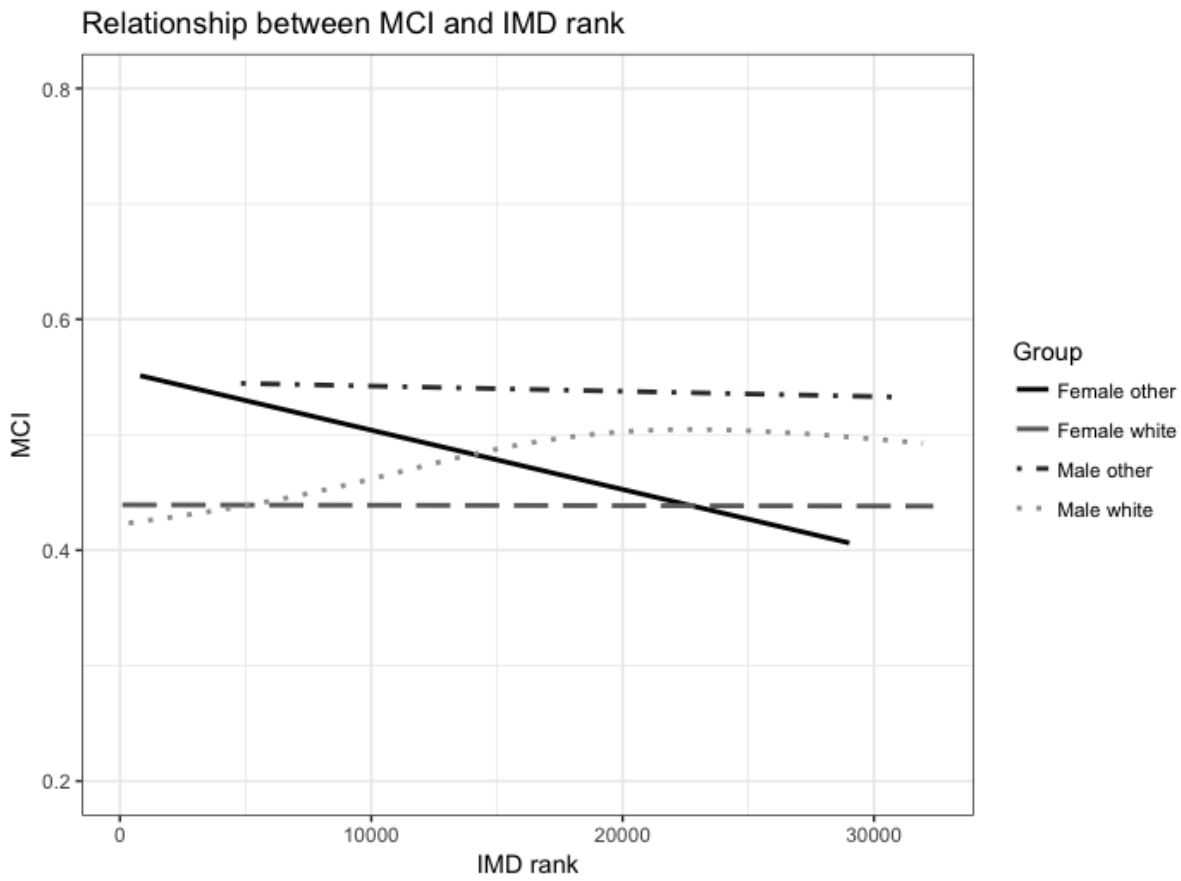


Table 20 P values obtained for each gender ethnicity subgroup from the generalized additive model investigating relationship between IMD rank and MCI

Group	N	P value
Female other	50	**0.004**
Female white	382	0.951
Male other	25	0.839
Male white	94	**0.034**

Table 21 Results of the comparison of mean MCI between the two most deprived quintiles (Q1-2) and the three least deprived quintiles (Q3-5) for each gender ethnicity subgroup

MCI	**Q1-2 mean**	**N**	**Q3-5 mean**	**N**	**P**
female other	0.52	31	0.46	19	**0.008**
female white	0.44	117	0.44	265	0.734
male other	0.55	16	0.53	9	0.753
male white	0.44	26	0.50	68	**0.001**

Table 22 Results of the comparison of mean MCI between ethnicity groups of the same gender in the two most deprived quintiles (Q1-2) and the three least deprived quintiles (Q3-5)

MCI	**Q1-2 mean**	**N**	**Q3-5 mean**	**N**
female other	0.52	31	0.46	19
female white	0.44	117	0.44	265
P	**0.0001**	P	0.399	
male other	0.55	16	0.53	9
male white	0.44	26	0.50	68
P	**0.0001**	P	0.292	

5.6.2 Patients aged between 18 and 49 years

5.6.2.1 Dorsal tilt

In younger patients, no relationship was seen between dorsal tilt and IMD rank in any of the subgroups. Numbers of patients from other ethnicities was small.

Figure 37 Generalised additive model analysis comparing dorsal tilt and IMD rank by gender and ethnicity in adult distal radius fracture patients in Leicestershire from 2007 to 2010 aged under 50 years

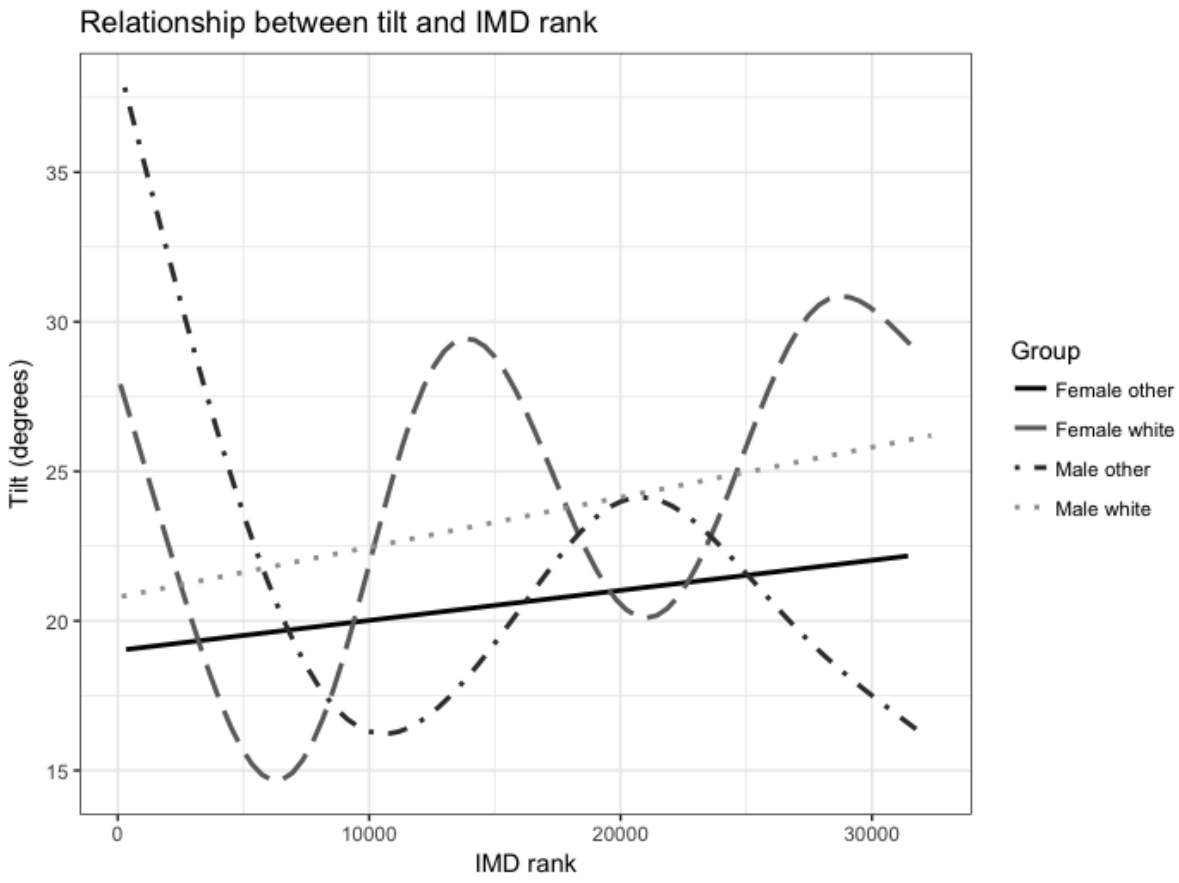


Table 23 P values obtained for each gender ethnicity subgroup from the generalized additive model investigating relationship between IMD rank and dorsal tilt in adult patients aged under 50 years

Group	N	P value
Female other	33	0.771
Female white	119	0.204
Male other	45	0.381
Male white	136	0.262

Table 24 Results of the comparison of mean dorsal tilt between the two most deprived quintiles (Q1-2) and the three least deprived quintiles (Q3-5) for each gender ethnicity subgroup in adult patients aged under 50 years

Tilt	**Q1-2 mean**	**N**	**Q3-5 mean**	**N**	**P**
female other	19.75	21	21.27	12	0.800
female white	23.21	45	25.39	74	0.524
male other	21.35	21	21.89	24	0.920
male white	21.76	57	24.66	79	0.336

5.6.2.2 MCI

No significant relationship was identified between MCI and IMD rank for any of the subgroups of younger patients.

Figure 38 Generalised additive model analysis comparing MCI and IMD rank by gender and ethnicity in adult distal radius fracture patients in Leicestershire from 2007 to 2010 aged under 50 years

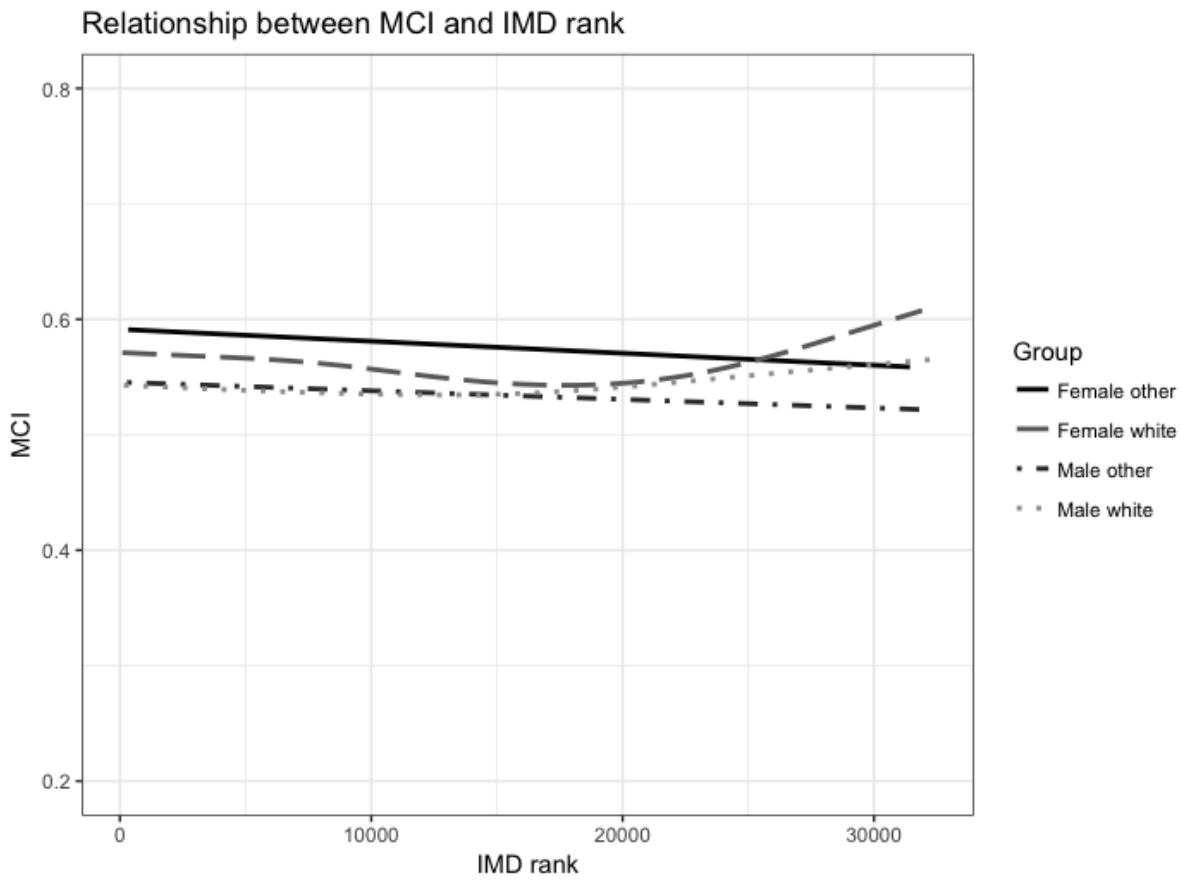


Table 25 P values obtained for each gender ethnicity subgroup from the generalized additive model investigating relationship between IMD rank and MCI in adult patients aged under 50 years

Group	N	P value
Female other	33	0.688
Female white	121	0.453
Male other	47	0.572
Male white	136	0.081

Table 26 Results of the comparison of mean MCI between the two most deprived quintiles (Q1-2) and the three least deprived quintiles (Q3-5) for each gender ethnicity subgroup in adult patients aged under 50 years

MCI	**Q1-2 mean**	**N**	**Q3-5 mean**	**N**	**P**
female other	0.57	21	0.59	12	0.469
female white	0.57	45	0.57	76	0.986
male other	0.54	22	0.53	25	0.936
male white	0.54	57	0.54	79	0.951

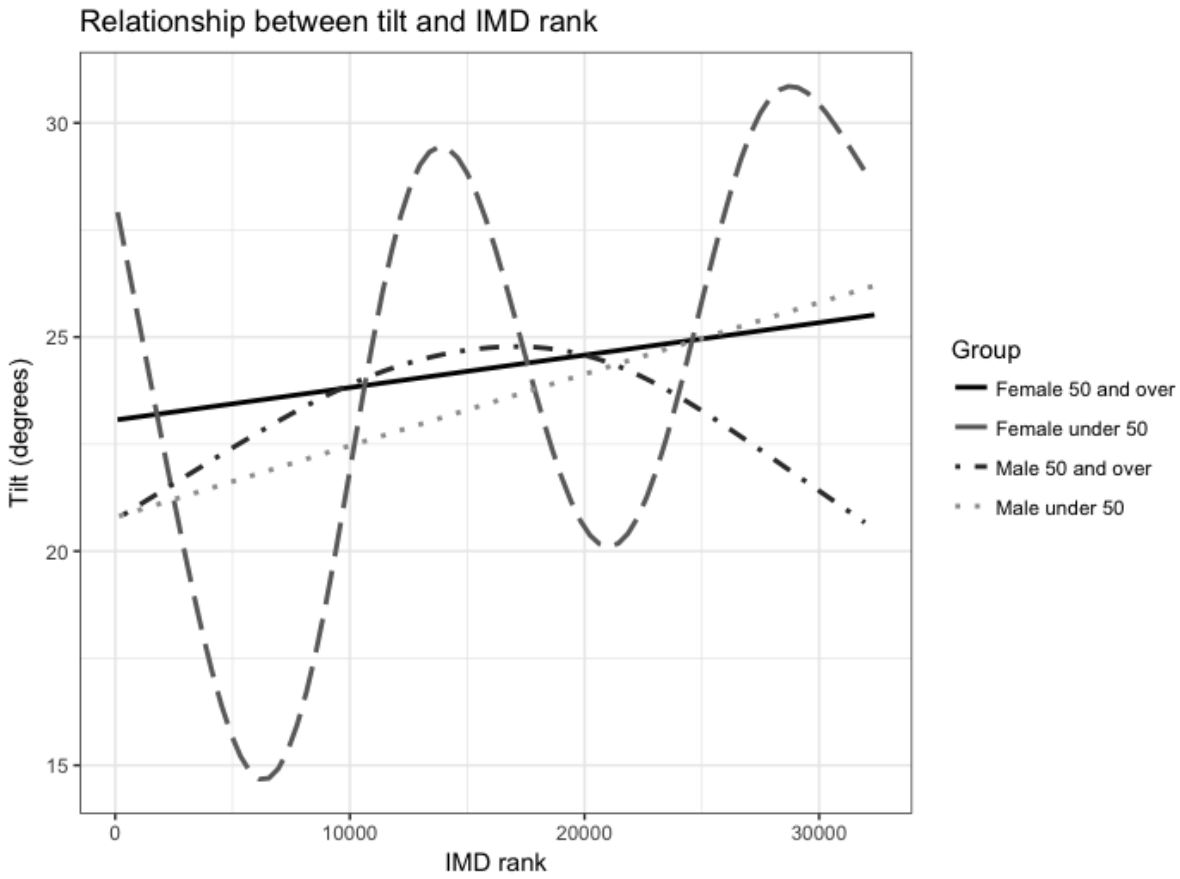
5.6.3 Comparison between ethnic groups

Plots of the generalised additive models are provided to allow visual comparison of the differences between the subgroups of patients of the same ethnicity.

5.6.4 White patients

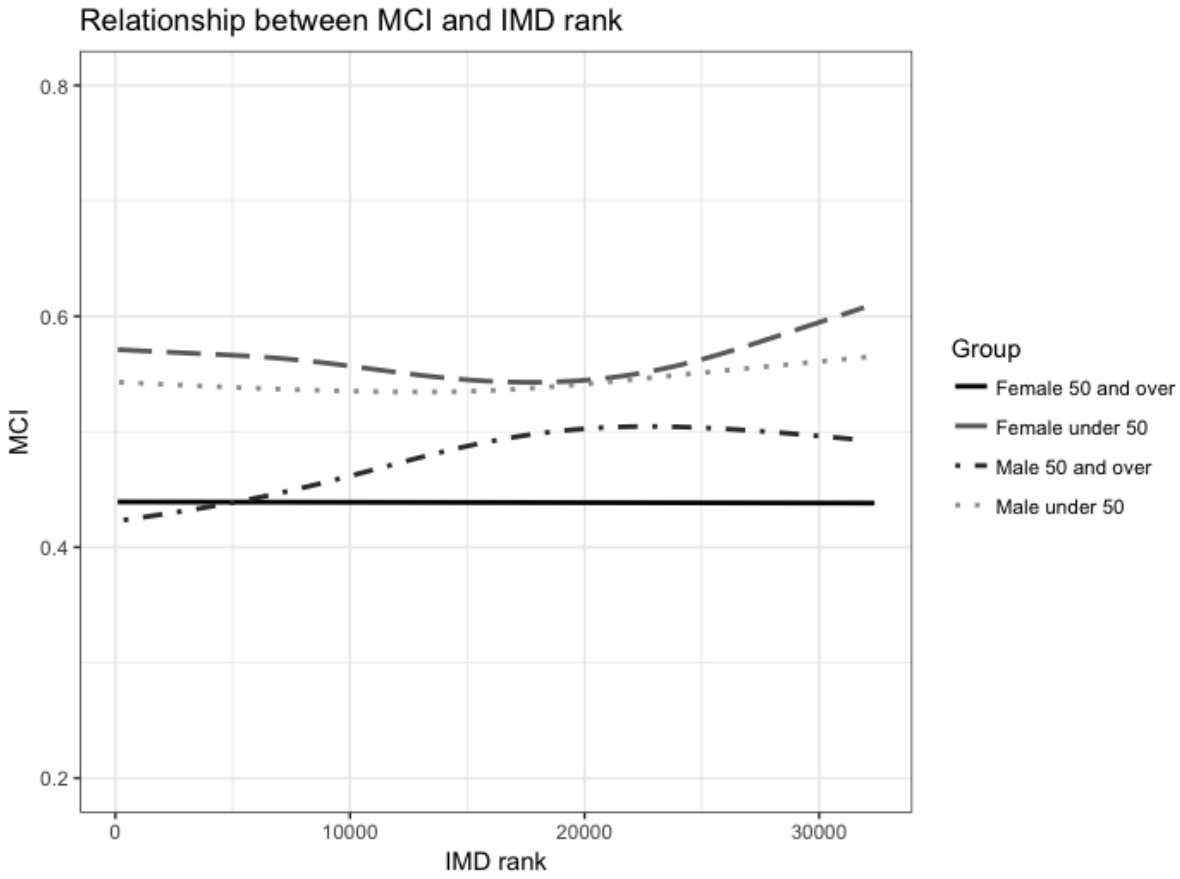
5.6.4.1 Dorsal tilt

Figure 39 Generalised additive model analysis comparing dorsal tilt and IMD rank by gender and age group in white distal radius fracture patients in Leicestershire from 2007 to 2010



5.6.4.2 MCI

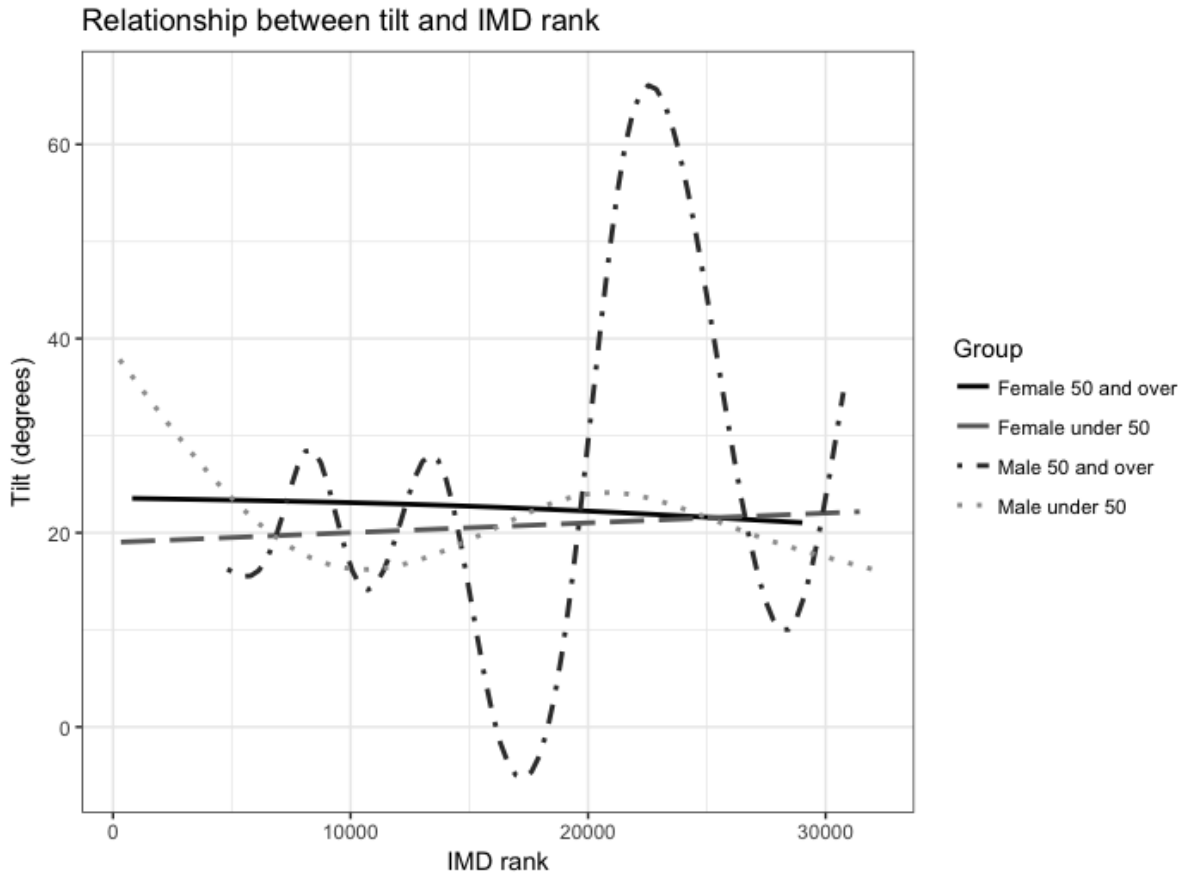
Figure 40 Generalised additive model analysis comparing MCI and IMD rank by gender and age group in white distal radius fracture patients in Leicestershire from 2007 to 2010



5.6.5 Patients of other ethnicity

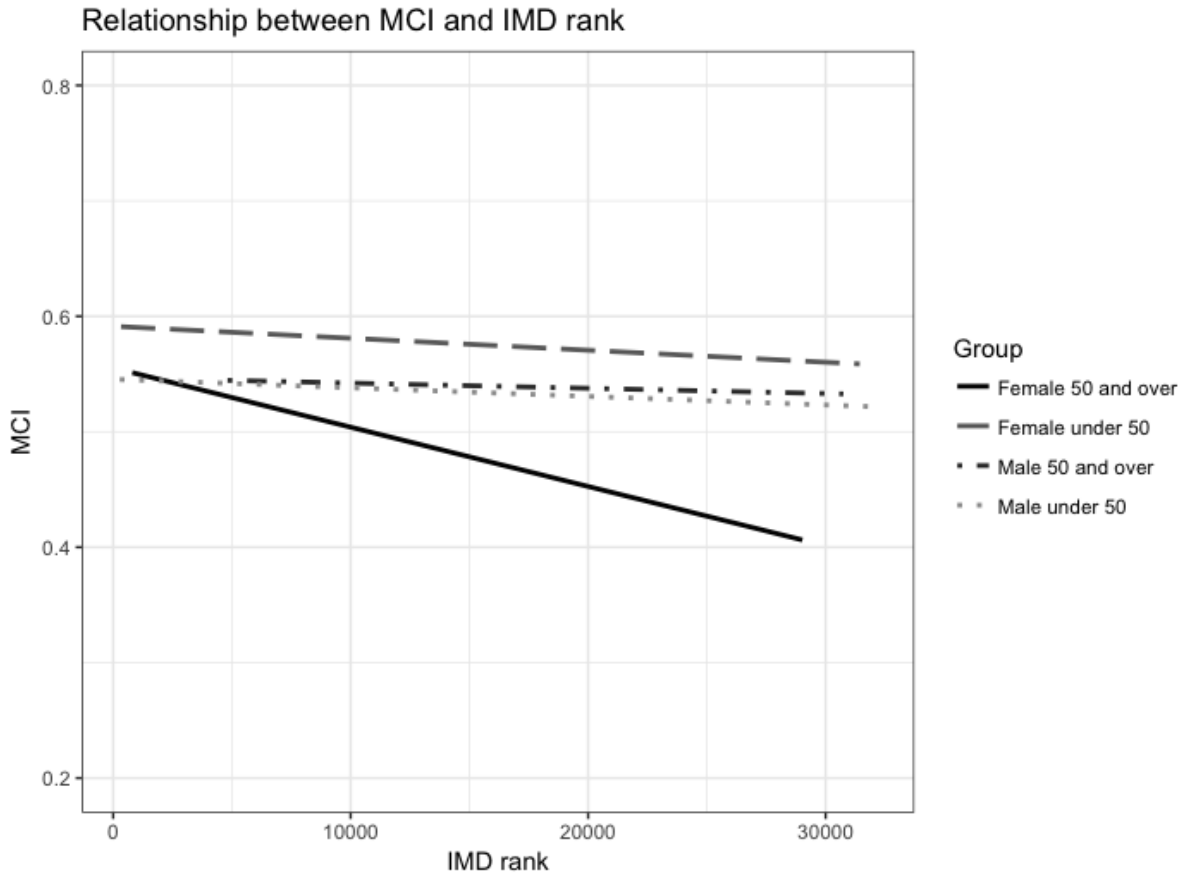
5.6.5.1 Dorsal tilt

Figure 41 Generalised additive model analysis comparing dorsal tilt and IMD rank by gender and age group in distal radius fracture patients of other ethnicity in Leicestershire from 2007 to 2010



5.6.5.2 MCI

Figure 42 Generalised additive model analysis comparing MCI and IMD rank by gender and age group in distal radius fracture patients of other ethnicity in Leicestershire from 2007 to 2010



5.7 Effect of deprivation and ethnicity on national distal radius fracture surgery rate

Full demographic data was available on 40,386 patients aged 50 years and over and 18,929 patients aged 18 to 49 years who underwent surgery for distal radius fracture over 4 years. Poisson regression models were constructed using total population at risk, calculated accurately for age, ethnicity, gender and quintile, as an offset.

Initial overdispersion of the models was corrected using forward selection and by creating separate models for under and over 50 years of age. This was chosen after age was seen to significantly interact with all other factors (section 2.8.1.13).

5.7.1 Patients aged under 50 years

Ethnicity was seen to interact with gender so this interaction was added to the model. Fixation rate significantly fell in the less deprived quintiles (IRR 0.75, CI 0.73-0.77, comparing the least deprived quintile to the most deprived). Rate was lower for all other ethnicities compared to white patients (Asian IRR 0.18, CI 0.17-0.20, Black IRR 0.10, CI 0.09-0.12, Other IRR 0.45, CI 0.41-0.49). Males of all ethnicity were more likely to undergo fixation (Appendix 8).

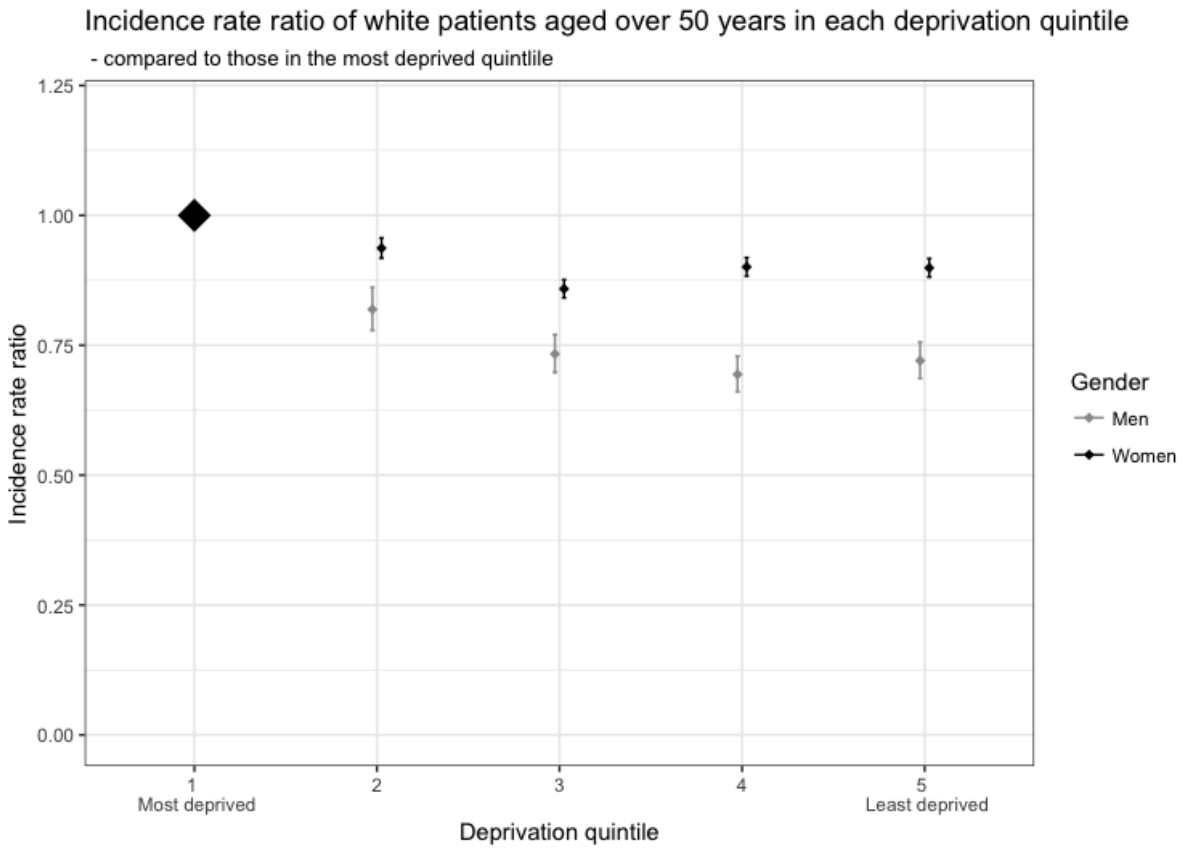
5.7.2 Patients aged 50 years and over

Significant interaction was seen between quintile and ethnicity, quintile and gender and ethnicity and gender. These interaction terms were added to the model.

Fixation rate significantly fell in the less deprived quintiles only in white patients. The influence of deprivation was greater in men (white women IRR 0.90, CI 0.88-0.92, white men IRR 0.72, CI 0.68-0.76, comparing the least deprived quintile to the most

deprived for each gender). White patients were more likely to undergo surgery. Fixation rate was significantly lower in white men compared to women (IRR 0.23, CI 0.23-0.24)

Figure 43 Incidence rate ratio of white patients who underwent surgery for distal radius fracture in each deprivation quintile compared to the most deprived quintile in the UK from 2009 to 2013



5.8 Summary of the effect of deprivation on distal radius fracture rate in Leicestershire

Deprivation was strongly associated with increased distal radius fracture rate. More fractures were seen than expected in the two most deprived quintiles for both age groups studied (section 9.6.1). Mean age of deprived distal radius fracture patients was significantly lower. When deprivation, ethnicity and age are considered being male is a risk factor for distal radius fracture. Modelling showed important differences between ethnic groups. Deprivation was an independent risk factor for distal radius fracture only in white patients. Women of other ethnicity aged 50 years and over in the most deprived quintiles had a higher MCI than those in the less deprived quintiles and when also compared to white women from the same quintiles (section 9.6.2). The reverse was true for white men in the most deprived quintiles who had a lower MCI than white men in the less deprived quintiles along with a lower MCI than men of other ethnicity in the same quintiles. These findings may help explain why deprivation increases fracture risk in white men yet has less effect on patients of other ethnicity.

Chapter 6 Influence of deprivation on treatment

This chapter aims to investigate if deprivation has an influence on the treatment of patients with a distal radius fracture. Characteristics of patients undergoing surgery for distal radius fracture in Leicestershire are compared with those treated conservatively using poisson regression modelling to identify if deprivation effects surgical treatment rate (section 2.8.1.3). Modelling of national patient data is used to investigate if deprivation influences treatment measures such as wait for surgery, daycase surgery, semi-elective surgery and post operative hospital stay (section 2.6.9, 2.8.1.6 & 2.8.1.9). Hospital trust data is used to explore national variation in surgical treatment with the effect of deprivation also studied (section 2.6.4, 2.6.6 & 2.8.1.7). This information can help identify and reduce inequalities in healthcare and provides useful information for hospitals to improve patient experience and pathways of care.

6.1 Surgical fixation rate in Leicestershire

Patients who underwent surgical fixation were compared with the total group who sustained fractures in Leicestershire over the four year period studied. A poisson regression model demonstrated no relationship with deprivation quintiles suggesting no difference in deprivation related to treatment. Patients aged under 50 years were less likely to undergo surgery (IRR 0.57, CI 0.48 to 0.68, p=0.001). There was no association with gender (p=0.391). White patients were more likely to undergo surgical intervention (IRR 1.74, CI 1.40 to 2.15, p=0.010) (Appendix 9).

Patients with intra-articular fractures (p=0.057) and those who sustained injuries outdoors (p=0.075) showed a tendency towards surgical fixation but this did not reach statistical significance.

Male gender was associated with intra-articular fracture (p=0.024). Injuries outdoors were strongly associated with the younger age group (p<0.001). There was no relationship between intra-articular fracture and any deprivation quintile.

6.2 National data Models

A series of regression models is reported to investigate the relationship between several measures of the quality of treatment and deprivation (IMD rank) along with a large number of independent variables in patients who required surgical fixation for a displaced distal radius fracture (Kirschner wires, plating, external fixation).

Independent variables included:

Patient details: age, gender, ethnicity, comorbidities, Charlson index, patient IMD score, procedure

Hospital trust details: total population, population aged 65 or over, population of women, cases performed per year, cases performed that month

Date/ seasonal details: year, day of week, month, cases performed per year, cases performed that month, minimum temperature

Hospital trust was included as a random effect for each model.

Significant values are included in the tables for each model along with results for deprivation as it is the main variable of interest. In the models day of the week was compared to Tuesday as this is a working day which is unlikely to be influenced by increased fracture rate at the weekend or different weekend hospital staffing and processes. Monthly results were compared to April as this month is unlikely to be affected by extremes of temperature and weather conditions seen in winter or summer which may influence fracture rate.

6.2.1 IMD rank

A linear regression model was created with IMD rank as the dependent variable and all the other variables mentioned above as independent variables (section 2.8.1.1). Low IMD rank indicates high deprivation so coefficients with a negative value are associated with more deprivation.

Men and black patients were more likely to be from more deprived areas. Higher numbers of comorbidities as measured by actual number of comorbidities and the Charlson score were both seen with deprivation. Trusts that carried out higher number of cases a year were associated with deprivation.

Increasing age and trust with a higher proportion of older patients were both associated with less deprivation.

Table 27 Patient and hospital trust factors which interact significantly with deprivation (measured by IMD rank) in patients who required surgical treatment for an acute distal radius fracture

Variable	Co-efficient	95% CI lower limit	95% CI upper limit	P value
Male	-1.069	-0.900	-1.238	<0.001
Black	-1.39	-0.127	-2.653	0.031
Comorbidity	-0.446	-0.382	-0.510	<0.001
Charlson score	-0.285	-0.135	-0.435	<0.001
Cases per year	-1.878	-0.125	-3.631	0.038
Older population	7.501	0.862	14.140	0.029
Increasing age	0.012	0.010	0.014	<0.001

6.2.2 Wait for semi elective trauma surgery

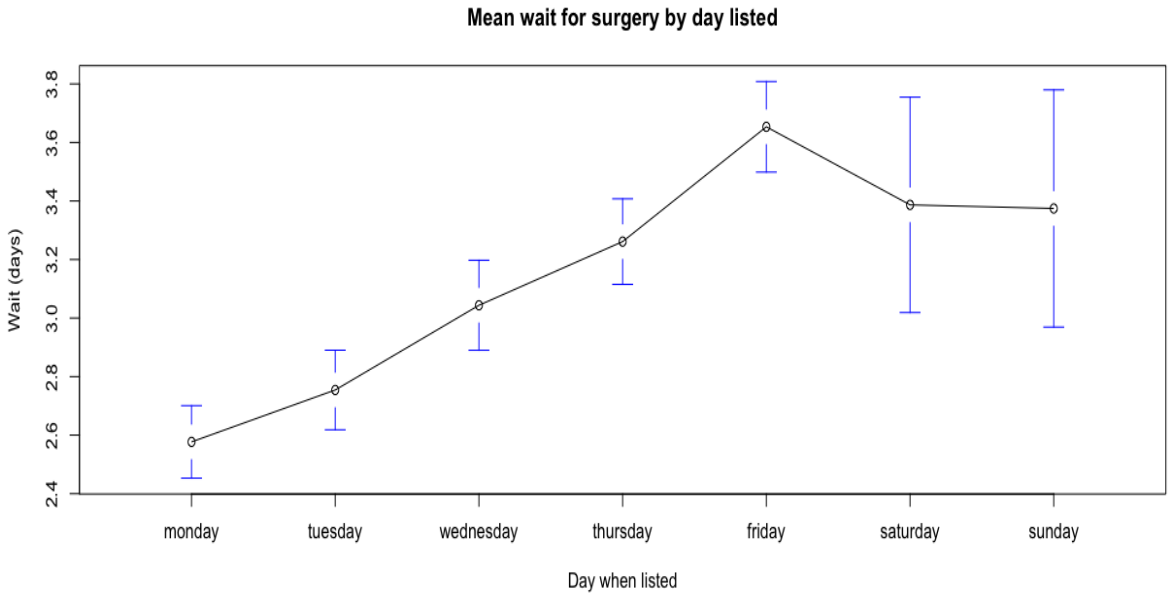
Linear regression modelling with hospital as a random effect demonstrated that patients who are listed for surgery and sent home to return on a planned date (n=9,318) wait longer if they are listed towards the end of the week (section 2.8.1.9). Mean time to surgery was 3.04 days (range 1 to 30 days, sd 3.14). Those listed from Thursday onwards wait on average more than three days. This is longer than the NICE guidance for fixation of intra-articular distal radius fractures. 6,538 patients underwent surgery within 3 days (70.2%) and 8,747 within 7 days (93.9%). Those with a higher number of comorbidities also had a significantly longer wait for surgery.

Table 28 Patient and hospital trust factors which interact significantly with wait for semi elective trauma surgery in patients who required surgical treatment for an acute distal radius fracture

Day of the week is the day the patient was listed for surgery

Variable	Co-efficient	95% CI lower limit	95% CI upper limit	P value
Comorbidity	0.066	0.010	0.122	0.02
Wednesday	0.413	0.224	0.602	<0.001
Thursday	0.594	0.404	0.784	<0.001
Friday	1.032	0.829	1.235	<0.001
Saturday	0.728	0.430	1.026	<0.001
Sunday	0.879	0.585	1.173	<0.001
Deprivation	*-0.002*	*-0.003*	*-0.001*	*0.537*

Figure 44 Mean wait for semi elective trauma surgery in patients who required surgical treatment for an acute distal radius fracture dependent on the day they were listed for surgery with 95% confidence intervals



6.2.3 Daycase

A logistic regression model was constructed to assess whether any of the factors were related to the likelihood of the patient undergoing surgery as a day case (section 2.8.1.6).

Day case surgery was less likely for men, older patients and those with more comorbidities. Those who present on a Friday, Saturday or Sunday were also less likely to have surgery as a day case.

Patients who sustained their injuries in the winter months, times of low temperature or in months with more cases performed were more likely to have day case surgery. Fixation with K-wires was more likely to be carried out as a day case compared to plating or external fixation.

Table 29 Patient and hospital trust factors which interact significantly with the likelihood of undergoing daycase surgery in patients who required surgical treatment for an acute distal radius fracture

All months from October to March inclusive were associated with more day case surgery. Day of the week is the day the patient was listed for surgery.

Variable	Co-efficient	95% CI lower limit	95% CI upper limit	P value
Male	-0.228	-0.156	-0.300	<0.001
Larger female population	-0.794	-0.024	-1.564	0.043
Increasing age	-0.009	-0.007	-0.011	<0.001
Comorbidity	-0.248	-0.219	-0.277	<0.001
Charlson score	-0.089	-0.016	-0.162	0.015
Friday	-0.221	-0.123	-0.319	<0.001
Saturday	-1.645	-1.486	-1.804	<0.001
Sunday	-1.887	-1.706	-2.068	<0.001
Months – Oct-March - min	2.349	2.182	2.516	0.002
Months – Oct-March - max	3.61	3.438	3.782	<0.001
K-wires	0.071	0.003	0.139	0.035
White	0.263	0.036	0.490	0.023
Cases per month	0.189	0.117	0.261	<0.001
Lower temperature	0.013	0.004	0.022	0.004
Deprivation	*0.0031*	*-0.0004*	*0.0066*	*0.079*

6.2.4 Pre operative wait for surgery

A further linear regression model investigating the wait to surgery showed that wait was longer for patients in September or those having fixation with K-wires. Patients who underwent external fixation or had surgery as a planned day case waited for less time.

Table 30 Patient and hospital trust factors which interact significantly with increasing wait for surgery in patients who required surgical treatment for an acute distal radius fracture

Variable	Co-efficient	95% CI lower limit	95% CI upper limit	P value
September	0.088	0.008	0.168	0.03
K-wires	0.140	0.107	0.173	<0.001
External fixation	-0.513	-0.408	-0.618	<0.001
Daycase surgery	-0.415	-0.367	-0.463	<0.001
Deprivation	*0.0003*	*-0.0015*	*0.0020*	*0.748*

6.2.5 Post operative stay

Linear regression demonstrated that men, older patients, patients with more comorbidities and those who underwent k-wire or external fixation stayed in hospital longer after surgery. Wait was also longer for those who presented on a Saturday or in January.

Length of stay was less in those who underwent surgery as a day case, at times of more monthly procedures and in patients who had type I diabetes.

Table 31 Patient and hospital trust factors which interact significantly with post operative length of stay in patients who required surgical treatment for an acute distal radius fracture

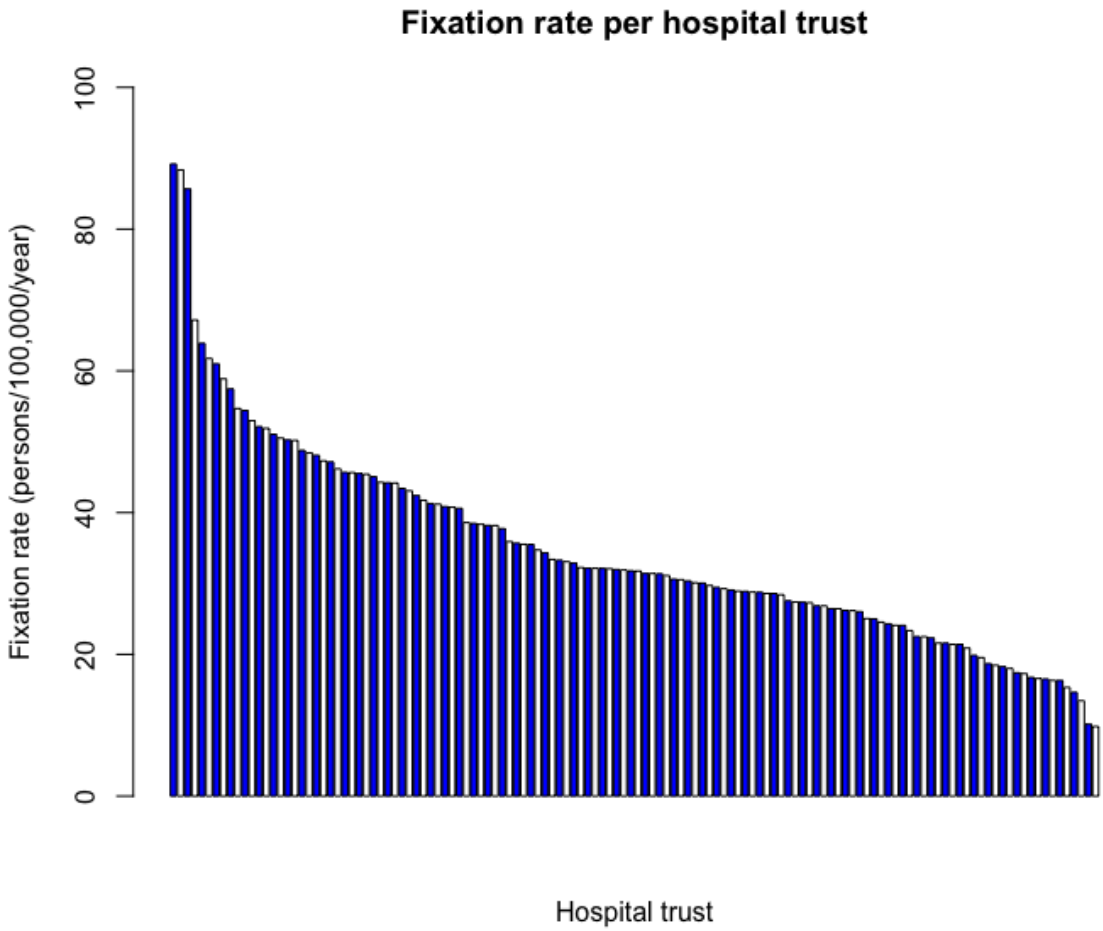
Variable	Co-efficient	95% CI lower limit	95% CI upper limit	P value
Male	0.379	0.364	0.394	<0.001
Larger trust population	0.158	0.015	0.301	0.033
January	0.508	0.125	0.891	0.009
Age	0.056	0.037	0.075	<0.001
K-wires	0.554	0.405	0.703	<0.001
External fixation	3.604	3.133	4.075	<0.001
Comorbidity	1.284	1.227	1.341	<0.001
Charlson score	0.318	0.181	0.455	<0.001
Saturday	0.294	0.033	0.555	0.027
Daycase surgery	-1.79	-1.578	-2.002	<0.001
Diabetes type1	-1.333	-0.978	-1.688	<0.001
Cases per month	-0.419	-0.248	-0.591	<0.001
Deprivation	*-0.0012*	*-0.0089*	*0.0065*	*0.762*

6.3 National Variation

59,802 surgical procedures for acute distal radius fracture for people aged 18 years and over were performed over the study period.

In England, the rate of surgical fixation of distal radius fracture ranged from 9.8 to 89.2 per 100,000 population (9.1 fold variation) (Figure 45). When the seven hospital trusts with the highest rates and the seven hospital trusts with the lowest rates are excluded the range is 16.5 to 58.9 per 100,000 population and the variation is 3.6 fold.

Figure 45 Acute distal radius fracture fixation rate (expressed per 100,000 person/years) by hospital trust in England from 2009 to 2013



Increasing size of hospital trust population was associated with reduced rate of fixation. (Figure 46). Trusts with a higher population of people aged over 65 years demonstrated a higher rate of fixation. Mean deprivation score of hospital trust, number of women and the presence of a hand unit did not influence rate of fixation (Table 32)(section 2.8.1.7).

Table 32: Negative binomial regression analysis of the relationship between hospital trust factors and surgical fixation rate in patients who required surgical treatment for an acute distal radius fracture

Variable	Co-efficient	95% CI lower limit	95% CI upper limit	P value
Population (100,000)	-0.202	-0.269	-0.135	**<0.001**
Women (100,000)	-0.064	-0.221	0.093	0.4286
Patients 65 and over (100,000)	0.827	0.339	1.315	**<0.001**
Hand unit	0.089	-0.105	0.283	0.907
Deprivation	*-0.0003*	*-0.0019*	*0.0013*	*0.733*

Figure 46 Plot of acute distal radius fracture fixation rate (expressed per 100,000 person/years) by hospital trust in England population with 95% prediction intervals

6.4 Summary of the influence of deprivation on treatment

Deprivation did not independently influence any of the indicators of patient treatment measured (section 9.7). Men, older patients and those with multiple comorbidities had a less positive healthcare experience in terms of the factors reviewed. Considerable variation of rate of surgical fixation of distal radius fractures exists between hospital trusts across England (section 9.8). Patients who present to hospital on a Friday, Saturday or Sunday are less likely to have day case surgery and wait longer for semi elective surgery after being sent home. Further work should focus on improving pathways of care for older people, those with poor health and preventing patients from suffering inferior care due to sustaining an injury at the weekend.

Chapter 7 Prospective investigation of fracture risk

Social deprivation is associated with many fractures but the reasons why are unclear. The aim of this chapter was to identify if deprivation was associated with falls risk, mechanism of injury or osteoporosis in patients with a fragility fracture of the distal radius. Details of patients aged 50 years and over with a distal radius fracture were prospectively recorded over a one year period (section 2.7.1). Patients were sent a questionnaire including questions regarding mechanism of injury, comorbidity assessment, falls risk assessment tool and FRAX assessment of bone health (section 2.7.2). Location and height of fall was compared between the most and least deprived patients. Regression analysis was used to investigate the relationship of deprivation with falls risk and FRAX score (section 2.7.2.5). Understanding the reasons why deprived patients are more likely to sustain fractures can allow preventative measures to be implemented.

7.1 Participants and response rate

Data from all patients who had sustained a distal radius fracture during the one year study period was screened. After removing patients from outside the region, those with no address or who had passed away 754 patients were identified of which 521 were aged 50 years and over. Surveys were sent to these 521 patients and were completed by 333 patients (279 female; 54 male). Response rate was 64%.

Comparison between characteristics of responders and the four year Leicestershire fracture group was performed. There was no difference in the proportions seen in the most and least deprived quintiles overall (p=0.58) and when examined by gender separately (men p=0.95, women p=0.55) (Table 33). This suggests that the survey responders are representative of the total distal radius fracture population.

Table 33 Comparison of survey responders and total population by gender and most (Q1-2) and least (Q3-5) deprived quintiles

	Survey responders		Total population		
	Q1-2	Q3-5	Q1-2	Q3-5	P value
All	108	225	951	1852	0.58
Women	85	194	759	1566	0.55
Men	23	31	192	286	0.95

Data regarding mechanism of fall, falls risk and osteoporosis risk factors was completed by 96% of participants. Responders were also asked their height and weight. This was completed by 72% of patients. Multiple imputation was therefore performed using gender, age, deprivation rank, number of comorbidities, falls risk factors and other osteoporosis risk factors to generate the missing height and weight values (section 2.8.2). These values were then used to calculate FRAX scores for all patients.

7.2 Mechanism of fall

Comparison was performed between place and height of fall between the two most deprived quintiles and the three least deprived quintiles. A significantly higher proportion of falls occurred in the home in less deprived patients (Q1/2: 35%: Q3-5: 48%, p=0.037) and more falls happened outdoors in the road or street in deprived patients (Q1/2: 39%: Q3-5: 24%, p=0.001). There was no difference in the height at which falls took place with most being from standing height (Q1/2: 81%: Q3-5: 86%, p=0.336).

7.3 Osteoporosis risk

There was no difference in FRAX scores for major 10 year fracture risk and 10 year hip fracture risk between the two most deprived quintiles and the three least deprived quintiles (Table 34). Linear regression analysis was carried out to investigate the relationship between IMD rank and the two FRAX scores but no association was found (major fracture risk: p=0.274, hip fracture risk: p=0.283). FRAX score does incorporate gender and age but due to the likely large effect of these variables further separate linear regression models were constructed for each gender which included age as a separate independent variable. This again demonstrated no association between IMD rank and FRAX scores. Increasing age was significantly associated with higher FRAX scores for both genders.

Further regression analysis of individual osteoporosis risk factors revealed that smoking was the only risk factor with a significant relationship with deprivation (Table 35). A lower rate of smoking and higher rate of rheumatoid arthritis was seen with increasing age. Men were more likely to smoke and less likely to have rheumatoid arthritis.

Table 34 Mean values for each osteoporosis and falls risk score for patients in the two most deprived quintiles(Q1-2) compared to those in the three least deprived quintiles(Q3-5)

	Q1-2 mean score	Q3-5 mean score	P value
FRAX 10yr major fracture	15.75 sd 11.1	17.43 sd 12.2	0.227
FRAX 10yr hip fracture	6.50 sd 8.1	7.75 sd 10.0	0.257
Falls risk factors	3.62 sd 3.2	2.79 sd 3.1	**0.028**

Table 35 P values from individual regression models investigating the relationship between osteoporosis risk factors and deprivation (as measured by IMD rank), age and gender

	Deprivation				Age				Gender (male)			
Osteoporosis risk	Co-efficient	95% CI lower limit	95% CI upper limit	P value	Co-efficient	95% CI lower limit	95% CI upper limit	P value	Co-efficient	95% CI lower limit	95% CI upper limit	P value
Parental hip fracture	-0.005	-0.040	0.030	0.762	-0.021	-0.053	0.011	0.189	-0.987	-2.216	0.242	0.116
Smoker	-0.052	-0.095	-0.009	**0.019**	-0.048	-0.089	-0.008	**0.020 ***	1.079	0.190	1.968	**0.017**
Steroids	-0.003	-0.032	0.025	0.812	-0.018	-0.044	0.008	0.183	-0.773	-1.681	0.136	0.1
Secondary osteoporosis	-0.005	-0.040	0.030	0.771	0.028	-0.004	0.059	0.083	-0.821	-2.046	0.405	0.189
Alcohol	-0.025	-0.072	0.023	0.307	-0.031	-0.072	0.011	0.15	-0.683	-1.692	0.326	0.184
Rheumatoid Arthritis	-0.024	-0.057	0.009	0.15	-0.044	-0.074	-0.013	**0.005**	-1.484	-2.947	-0.021	**0.047 ****

*less likely to be a smoker with increasing age

**less likely to be male

7.4 Falls risk assessment

Number of falls risk factors was significantly higher in those in the two most deprived quintiles compared to the three least deprived (Q1/2: 3.62: Q3-5: 2.79, p=0.028). Linear regression analysis also demonstrated a significant relationship between lower IMD rank and increased number of falls risk factors (p=0.002). Increasing age was also a significant factor (p<0.001).

A significantly higher proportion of people with a total falls risk score of four or greater (indicating risk of falling) was seen in those from the two most deprived quintiles (Q1/2: 39%: Q3-5: 28%, p=0.041). Mean IMD rank was lower in those with a score of four or greater indicating more deprivation (score ≥4: mean IMD rank 16874, score <4: mean IMD rank 19094, p=0.042).

Separate regression analysis of the individual risk factors was performed (Table 36). Being worried about falling, having trouble stepping up onto a curb, often needing to rush to the toilet, taking medication which causes light headedness or tiredness and feeling sad or depressed were associated with deprivation. Out of these factors only two were not also associated with increasing age: taking medication which causes light headedness or tiredness and feeling sad or depressed. Gender was not an influence.

Table 36 P values from individual regression models investigating the relationship between falls risk factors and deprivation (as measured by IMD rank), age and gender

	Deprivation				Age				Gender (male)			
Falls risk	Co-efficient	95% CI lower limit	95% CI upper limit	P value	Co-efficient	95% CI lower limit	95% CI upper limit	P value	Co-efficient	95% CI lower limit	95% CI upper limit	P value
fallen in the past year	-0.017	-0.040	0.006	0.138	0.015	-0.005	0.036	0.149	-0.114	-0.732	0.504	0.718
advised use cane or walker	-0.001	-0.004	0.002	0.643	0.103	0.072	0.135	**<0.001**	-0.554	-1.475	0.367	0.238
feel unsteady	-0.011	-0.036	0.014	0.373	0.068	0.045	0.092	**<0.001**	0.021	-0.650	0.691	0.952
hold onto furniture	-0.025	-0.054	0.005	0.101	0.067	0.039	0.095	**<0.001**	0.142	-0.651	0.935	0.725
worried about falling	-0.038	-0.062	-0.014	**0.002**	0.051	0.029	0.073	**<0.001**	-0.608	-1.295	0.079	0.082
push with hands from a chair	-0.016	-0.041	0.008	0.193	0.062	0.040	0.085	**<0.001**	0.035	-0.621	0.692	0.916
trouble stepping onto curb	-0.065	-0.095	-0.034	**0.024**	0.077	0.047	0.106	**<0.001**	-0.358	-1.259	0.542	0.436
rush to the toilet	-0.038	-0.064	-0.013	**0.003**	0.051	0.028	0.075	**<0.001**	-0.105	-0.800	0.589	0.766
lost feeling in feet	-0.010	-0.048	0.029	0.63	0.054	0.018	0.090	**0.003**	0.435	-0.539	1.409	0.381
medicine makes light-headed or tired	-0.047	-0.077	-0.018	**0.002**	0.025	-0.001	0.052	0.064	-0.242	-1.076	0.592	0.570
medicine for mood/sleep	-0.022	-0.053	0.009	0.17	-0.003	-0.031	0.025	0.841	0.453	-0.306	1.212	0.242
feel sad or depressed	-0.040	-0.067	-0.012	**0.004**	0.019	-0.005	0.044	0.118	0.312	-0.383	1.006	0.379

7.5 Summary of prospective investigation of fracture risk

This study has identified some key findings. Distal radius fractures in more deprived patients are more likely to occur outdoors. Osteoporosis and risk of fracture measured using the FRAX score was not associated with deprivation (section 9.9.1). An important relationship between deprivation and higher falls risk leading to distal radius fracture has been identified (section 9.9.2). Further work should concentrate on understanding the mechanism for this and focus on specific falls prevention strategies.

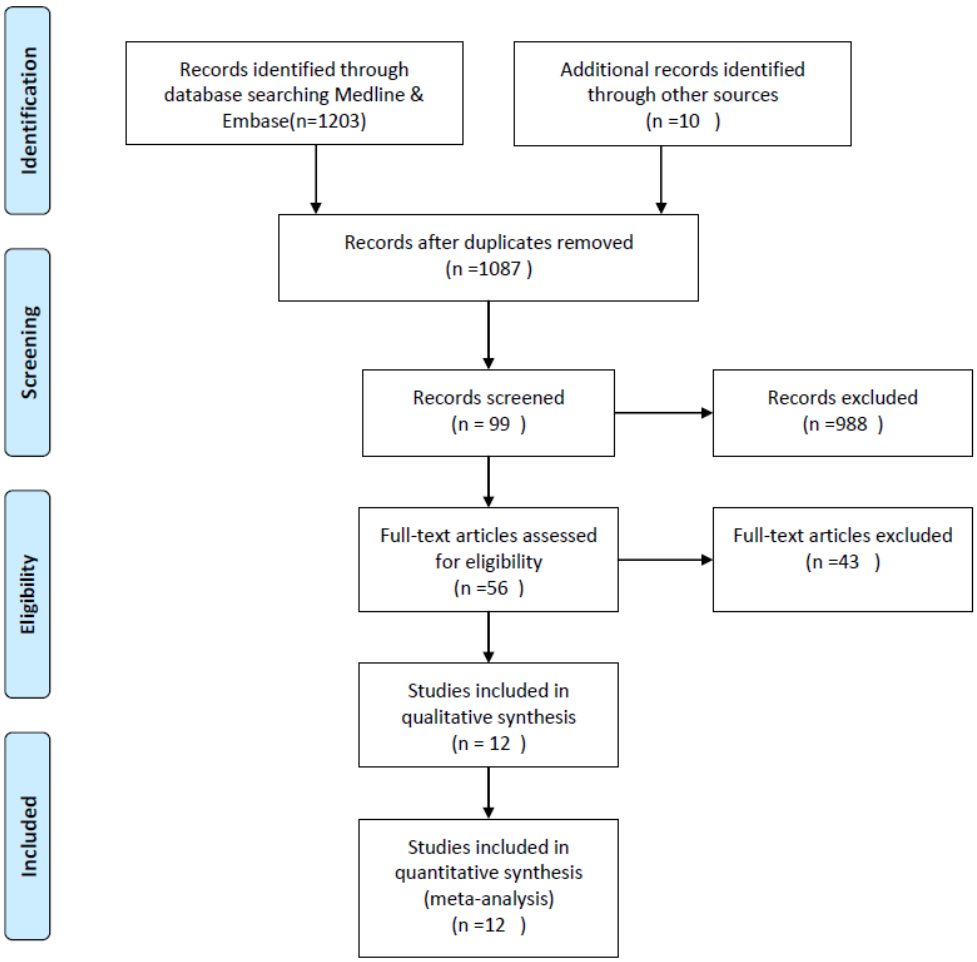
Chapter 8 Risk of distal radius fracture after hip fracture

Distal radius fracture is common and the prevalence is increasing. Distal radius fracture is known to be a risk factor for a subsequent hip fracture. The aim of this chapter was to quantify the risk of hip fracture risk in men and women who have suffered a distal radius fracture compared to those who have not. A systematic review and meta-analysis of previous studies, including many large, recent, high quality studies was performed (section 2.5). The findings may assist with health care resource planning, assessment and management of patients presenting with distal radius fracture, and guide appropriate application of interventional strategies.

8.1 Systematic review and meta-analysis

A systematic review and meta-analysis was performed. The initial literature search identified a total of 1,203 articles. 10 further records were found by hand reference searching. After duplicate screening there were 1,087 records which was reduced to 99 for consideration after initial screening by the review team. (Figure 47)

Figure 47 Flow chart of study identification, screening and selection.



Secondary screening excluded 43 records leaving 56 for full text review(86-94, 187-232). After assessment of quality and bias 12 studies were deemed suitable to be included.

Five studies were retrospective and seven prospective. All 12 studies were published in English. 6 studies were from the United States and 2 from the United Kingdom. The other 4 were conducted in Canada, Denmark, Sweden and Taiwan.

Five studies reported results for women only and 1 for men only. 6 described combined results for men and women together (Table 37). Out of these 6 studies 3

also reported their results separately for men and women. This meant 4 studies provided individual results for men and 8 for women (Table 38 & 39).

Table 37 Description of Studies Included in the Meta-Analysis - Combined results for men and women

Study	Study Location	Study Period	Number (Total)	Number (wrist fractures)	Number with subsequent NOF	HR/SIR/RR	Control Population	Follow-up (person years)
Owen et al. 1982	United States	1945-1959	394	394	54	6.4 (2.6 to 13.1)	Clinical/Societal	6,145
Mallmin et al. 1993	Sweden	1968-1972	1,338	1,338	223	2.27 (1.15 to 4.5)	Epidemiological	6,611
Cuddihy et al. 1999	United States	1975-1994	1,288	1,288	78	2.66 (0.98 to 5.79)	Clinical/Societal	9,664
Robinson et al. 2002	United Kingdom	1988-1999	1,075	1,075	-	3.22 92.81-3.66)	Clinical/Societal	Mean FU 3.7 yrs
Van Staa et al. 2002	United Kingdom	1988-1998	13,581	13,581	-	2.0 (1.8-2.1)	Clinical/Societal	665,000
Chen et al. 2013	Taiwan	2000-2007	44,450	3,762	19	3.45 (2.59-4.61)	Epidemiological	3,748

Epidemiological means a comparison of individuals with or without a prior fracture, and clinical/societal means the relative risk of a hip fracture in an individual or a group of individuals compared with the average risk of a hip fracture in the population.

Table 38 Description of Studies Included in the Meta-Analysis – Women only

Study	Study Location	Study Period	Number (Total)	Number (wrist fractures)	Number with subsequent NOF	HR/SIR/RR	Control Population	Follow-up (person years)
Owen et. al 1982	United States	1945-1959	350	350	47	1.3 (0.9 to 1.7)	Clinical/Societal	6,145
Lauritzen et al. 1993	Denmark	1976-1984	1,162	1,162	49	1.8 (1.3 to 2.2)	Clinical/Societal	4,588
Mallmin et al. 1993	Sweden	1968-1972	1,126	1,126	197	1.54 (1.24 to 1.93)	Epidemiological	34,221
Cuddihy et al. 1999	United States	1975-1994	1,045	1,045	72	1.44 (1.12 to 1.86)	Clinical/Societal	9,664
Schousboe et. al 2005	United States	1989-2002	7,880	1,224	-	1.43 (1.17 to 1.74)	Epidemiological	Mean FU 10.1 yrs
Hodsman et al. 2008	Canada	1990-2004	21,432	1,225	-	1.29 (0.88 to 1.89)	Epidemiological	359,737
Gehlbach et al. 2011	10 countries*	2006-2008	51,762	4,411	-	1.04 (0.71 to 1.51)	Epidemiological	2 yrs
Crandall et al. 2015	United States	1993-2010	160,930	8,792	431	1.5 (1.32 to 1.71)	Epidemiological	Mean FU 11.8 yrs

*Australia, Belgium, Canada, France, Germany, Italy, Netherlands, Spain, United Kingdom and United States

Epidemiological means a comparison of individuals with or without a prior fracture, and clinical/societal means the relative risk of a hip fracture in an individual or a group of individuals compared with the average risk of a hip fracture in the population.

Table 39 Description of Studies Included in the Meta-Analysis – Men only

Study	Study Location	Study Period	Number (Total)	Number (wrist fractures)	Number with subsequent NOF	HR/SIR/RR	Control Population	Follow-up (person years)
Owen et al. 1982	United States	1945-1959	44	44	7	6.4 (2.6 to 13.1)	Clinical/Societal	6,145
Mallmin et al. 1993	Sweden	1968-1972	212	212	26	2.27 (1.15 to 4.5)	Epidemiological	6,611
Cuddihy et al. 1999	United States	1975-1994	243	243	6	2.66 (0.98 to 5.79)	Clinical/Societal	9,664
Barrett-Connor et al. 2012	United States	2000-2002	5,878	-	-	1.9 (1.1 to 3.2)	Epidemiological	Mean FU 8.9 yrs

Epidemiological means a comparison of individuals with or without a prior fracture, and clinical/societal means the relative risk of a hip fracture in an individual or a group of individuals compared with the average risk of a hip fracture in the population.

Meta-analysis of women only studies revealed low heterogeneity. There was a significantly increased log relative risk of suffering a hip fracture after a distal radius fracture of 0.36 (95% CI 0.24 – 0.47) compared to those with no previous distal radius fracture (Figure 48). For men only studies heterogeneity was again low. Log relative risk was 0.75 but not significant with 95 % confidence intervals of -0.07 to 1.58 (Figure 49). Combined studies of pooled results for men and women had high heterogeneity. Using a random effects model log relative risk was 0.60 (CI 0.34 – 0.86) (Figure 50).

Figure 48 Meta analysis of studies reporting results for risk of hip fracture after distal radius fracture for women only

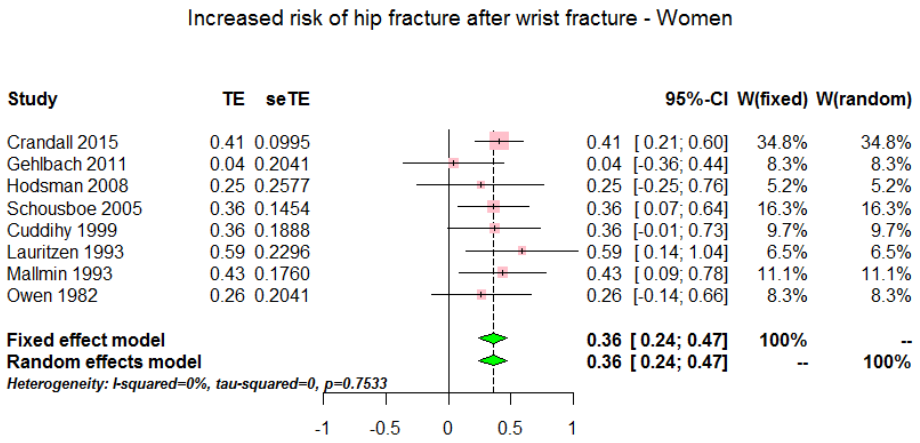


Figure 49 Meta analysis of studies reporting results for risk of hip fracture after distal radius for men only

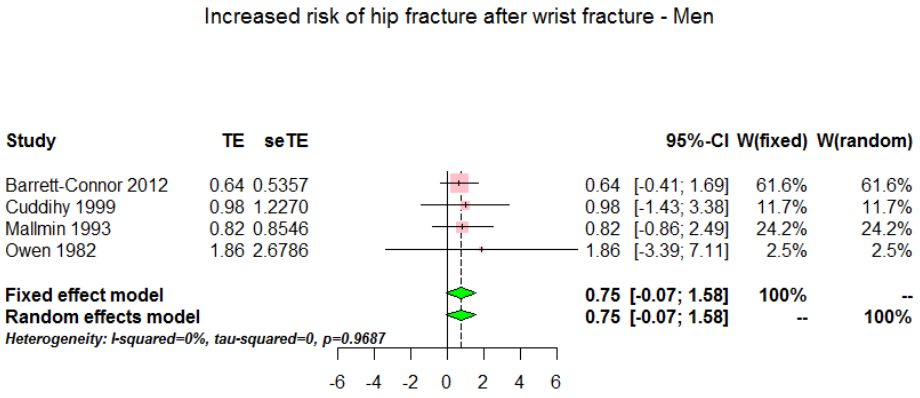
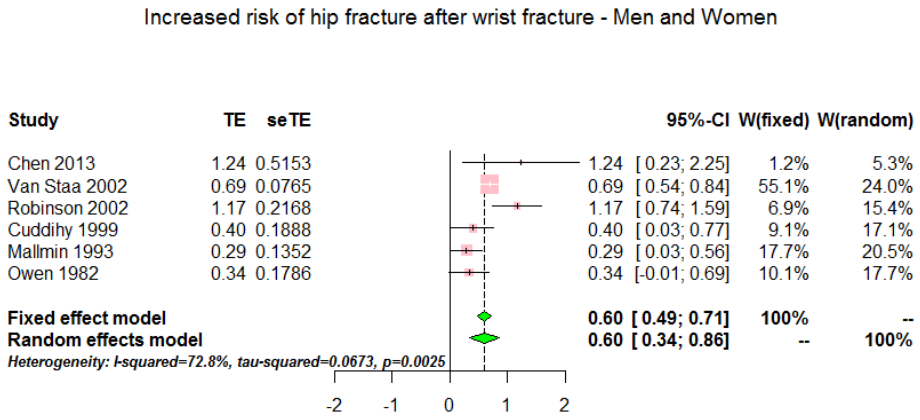


Figure 50 Meta analysis of studies reporting results for risk of hip fracture after distal radius for men and women combined



8.2 Summary of risk of distal radius fracture after hip fracture

This meta-analysis confirms an increased relative risk of hip fracture after distal radius fracture in women (section 9.4.1). Previous distal radius fracture in women was associated with a relative risk of hip fracture of 1.43 (CI 1.27 to 1.60). Further studies are required in men but the findings suggest men with a distal radius fracture are also at higher risk of a hip fracture. Identification of those at highest risk of further fractures allows resources to be targeted efficiently. Effective interventions are available to prevent subsequent fractures such as a hip fracture (section 9.13). When a patient presents with a distal radius fracture these treatments can be commenced.

Chapter 9 Discussion

Distal radius fractures are the most frequently treated fracture worldwide and a huge burden on healthcare resources. Around 70,000 individuals are affected each year in the UK(98). Distal radius fracture is largely an osteoporotic fragility fracture. With an ageing population the number of distal radius fractures continues to rise(233). Estimates for the direct medical cost alone for treatment of fractures of the forearm and wrist have been predicted to total over £35 million by 2020 in the UK(99) .

Previous fragility fracture is widely understood to be a risk factor for subsequent hip fracture. Several studies report increased fracture rate with deprivation but the reasons for increased fracture risk have not been established(27, 36, 52). Understanding reasons for inequalities in healthcare and which groups are at higher risk of injury can allow preventative mechanisms and prophylactic treatments to be put in place. Even relatively modest changes in distal radius fracture rate will have a large impact on health services.

The unique make-up of the Leicestershire population provides an excellent opportunity for studying the effects of deprivation and ethnicity on fracture rate. Overall Leicestershire has less deprivation than average for England. However, there are significant pockets of deprivation within the city. A large ethnic population enables the influence of ethnicity to be studied which is not possible in most parts of the country. There is only one emergency department in the whole county. This serves a large population of approximately one million people. A few minor injury units may manage distal radius fractures but the numbers are small and any significant injuries would be referred and captured in the local data. Utilising this data, along with national HES data, has allowed meaningful findings to be made in this thesis.

9.1 Accuracy of radiographic measurement

Almost every patient who sustains a distal radius fracture will undergo a plain radiograph. These investigations are cheap, quick and simple to perform. They are used by clinicians for diagnosis, planning treatment and monitoring healing. A huge wealth of information can be gained from each radiograph. In this thesis I wished to use radiographs to measure displacement and bone quality. For useful information to be obtained it is important that the measurement of these parameters is accurate, reliable and reproducible. Tests were therefore undertaken to investigate this. This information can be used by clinicians and other researchers.

9.2 Measurement of displacement

9.2.1 Extra-articular radiographic parameters

There is currently little available evidence to demonstrate the validity and reproducibility of radiographic measurements of distal radius fractures, and the studies that have been identified predate the introduction of modern hospital imaging systems such as PACS(131, 234).

The results in this thesis demonstrate strong correlation of both inter and intra-observer measurement of three of the four parameters measured: radial height, radial inclination and dorsal/palmar tilt.

The results of correlation of these parameters suggest that, following appropriate training, the degree of displacement of distal radius fractures can easily, and reliably be calculated using digital imaging software. It can therefore be used as a quick and cheap adjunct to assist management planning. Analysis of fractures using digital software is beneficial, as visual estimation alone has been shown to correlate poorly with actual measurement, and result in treatment decisions that may conflict with

those made based on such methodology when clinically relevant thresholds for acceptable displacement are applied(235).

There may be scope to apply the described methodology to the development of protocols for the management of distal radius fractures. Abramo et al. evaluated a standardised treatment algorithm which based management on the radiographic appearance of the fracture (i.e. the degree of fracture displacement), reducibility and stability, and the demands of the patient(236). They concluded that a protocol ensured similar and good subjective end results were achieved regardless of the severity of the fracture. Confirmation that measurements of fracture displacement are reliable could therefore support implementation of such a protocol into emergency departments to assist clinicians in management decisions.

9.2.2 Intra-articular radiographic parameters

An initial analysis of a small sample of intra-articular fractures revealed poor correlation. To investigate this in more detail, a larger, adequately powered study to determine if measurements of articular congruity of distal radius fractures are consistent between independent reviewers, was performed using the prospective study data.

Despite a larger sample size, the results still demonstrate poor inter and intra-observer correlation for measurement of both parameters of articular congruity, suggesting measurement of these parameters is intrinsically more difficult than the extra-articular components previously reviewed. Notably, when correlation for radiographs with ≥ 2mm displacement was calculated independently, correlation was even poorer. This corresponds with other aforementioned studies but is significant as this is the generally accepted level beyond which intervention is advisable(234, 237). The observers stated that they found measurements difficult due to comminution and the multi plane nature of fractures causing difficulty clearly identifying the fracture line itself and therefore accurate placement of the digital measuring tools.

A review of the radiographs of the 20 fractures with the highest and lowest respective agreement was performed. Those with the highest agreement were minimally displaced, less comminuted, frequently had two large fragments and the fracture involved a small area of the articular surface of the distal radius. Those with poor agreement were significantly displaced, comminuted, involved large amounts of articular surface and were often impacted. Methods of measuring intra-articular step and gap generally involve the placement of several points from which to measure between and rely on large identifiable fracture fragments. Clearly with complex, broad, comminuted fractures this will be challenging and difficult to reproduce.

This data is of importance as it suggests that the use of computer assisted measurements of intra-articular fracture displacement using radiographs is unreliable, and therefore may not be useful to assist with management decisions, audit or research. Computed Tomography (CT) scanning has been advocated in the pre-operative assessment of complex intra-articular fractures for this reason. Evidence exists that CT evaluation improves the sensitivity of articular surface gapping and may alter treatment plans compared with decision making based on radiographs alone(160, 238). However, O'Malley et al. demonstrated that concordance of management decisions between observers based on CT may be poor(235). Newer methods of measuring step and gap on plain radiographs should be developed which do not rely on fractures having large, identifiable fragments.

This work has limitations. Measurements were performed by junior trainees, with limited experience in the review of radiographs of distal radius fractures, making erroneous measurement possibly more likely. However, the strong correlation of most parameters measured suggests that assessment was generally accurate, and junior trainees can therefore utilise the methodology described reliably. It may in fact be of greater relevance to junior staff, who may be less familiar with the management planning considerations for these injuries than senior colleagues, and therefore gain greater benefit from exact measurement when making decisions in the clinical environment. Measurement was made to 0.1mm and 0.1 degree, and this may reflect excessive precision to be practical in the clinical environment, particularly if computer

monitors are of poor resolution. However, having demonstrated strong correlation to this level of accuracy one would expect similar concordance at lower precision levels.

Measurement of radial height, radial inclination and dorsal/palmar tilt is a useful and reproducible means of assessing the degree of displacement of distal radius fractures by individuals trained in correct methodology. Inexperienced trainees can quickly be trained to perform the measurements to a high standard. They may therefore be used as a reliable adjunct to management planning, including protocols and guidelines based on radiographic parameters, and for audit and research purposes. Measurement of intra-articular distal radius fracture displacement is challenging and not reproducible using radiographs alone, despite the use of digital techniques. Results used for research purposes must be interpreted with caution.

In clinical practice the overall assessment of the injury in the context of the individual patient, their functional demand and wishes following appropriate counselling of relative risks and benefits of different management strategies, is of greater importance. However, accurate measurement of radiographic parameters can aid communication and help clinicians recognise fractures which may require intervention or specialist referral.

9.3 Measurement of bone health

The results show a high level of inter-observer (ICC 0.85, 95% CI:0.82-0.88) and intra-observer (ICC 0.93, 95%CI:0.86-0.96; ICC 0.91 95%CI:0.84-0.95) agreement between measurements of MCI. These were achieved following another single short, standardised training session in two doctors with no previous experience in MCI measurement. This would suggest that MCI is a reliable and reproducible measurement that can be quickly and accurately measured with the aid of digital imaging software.

These results differ to those from older studies carried out prior to the widespread use of digital imaging software which criticised the reproducibility of MCI measurements. Naor et al quoted an intra-observer variability equivalent to 10% of the normal MCI in their 1972 paper and in 1976 Dequeker et al published figures stating the inter and intra-observer error in MCI measurements of the 2nd metacarpal equate to 1.5% and 1.2% for the outer cortical diameter and 6.4% and 4.8% for the inner cortical diameter respectively(239, 240).

It has been suggested that peripheral measurements of BMD have poor correlation with each other and with central DXA but MCI has been shown to correlate significantly with both forearm BMD and central BMD measurements indicating that MCI can be successfully used for assessment of bone mass and quality, and for predicting osteoporotic fractures(165, 166, 241, 242). The results in this thesis show a relationship between MCI and BMD of the spine and T-score which again suggests that MCI reflects BMD.

BMD declines with age, and following the menopause in women(243). Huachou et al looked at age and menopause-related changes in MCI in a sample of 383 women and found an annual decrease of 1.11% per year with acceleration in the rate of decrease in the 50-59 year old age group and in the early post-menopausal period(244). Similarly, these results show a sharp linear decrease in MCI after age 50. They found that the changes in MCI were more dependent on menopausal status than on ageing.

R^2 values in this work were similar to other studies looking at the relationship between patient factors and measures of fragility. Seo et al analysed the interaction between seven variables including age and BMI with BMD in over 2,000 Korean patients using multivariate regression and obtained an R^2 value of 0.21(245). In a similar analysis Kroger et al found that anthropometric and lifestyle factors explained only 18.7-25.4% of the variability of BMD in 14,220 peri-menopausal women(246).

This study also looked at the relationship of MCI to dorsal displacement in distal radius fractures. It has previously been demonstrated that patients with lower T-scores on central DXA scanning have more severely displaced and unstable distal radius

fractures(247). The results obtained in this work did not show a significant trend for increasing displacement with lower MCI.

Low BMD plays a greater role in the pathogenesis of fractures in older patients. Results in this thesis show that MCI correlates with BMD spine and that this correlation is stronger when MCI is less than 0.5. Most patients with an MCI <0.5 are older. This would suggest that MCI is more useful as a measure of BMD in this age group and is of more use in the analysis of distal radius fractures that have been sustained because of bone fragility rather than in all fractures of the distal radius fracture.

A wrist fracture can provide health practitioners with the opportunity to assess an individual's future fracture risk and allow initiation of preventative strategies and treatment. DXA scanning is the current gold standard for BMD assessment although other modalities such as quantitative CT and ultrasound are available. These incur a financial cost, a wait for an appointment and additional radiology staffing and reporting. The current cost of a DXA scan payable by commissioners is £69(248). The majority of PA radiographs taken for a distal radius fracture include the 2nd metacarpal. Calculation of the MCI from the 2nd metacarpal can allow a quick, simple and cheap assessment of a patient's bone mineral density.

91% of the patients included in this study with a distal radius fracture had plain film radiographs taken at presentation which enabled calculation of MCI from the second metacarpal. This suggests that most patients presenting with a distal radius fracture can have a quick and reliable assessment of BMD performed without the need for further investigations saving money, time and reducing radiation dose. This measurement can aid clinicians in determining which patients are at risk of further osteoporotic fractures and which should be referred on for further investigation and secondary fracture prevention therapies.

Table 40 demonstrates the relationship of MCI to T-score. The World Health Organisation defines a normal T-score as -1 or higher, osteopenia as a T-score between -1 and -2.5 and osteoporosis as a T-score of less than -2.5(166). The results suggest that these correspond to the MCI values seen in Table 40. Examples of

radiographs with MCI measurements that would fall into the osteopenia and osteoporosis categories are shown in figure 51 and figure 52 respectively with figure 53 showing a patient with normal BMD as calculated by MCI.

Table 40 MCI values corresponding to T-score values used to diagnose osteopenia and osteoporosis

	T-score	**MCI**
Normal	≥-1	≥0.50
Osteopenia	<-1 and >-2.5	<0.50 and >0.44
Osteoporosis	≤2.5	≤0.44

Figure 51 Example radiograph of an osteopenic patient (MCI of 0.50, equivalent to a T-score of -1)

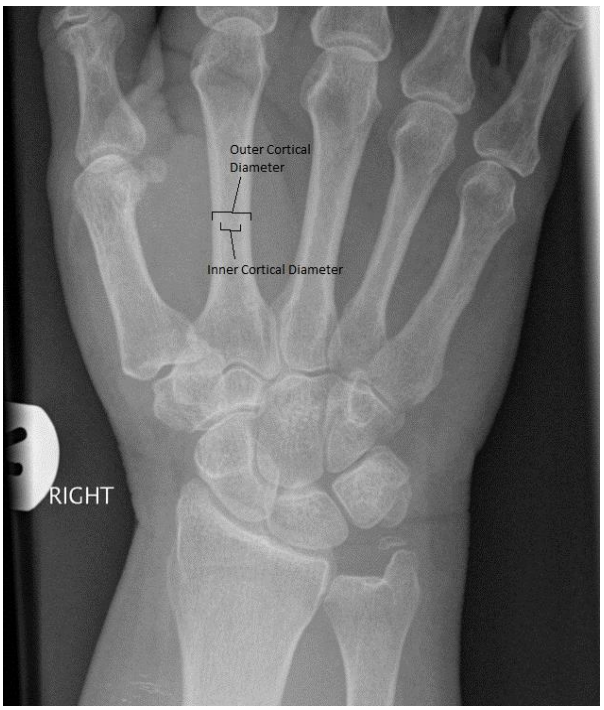


Figure 52 Example radiograph of an osteoporotic patient (MCI of 0.44, equivalent to a T-score of -2.5)

Figure 53 Example radiograph of a patient with normal BMD (MCI of 0.53)

This data suggests that if the patients combined cortical width at the narrowest part of the 2nd metacarpal shaft is less than half the whole width of the metacarpal (i.e. an

MCI of <0.50) then the patient is likely to be osteopenic. If the cortex occupies approximately 40% of the metacarpal width or less, then the patient is likely to be osteoporotic.

Limitations are noted. Measurements were again performed by junior trainees, with no experience of measuring. However, the strong correlations again demonstrated suggest that assessment was generally accurate, and junior trainees can therefore utilise the methodology described reliably. The sample of patients with a DXA scan and radiograph of the 2nd metacarpal was randomly generated. This meant patients undergoing the investigations for any indication were included. Data was not collected on whether patients were taking bone protective treatment at the time of either scan or the duration and nature of this treatment. Maximum anti-resorptive effects of bisphosphonates for example are seen within 3 months of commencing oral therapy and sooner for those receiving intravenous bisphosphonates(249).

The radiographs were from both left and right hands and no record was made from which side measurements were taken or which was the patient's dominant side. However, Kimura et al showed that MCI is nearly identical in both right and lefts hands as are other measures of bone mineral density and cortical thickness(250).

Furthermore, it was not possible to retrospectively standardise the angle at which AP and lateral radiographs of the 2nd metacarpal and distal radius were taken which could have affected the measurements. The radiology department have a standard protocol for radiographs of the hand and wrist which remained constant throughout the study period. The AP views from which MCI was calculated were obtained by placing the palm of the hand flat on a horizontal surface and the X-ray beam angled directly above. This approach is more representative of how MCI can be calculated and used in clinical practice.

In summary, this work demonstrates that MCI is a reliable and reproducible measurement which correlates with DXA measurements of BMD and T-score and that it declines with age. No association with dorsal angulation of distal radius fractures was seen. MCI provides a rapid, low cost assessment of bone frailty which can be

conducted in most patients who present with a distal radius fracture without the need for further investigations.

The aim of this thesis was not an in-depth analysis of radiographic measures but important results have been identified which are useful for clinicians and those carrying out research using radiographs.

9.4 Is distal radius fracture associated with a higher risk of subsequent hip fracture?

9.4.1 Meta analysis

Approximately 300,000 fragility fractures are seen in the United Kingdom (UK) each year(76). The greatest economic burden is due to hip fractures with nearly 85,000 UK hospital admissions per year accounting for over 1.8 million hospital bed days and an estimated cost of hospital care alone of over £1.9 billion(80). Incidence is rising and projections suggest the number of hip fracture hospital admissions could rise to 140,000 per year by 2036 if effective preventative strategies are not introduced(81). The cost of treating other fragility fractures is lower but still significant at over £200 million per year(251).

The purpose of this systematic review and meta-analysis was to investigate and quantify the relative risk of hip fracture for men and women who have suffered a distal radius fracture. Previous distal radius fracture in women was associated with an overall relative risk of hip fracture of 1.43 (CI 1.27 to 1.60) compared to those without. A similar association was demonstrated in studies looking at pooled results for men and women together (RR: 1.82 (CI 1.40 – 2.36)). Results of the four trials providing results for men only did not demonstrate a statistically significant increased relative risk (RR: 2.11 (0.93 – 4.85)).

Identification of high risk patients, and understanding of the reasons why they are at risk, allows effective primary prevention to be initiated. Successful primary prevention will prevent an initial distal radius fracture and reduce the risk of hip fracture.

Following a distal radius fracture secondary preventative measures can be commenced. Osteoporosis is very common but difficult to detect. Unlike an osteoporotic spine fracture which may run a more indolent course a patient with a distal radius fracture is likely to seek medical attention acutely. This then provides the

opportunity to initiate secondary prevention. In the current economic climate resources are scarce and must be used prudently so targeting high risk groups is an efficient strategy.

Previous evidence has suggested men have a higher risk of hip fracture following a distal radius fracture. Robinson et al carried out a large prospective study of patients over 45 with a further fracture after an initial low energy index fracture(87). They found men were at higher risk of a second fracture following all the index fractures they investigated. Van Staa et al looked at over 200,000 patients in the UK General Practice Research database and found relative risk of further fractures was higher in men(230). In a study using life tables and then a subsequent meta-analysis from 2003 Haentjens et al found men had a relative risk of 3.22 (CI 2.81 to 3.66) (92, 208). They suggested distal radius fracture is an early and sensitive marker of skeletal fragility in men. In their meta-analysis three studies with data for men were included. Sample size was small in these studies and confidence intervals large. This search only identified one additional study which despite showing a significantly increased relative risk (RR 1.9 (1.1 to 3.2)) when meta-analysis was carried out the overall relative risk was not significant. It is likely that this is a type 2 error and RR would be significant with larger studies.

Heterogeneity was very low in the meta-analysis of separate gender studies (men: I^2=0%, P=0.97, women: I^2=0%, P=0.75) but high when results for men and women were combined (I^2=72.8%, P=0.0025). This again suggests important differences between men and women and is the most likely reason for the heterogeneity.

The main strength of this meta-analysis is the robust results obtained for relative risk of hip fracture after distal radius fracture for women. Overall sample size is large and heterogeneity low. Several important, large studies have been published since the previous meta-analysis by Haentjens et al(92). Whilst the results for men are not as reliable an important research question has been identified for investigation. This would suggest a prospective multi-centre longitudinal trial should be performed. A study design such as this would be required to enrol enough participants to answer the research question. Throughout the study stringent guidelines were followed and well recognised methods used. A multi-disciplinary advisory group was set up

including a senior clinical librarian, hand and wrist surgeons and statistical expertise. Regular meetings of the advisory group took place and any issues were resolved by consensus.

Limitations of this meta-analysis include the small number of studies reporting data for men only and the small sample size of these studies. The studies included report results for patients of different ages. All include the elderly but several also include younger adults. However, the number of distal radius fractures in the younger patients is likely to be small and not affect the results. Publication bias is a concern with studies showing significant positive findings potentially being more likely to be published.

This meta-analysis confirms and quantifies the increased relative risk of hip fracture after distal radius fracture in women. Further studies are required in men but one would expect that men with a distal radius fracture are at higher risk of a subsequent hip fracture. Identification of those at highest risk of further fractures allows resources to be targeted to those who need them most. Effective strategies are available to prevent further fractures including hip fracture. Presentation with a distal radius fracture provides an opportunity to implement these interventions.

9.5 Epidemiology of distal radius fracture in Leicestershire – a 10 year review

The aging population profile of the UK and the inherent associated challenges is well described. The profile in the Leicestershire study region closely matches that of the UK as whole, with change occurring at a similar rate. Ten years of data was reviewed for patients presenting with distal radius fracture to a single hospital trust, to define current incidence rates of distal radius fracture, and to determine if this is changing over time as the population ages.

This local Leicestershire data correlates with previous studies in demonstrating a bimodal distribution of distal radius fracture(101, 102). Post-menopausal women are most commonly affected, reflecting the significant impact of underlying osteoporosis in this population. Young men are injured more frequently than young women due to high-energy trauma. A recent UK multi-centre trial reported incidence rates of 9/10,000 and 36.8/10,000 person-years for men and women respectively, compared with our calculations of 83.9/100,000 person-years and 170.2/100,000 person years(98). The variation in rates for women is likely a consequence of their study including patients aged over 35 only. Fracture incidence in young women is low, resulting in lower overall female incidence rate. Reporting on data collected in the same study region in the 1980s, Donaldson et al. reported rates of 21.3/10,000, 18.2/10,000 and 24.3/10,000 for all patients, males and females(101). Although this study included paediatric patients, the disparity with my calculations suggests there may have been a real reduction in fracture incidence over time.

Early studies describe a steady rise in the rate of distal radius fracture in women from the age of about 40, before a plateauing of fracture incidence in the mid-sixties to early seventies(114, 252, 253), a trend which has been reproduced in a more recent study from Norway(104). However, other studies show no such plateau, with a continued rise with increasing age(105, 107, 108). In this thesis the data correlates most closely with that described by Lofthus et al.(110); a sharp increase in incidence of distal radius fracture in the peri-menopausal period climbing to a peak mean

incidence of 515/100,000 person-years in the 80s before a decline in the over 90 age group. Most other studies stop calculating incidence at 80 or 85, which may explain this seemingly new trend. In older men, the findings are consistent with those previously described(105, 107, 108); a steady but more gradual rise in distal radius fracture incidence occurring from the age of about 70, reflecting the delayed onset of osteoporosis in male patients.

Because of the aging population it could be expected to see an increase in the overall incidence of distal radius fracture. Previous evidence has demonstrated a real increase in age-specific incidence in distal radius fracture over time in multiple locations(254, 255). This data shows no statistically significant change in either of these measures. The study duration may be too short to demonstrate these trends. However, other studies have shown no change in incidence of distal radius fracture with time(109, 110). Lofthus et al. reported no increase in fracture incidence in Oslo over a 20 year period, while Jaglal et al. described a decline in the incidence of osteoporotic hip and distal radius fracture over a 13 year period in Ontario, and correlated this with a simultaneous increase in BMD testing and treatment with bone-sparing medications. The Leicestershire results may reflect similar mechanisms. Proactive treatment of patients at risk of fragility fracture is more prominent in the minds of both specialist and general medical practitioners, and fracture liaison services have improved significantly over recent years following publication of specific guidelines(248, 256). The benefits of these services has been clearly demonstrated elsewhere in the UK and may be relevant to our study outcomes(111).

The data demonstrate statistically significant fluctuations in rate of fracture in specific years, most notably in 2009 and 2010. These findings are likely to be the consequence of particularly severe winters. In particular, a significantly increased rate of fracture was noted in the female 40-69 age group, and most markedly in those aged 50-59, during these years. It could be hypothesised this is secondary to occult osteoporosis whilst maintaining high activity levels, therefore increasing risk of fracture in slippery conditions. Similar findings have previously been reported in studies on the effect of weather on distal radius fracture incidence in Rochester, Minnesota(116).

Analysis of seasonal data supports this conclusion. Overall fracture incidence increased in the winter compared with the other seasons, with this finding most marked in the female over 50 population. Melton et al. reports that seasonal variation in fracture incidence persisted after adjustment for weather conditions citing possible causes of reduced light levels with a resultant increased risk of falling in individuals with poor vision, and reduced vitamin D synthesis that can lead to osteoporosis(255). The findings correlate with other studies reporting on seasonality and poor weather conditions conducted in the UK and internationally(104, 115, 116, 257).

Analysis of weekly incidence of fracture also revealed notable trends. I report an increase in the number of fractures sustained during or immediately after a weekend. This primarily resulted from an increase in number of injuries in the under 50 age group, possibly consistent with fractures sustained in sporting or leisure activity. More significant were the findings relating to mean age at fracture across a week. This decreased significantly over the weekend period in the overall population and in the over 50 group in isolation. I postulate that those aged 50-70 are more likely to be active over the weekend compared to those aged over 70, and therefore at greater risk of fracture.

The projections for the future national incidence of distal radius fracture are based on the gender and age specific average incidence of injury over the 10-year period and the ONS UK population projections for the next 20 years(157). A 23.1% overall increase in the number of fractures by 2036 to total over 83,000 fractures is predicted. In the over 50 age group one would expect a 33.2% increase with almost 60,000 fractures in 2036. These figures are lower than those predicted in previous studies. Burge et al. estimated that over 60,000 distal radius fractures would be sustained in the over 50 demographic annually by the year 2005(99). However, these figures were calculated using incidence rates from a study conducted in Cardiff(258) over a single year, which reported an overall incidence of 4.79 fractures/1000 person-years, nearly four times greater than the Leicestershire overall mean incidence rate, explaining the disparity in projections. One would expect the methodology in this thesis to give a more accurate estimate of future fracture numbers because of the age and gender specific population projections, and average incidence rates calculated over an

extended period. However, the variation seen may add weight to the idea that improved detection and preventative methods have reduced the rate of fracture.

There are potential limitations to this study. The incidence rates may underestimate the true figure; although UHL is the only hospital trust in this region, patients living in the peripheries may have attended other hospitals, though one would expect this to be of minor influence and the figures to therefore be reliable. Data collection was based on ED coding but measures were taken to ensure the accuracy of this and it was consistently high. Many databases include only fractures which required intervention but the Leicestershire data also included cases treated non-operatively. Population estimates were collected from national governmental departments and therefore should be precise. The study could be strengthened by more rigorous analysis of data for narrower age bands. This was performed to calculate overall incidence rates, but trends in weekly and seasonal variation were not analysed as the numbers were too small to do so.

This section of the thesis reports one of the largest analyses of distal radius fractures performed in the UK to date. Multiple trends have been identified, some of which have not previously been described. The ability to make estimates for the number of distal radius fractures at specific weekly or seasonal periods are useful for workforce and resource planning in emergency departments, trauma units and subsequent rehabilitation and social care services. Furthermore, given the predictive value of distal radius fracture for fragility fracture at other anatomical sites, the data will assist with forecasting the overall burden of management and prevention of osteoporosis.

Valuable and current information regarding the epidemiology of distal radius fracture based on one of the largest databases recorded is presented, which can be extrapolated to make projections of the burden of this injury to the UK in the future. Incidence of distal radius fracture does not appear to be rising but with an aging population the number of fractures is increasing. Estimates for the direct medical cost alone for treatment of fractures of the forearm and wrist have been predicted to total over £35 million by 2020(99). With healthcare resources under ever-increasing demand, it is vital that we act to implement preventative strategies to reduce the burden of fragility fracture in the future.

9.6 The influence of deprivation on distal radius fracture

9.6.1 Effect of deprivation on distal radius fracture rate

Further in-depth analysis of four years of the Leicestershire data (2007-2010) demonstrated that deprivation was strongly associated with distal radius fracture. Similar results were seen in both age groups studied (below 50, 50 and over) with more fractures seen than expected in the two most deprived quintiles and less seen in the least deprived two quintiles. The number of fractures seen in the median quintile (quintile 3) was as expected. Mean age of the deprived distal radius fracture patients was significantly lower; they sustain their fractures almost 4 years earlier than those in the less deprived quintiles. A similar finding was also seen in those aged 50 and over with patients in the least deprived quintiles suffering a fracture nearly 2 years later.

Incidence of distal radius fracture is higher in women but the poisson regression model has shown that being male is a risk factor for distal radius fracture when deprivation, ethnicity and age are considered.

Curtis et al reported fracture rates by gender and IMD quintile from UK General Practitioner data in their study involving 11.3 million people(27). They also found deprived men had higher risk of fractures. In men, the relative risk of vertebral, wrist and hip fractures increased with deprivation. No association between risk of wrist or hip fractures was seen in deprived women and vertebral fracture risk was reduced. They suggested that the difference between genders with deprivation was due to adverse lifestyle factors such as smoking, alcohol and poor diet which are seen more often in men than women(28-30). Other studies have reported similar findings(32).

The poisson regression analysis of the whole group revealed significant differences related to ethnicity with deprivation not being associated with fracture risk in patients of other ethnicities compared to white patients. Fracture risk was higher for men, patients aged 50 and over, and for white patients. Similar findings were seen

reviewing the national data of patients in England who underwent surgical fixation. In patients aged 50 years and over deprivation was only related to fracture risk in white patients. Trends related to deprivation were not seen in the other ethnic groups.

Curtis et al also reported fracture rate by ethnicity. They found white patients had the highest fracture rate, it was lowest in black patients and intermediate for South Asians. This is consistent with other studies and the incidence rates in this thesis. Differences in height, body composition, bone architecture and bone mineral density between races have been demonstrated between ethnicities with black people having higher BMD. White people are generally taller which increases fracture risk. No analysis to investigate interactions between factors was carried out by Curtis et al and they acknowledged that some data was missing with ethnicity unknown for 44% of patients with a wrist or forearm fracture.

In the whole cohort of patients, who underwent surgical fixation in England over the four year period studied, deprivation was associated with being male, black and having more medical problems. This information is unsurprising and it is well described that deprivation is associated with these factors. A higher number of cases per year was also associated with more deprivation. This could reflect the higher rate of fracture in deprived areas and that large units carrying out many procedures are likely to be in major cities who have high rates of deprivation. Increasing age and hospital trusts with a larger proportion of older patients were associated with less deprivation. Again, this is unsurprising as older patients tend to be more affluent.

9.6.2 Effect of deprivation on radiographic measurements

Radiographic analysis of patients in the two age groups did not demonstrate any significant findings. The GAM relationship between increasing deprivation and increasing intra-articular step size in younger patients came close to significance potentially suggesting more displaced intra-articular fractures occur in younger, deprived patients ($p=0.052$).

Further sub analysis of radiographic findings split by age, gender and ethnicity revealed interesting results. No differences were seen between the groups in the younger patients. In those aged 50 years and over women in the most deprived quintiles had a higher MCI than those in the less deprived quintiles and when also compared to white women from the same quintiles. This may help explain why an association with fracture and deprivation was not seen in those of other ethnicity. These findings may represent a deprived ethnic population who are still required to be active, and possibly in employment, who therefore maintain bone mineral density. The reverse was true for white men in the most deprived quintiles who had a lower MCI than white men in the less deprived quintiles along with a lower MCI than men of other ethnicity in the same quintiles. These findings may help explain why deprivation increases fracture risk in white men yet has less effect on patients of other ethnicity. However, it must be noted that the number of patients becomes small on sub-analysis, particularly men and patients of other ethnicities.

9.7 The influence of deprivation on distal radius fracture treatment

Regression analysis comparing those who underwent surgery in Leicestershire to all of those who sustained a distal radius fracture in the same region allowed independent factors for fixation to be identified. Patients aged 50 years and over were more likely to undergo surgery which is most likely due to the increased rate of displaced fragility fractures. Deprivation did not influence fixation rate which supports the radiographic findings showing no overall association between deprivation and displacement.

White patients were more likely to undergo surgical intervention (IRR 1.737, CI 1.139 to 2.648, p=0.010). This was despite our radiographic analysis, which included all patients who underwent surgery, showing no difference in displacement between the ethnic groups. The reasons for this are likely to be complex and beyond the scope of this thesis but an important research question has been identified. Cultural beliefs, family support systems, functional demands and language may play a part but bias must be considered. Unconscious bias is part of normal cognitive processing where a

person's subconscious prejudicial beliefs or unrecognized stereotypes influence their responses. Surgical decision making is understood to be particularly vulnerable to unconscious bias and is well described in many surgical specialties including orthopaedics(259).

The modelling of the National data against measures of quality of care, including deprivation as an independent variable, produced some useful findings.

9.7.1 Wait for semi elective trauma surgery

These results are reassuring and demonstrate that most hospitals are able to meet the NICE guidelines for timing of surgical fixation. Increasing number of medical comorbidities was associated with increased wait to surgery. Differences existed between hospitals which were eliminated when hospitals were added to the model as a random effect. The decision to operate, when taken on a Friday, Saturday or Sunday, was associated with a longer wait for surgery.

Specialist surgeons will often be required to operate on complex intra-articular fractures. Many hospitals, particularly smaller ones, will only have one or two surgeons available over weekend periods. It is therefore unlikely that they will have necessary sub speciality cover available to operate on complex distal radius fractures over the weekend. Therefore, for a fracture that is first seen by a specialist on a Friday it may be difficult for the surgery to be performed over the weekend by a necessary specialist surgeon. Larger hospitals may be able to innovatively plan their weekend and holiday on-call cover to ensure there are surgeons available to deal with most the commoner complex fractures.

9.7.2 Pre-and post-operative wait to surgery

Preoperative wait for surgery was less in those undergoing day case surgery and treatment with external fixation. External fixation is often used for severe displaced fractures with significant soft tissue injury. These usually require urgent surgery so this is likely to be the reason for the reduced wait for these patients. Having surgery as a planned day case was also associated with less wait. This suggest that units who are able to offer this service can do it in a timely fashion and patients being treated as a day case are not disadvantaged compared to those who are inpatient. This may also be influenced by the fact that patients chosen to be treated as a day case are likely to be medically fit.

It is unclear why the month of September is associated with a longer wait to surgery. This may be an anomaly. However, it could represent the fact that September is likely to be the month when initial winter weather is first seen and therefore could lead to an increase in fracture rate. During winter, hospital trusts are often able to employ methods to increase their capacity for surgery to deal with the increased number of patients. In September, these mechanisms may not be put in place yet and therefore hospitals are not prepared for the increased workload that the start of winter weather may bring. This could suggest the hospitals may be being reactive rather than actively planning. Patients having treatment with K-wires also waited longer. K-wires are often favoured in older patients and those who have more comorbidities and this may explain a longer wait due to surgical and anaesthetic planning reasons.

Increased post- operative length of hospital stay was seen in men, older patients, patients with more comorbidities and those treated with K wires or external fixation. This is likely to reflect the fact that these factors are more likely to be seen in patients with poorer health or more severe fractures. Admission or listing for surgery on a Saturday is also associated with a longer stay. As seen in the other models this may be due to an initial longer wait for surgery. Interestingly diabetes type I was associated with a shorter hospital stay. Reasons for this could be that type I diabetes is seen in younger patients compared to Type 2 diabetes. Another reason could be that these

patients are identified to be at risk of medical and surgical complications so a high level of care is devoted to them leading to a smooth pathway with minimal stay and good outcomes.

9.7.3 Day case surgery

Similarly to the models above factors relating to generally poorer health such as being male, older and more comorbidities reduce the likelihood of day case surgery. Patients admitted or listed for surgery on a Friday, Saturday or Sunday were significantly less likely to have day case surgery. This suggest that day case services stop or are commonly reduced at the weekend. During the winter months (from October to March), during months when more cases are performed and at times of low temperature day case surgery rate is higher. This may again reflect the ability of hospitals to increase their capacity during the busy winter months. More K-wire procedures were performed as a day case compared to plating and external fixation. This technique is often used for simpler fractures and is unlikely to be used for severe injuries requiring hospital admission so may often be more suitable to carry out as a day case.

9.8 National variation in fixation rate

Considerable variation exists across England in the rate of surgical fixation for distal radius fracture. With the seven hospital trusts with the highest and lowest rates of fixation excluded patients still experience a 3.6 fold difference in treatment rate depending on where they live.

Only three other studies have investigated variation in distal radius fracture treatment and none from the United Kingdom. An in-depth analysis was therefore performed in this thesis. Fanuele et al studied Medicare claims in the US and found a significant

variation related to age and religion(149) . Chung et al built on this further and reported that women, white patients and those treated by a hand surgeon were more likely to receive internal fixation(150). A recent study from the Netherlands showed no variable influenced operative rate except a small significant increase in fixation with increasing age in one of the years studied(151).

Preference sensitive care describes medical treatment for which the evidence does not clearly support one treatment option over another(260). Many surgical procedures including distal radius fracture fixation are an example of this. Decision making should therefore be shared, with patients making an informed choice from clinically appropriate options after discussion regarding risks, benefits and current evidence with a clinician. Most surgeons can agree that very displaced fractures will require surgical intervention but for those which have a moderate amount of displacement there is only limited evidence and guidance about those which would benefit from surgical intervention. Without high quality evidence, it is difficult to understand the value of the intervention.

This analysis has shown hospital's serving a smaller population have a higher tendency towards fixation. "Roemer's Law," is the notion that an increase in the number of hospital beds per population increases rate of hospital utilisation(261). It was deduced after a positive correlation between the number of hospital beds available and the number of hospital days used per population was identified. It is thought to be due to induced demand, which occurs when clinicians encourage patients to use services that they may not have chosen if fully informed. Essentially it means that if capacity is available then it will be utilised. It could be hypothesized that smaller units are less busy and have more capacity to treat fractures surgically. This may be an example of overuse of an intervention. Conversely it may be that large, busy units with limited theatre capacity treat more patients conservatively and deny patients an effective intervention. Another reason may be that clinicians in the larger university hospitals have considered the inconsistent evidence regarding fixation and have a higher threshold for intervention. However, there was no change in fixation in specialist hand units in which one would expect clinicians to have a thorough understanding of the published literature.

Other reasons for variation may include the initial fracture assessment and management. The Leicester trauma unit is large and busy with a low surgery rate. All displaced fractures are referred to the oncall trauma team from ED and nearly all displaced fractures are manipulated that day in fracture clinic under image intensifier guidance. This prompt reduction and cast stabilisation by a specialist team may often be adequate definitive treatment limiting the need for surgical fixation. If initial reduction and stabilisation is inadequate or referral is delayed, then reduction and surgical stabilisation is more likely to be required.

Increased fixation rate is seen in trusts with higher populations of older people. This is likely to be warranted variation due to a higher rate of fragility fractures which are often displaced and unstable requiring surgical treatment and related to the needs of the population. Interventions such as bone health programs and falls risks prevention may reduce osteoporosis and falls and subsequently the number of displaced fractures in older patients but are long term and costly.

This analysis demonstrates significant variation in surgical treatment for distal radius fracture in England. Variation in the characteristics of the trust population account for some of this. Variation in fixation rate related to the size of the trust appears unwarranted. Improved initial treatment pathways may reduce the need for surgical intervention. Further research is required to identify which patients with distal radius fracture would benefit from surgical fixation and provide evidence stop based guidance to clinicians and reduce unwarranted variation.

Limitations of these models include the use of HES data which only contains details of those admitted to hospital. This does not identify those patients who have attended and had a distal radius fracture treated conservatively or with reduction in the ED or fracture clinic as the definitive treatment. However, in terms of cost and resource usage it is more important to identify trends with those admitted to hospital and treated with more expensive surgical interventions. investigation of trends in type of fixation was not attempted. This has already been reported by Costa et al in response to the DRAFFT study(127). Type of intervention changed but the overall rate of fixation did not change over the same period as studied in this thesis. For this analysis hospital trust size, has been equated with ‘busyness’ of that unit and access to theatre

for surgical intervention. Anecdotally that seems correct with large trauma units dealing with the highest volume of patients. However, to investigate this further would require a complex study involving staffing levels and theatre availability for all hospital trusts. In this analysis, the background trust population has been used as the denominator to calculate the rate of intervention. Others have used the total number of distal radius fracture in each population. The method used in this thesis allows simple calculation of fixation rate for different geographical areas which is easily obtainable to allow comparison.

It was reassuring that deprivation did not seem to independently influence patient's individual treatment. It was a recurring theme that men, older patients and those with multiple comorbidities have less positive healthcare experience in terms of the factors reviewed. Whilst this is inevitable to some degree further work could focus on improving pathways of care for those with poorer health. It was noticeable how hospitals do have the ability to increase workload and improve services for their patients during busy times. Further investigation of these efficiency measures may be helpful in improving service throughout the year. Weekend services are a controversial subject. It is difficult to maintain appropriate staffing levels and sub-specialty expertise throughout the full week. Those who present on a Friday, Saturday or Sunday are less likely to have day case surgery and they wait longer for surgery after being sent home. Trusts should look further into ways of preventing patients from suffering an inferior pathway of care due to suffering an injury at the weekend.

9.9 Investigation of fracture risk

The prospective analysis of fracture risk revealed important findings. Fractures in more deprived patients are more likely to occur outdoors. Osteoporosis and risk of fracture measured using the FRAX score was not associated with deprivation. Falls risk is associated with increased deprivation.

9.9.1 Osteoporosis and deprivation

As discussed in detail in earlier sections the relationship between osteoporosis and deprivation is complex and not well understood. Some studies do show a significant relationship between increasing deprivation and osteoporosis but several others do not. Curtis et al found osteoporotic fractures were associated with deprivation in women but not men(27). Regression analysis in this thesis demonstrated that the effect of deprivation in older patients was more significant in men. This prospective analysis did not reveal a relationship between deprivation and osteoporosis for patients aged 50 years and over. The study population was representative of the background population which is largely white and female. It has been shown that lifestyle factors which are adverse to bone health are more commonly seen in men. This may explain the difference between genders. The radiographic analysis in this thesis would support this with deprived men having lower MCI. It may be that the effect of osteoporosis is mainly seen, in relation to deprivation, in white men from deprived areas who are at high risk of having a lifestyle which contribute to poor bone health. Due to smaller numbers of fragility fractures in men these findings are difficult to identify and in this analysis numbers may have been too small to demonstrate this.

The only component of the FRAX score which was associated with deprivation (and male gender) was smoking. This has been well described previously with smoking rates being shown to be four times higher amongst the most disadvantaged. It is also thought that the disadvantaged are at increased risk of harm due to tobacco. Interventions to prevent smoking are less successful in those who are more deprived. Hiscock et al found that raising the price of tobacco was the intervention most likely to reduce health inequalities due to smoking(262).

Smokers from more deprived areas describe different reasons for smoking and relapsing after quitting involving more nervousness and depressive symptoms. More problems with living conditions including homes and the outside neighbourhood were reported in those from deprived areas. This is thought to contribute to more stressful lives and quitting smoking not being a priority. Smoking is a modifiable risk factor so any effective interventions to reduce smoking rate, especially among more deprived

patients and men, may have some positive effect on bone health along with general health. The relationship between smoking, male gender and fracture risk found may allude to negative lifestyle factors affecting bone health seen in deprived men. A study with a large cohort of men may demonstrate this more clearly.

9.9.2 Falls risk and deprivation

Falls risk was significantly associated with increasing deprivation. Patients with deprivation were significantly worried about falling, had trouble stepping onto a curb and often had to rush to the toilet. These risks were also associated with increasing age. Feeling sad or depressed or taking medicine which makes them lightheaded or tired was independently associated with deprivation alone. Depression and other mental health problems are well known to be associated with deprivation(263). Polypharmacy, drug side effect problems and depression are potentially modifiable through primary care.

Limitations of this prospective analysis include the response rate of 64% despite multiple efforts to increase response rate. This is a common finding with this type of data collection and the comparisons with the population studied show that the data is representative of the overall population. The number of patients of other ethnicity in the study is low and the responders are mainly white women. This does not allow analysis of trends related to ethnicity but again it is representative of the largest group of people to suffer a distal radius fracture, white women, and therefore the most important to target for prevention.

Higher falls risk with deprivation leading to distal radius fracture is a key finding from this thesis. Further work should concentrate on understanding the reasons for this and identify preventative strategies.

9.10 Burden of falls

Every year 30% of people over 65 will fall and the rates increase with increasing age(264). Almost a third of these who fall suffer injuries which cause reduction in independence and mobility and increase the risk of death(265). 5% of falls result in a fracture(266). Repeated falls can lead to fear of further falling, depression and loss of self-confidence leading to social withdrawal. Falls prevention strategies have been shown to be effective. The National Service Framework for Older People and recent NICE guidelines set out guidance for prevention of falls(177, 267). Multifactorial interventions including strength and balance training, vision assessment, home hazard identification and medication review can reduce incidence of falls(268-270).

With an ageing population, the number of falls is expected to rise so further work is required to reduce falls and the subsequent morbidity, mortality and healthcare burden. Falls risk factors can be classified into three groups: intrinsic factors, extrinsic factors and exposure to risk.

Intrinsic factors include previous falls, age, and female gender. Medicines such as the use of benzodiazepines, diuretics, psychotrophic drugs and some anti arrhythmic medications increase risk(271, 272). Polypharmacy is also associated with falls, with a significant increased risk if a patient is taking more than four medications, irrespective of the type of drug(273). White people are also more likely to fall(274). Other medical comorbidities, gait, vision and foot problems(275, 276), sedentary behaviour(277), fear of falling(278) and impaired cognition(279) are also intrinsic risk factors.

Extrinsic risk factors relate to environmental hazards, footwear and inappropriate walking aids. Up to 50% of falls amongst those living in the community has been thought to be due to environmental factors(280). These include poor lighting, uneven surfaces and slippery floors.

The risk exposure is thought to be highest in the most inactive and the most active people. Some studies have suggested walking increases risk of falls whereas others have suggested more physical activity reduces fall rate(281, 282). Some activity may increase risk by exposing people to environmental hazards(283).

It is thought that intrinsic factors are the most important in patients aged 80 and over(280). In younger older people, extrinsic factors are more significant. Falls risk for all patients increases exponentially with increasing number of these risk factors(284).

In deprived patients, it seems likely that risk factors from all three groups are present. This analysis has identified risks related to medication, depression, falls outdoors and concerns about falling. The multifactorial falls prevention methods are largely targeted at frail, elderly people who fall indoors. Distal radius fracture patients are generally fitter and more mobile than hip fracture patients with more injuries occurring outdoors. This is particularly true of the deprived patients who were younger and had a significantly higher proportion of injuries outdoors. Injury rate was seen to rise in the younger women of the older age group during low temperatures. Prevention of outdoor falls in this group has enjoyed comparatively little attention and there are no established guidelines(285-287). Simple measures such as walking aids, appropriate footwear and avoidance of walking outdoors in slippery conditions would seem sensible and acceptable(288).

The World Health Organisation published a report by Todd et al in 2004 entitled: What are the main risk factors for falls amongst older people and what are the most effective interventions to prevent these falls?(289)

The report reviewed evidence and identified gaps in knowledge and conflicting evidence regarding falls. They noted that there was very limited research regarding the relationship between falls risk and socio-economic factors and the effectiveness of interventions in different socio-economic groups. It was also seen that very few studies have investigated the relationship between ethnicity and falls or the effectiveness of fall prevention for men or different ethnic groups.

They suggested a three stage approach to falls and subsequent fracture prevention.

1) Identifying high-risk groups of older people

2) Further assessment of high-risk older people to identify individual risk factors for falling

3) Interventions to reduce risk factors

This thesis provides valuable information to help identify those at risk and recognise the most important risk factors for falling which can then be used to put in place specific preventative interventions.

9.11 Increase of deprivation

The respected Joseph Rowntree foundation has recently published a report entitled UK poverty 2017(290). They define poverty using the main indicator being whether someone lives in a household with an income less than 60% of expected median income. For the past 20 years poverty has been falling in the UK. However, they noted that this trend appears to be reversing. Poverty amongst those aged over 65 has risen from 13% in 2011/12 to 16% in 2017. Poverty is also increasing amongst children and adults of working age with children. These findings were thought to be due to higher costs of housing, less state support through benefits and tax credits and a lack of impact of a continued rise in employment. One in eight workers were found to live in poverty. Housing standards are inferior in the poorest 20% of the population with 23% living in non-decent housing. Non-decent housing is defined using several standards including warmth, facilities, state of repair and safety. Physical health was measured on a score between zero and 100 with a higher score indicating better health. Significant differences are seen related to poverty with lower scores in the poorest fifth of the population. Differences between those on higher and lower incomes is greater amongst pensioners. Mental health was also adversely affected by poverty. More anxiety and depression was seen in those from the poorest fifth of the population. This has increased over the last 20 years.

It must be remembered that the methodology used to define poverty in the Rowntree report is different to that of the IMD. However, they do report many results by fifths of the population. The IMD uses ranking and quintiles primarily. These are based on scores of the severity of deprivation but are relative. The report above has demonstrated that poverty is increasing with a higher proportion of people living in poverty. Therefore, one would expect that those in the most deprived IMD quintiles

will be experiencing a greater severity of deprivation and potentially that those in the middle quintile are becoming more deprived. This would not be reflected using IMD quintiles or rank but is likely to lead to an even higher rate of fracture in the most deprived quintiles.

9.12 Further projections and cost

Leicestershire and Rutland has a population of 1,017,697 people with 132,301 people living in the most deprived quintile. Incidence rate was 194 fractures per 100,000 population per year for this most deprived quintile. In a city the size of London with a population of 8,308,400 people of which 2,176,801 live in the most deprived quintile this would equate to 4,219 distal radius fractures from this group alone per year.

LSOA's contain approximately equal numbers of residents. The total population for England is split into quintiles by dividing the total number of LSOA's into five equal groups. The most recent estimates for the population of England show an expected population of people aged 18 and over of 43.5 million people. This equates to roughly 8.7 million people in each quintile. Using the incidence rates generated from Leicestershire there would be 10,353 fractures in the least deprived quintile compared to 16,878 in the most deprived quintile per year in England.

The UK DRAFFT trial and economic analysis provides relevant and up to date information from which projections can be made for distal radius fracture resource use(126, 129). An estimate of fracture fixation rate can be calculated from the DRAFFT screening data *((fixation: [eligible for trial and wanted surgery - 617; Ineligible but required surgery:fracture required opening - 430; open fracture(>Gustilo 1) – 43, 617+430+43=1090) (total adult fractures within 3cm of radiocarpal joint – 5947) (1090/5947=0.18 : 18% fixation rate))*. This gives an estimated fixation rate of 18%.

If this fixation rate is applied to the national quintiles and it is estimated that half of the procedures were K-wire fixation and half volar locking plates the costs and surgical time for the least deprived quintile would be £7.2 million and 1,919 hours *(volar*

locking plates:0.18 5176.5*£4,287.89= £3,995,327.27, 0.18*5176.5*70mins= 65,223.9mins=1,087 hrs, K-wires: 0.18*5176.5*£3384.78=£3,153,836.45, 0.18*5176.5*53.57mins=49,910mins= 831.8 hrs).*

For the most deprived it would be £11.7 million and 3,128 hours *(volar locking plates:0.18*8439*£4,287.89=£6,513,390.67, 0.18*8439*70mins=106,331.4mins= 1,772 hrs, K-wires:0.18* 8439*£3384.78=£5,141,548.6, 0.18*8439 *53.57mins=81,373.9mins= 1,356 hrs).* A difference of £4.5 million is seen between the most and least deprived quintiles alone. Using the expected population trend increases identified this would mean that in 10 years time fractures from the least deprived quintile would cost £8 million and £13 million in the most deprived quintile with an increased difference of £5 million. With increasing poverty it is very likely that these costs will in fact be higher with a greater disparity between quintiles.

9.13 Fracture prevention strategies

NICE provide guidance regarding the identification, assessment and treatment of fragility fracture(291). They recommend consideration of assessment of fracture risk in all women aged 65 and over and men aged 75 and over. For women aged 50 to 64 and men aged 50 to 74 fracture risk assessment should be considered if other risk factors are present such as:

Steroid use

Previous fragility fracture

Family history of hip fracture

History of falls

Secondary osteoporosis

Smoking

Low BMI

High alcohol intake

From this thesis deprivation has been shown to be associated with fragility fracture, falls and smoking. Other studies have described a relationship with high alcohol intake. It therefore seems that deprivation is intrinsically linked with many fracture risk factors and they may act as a surrogate for deprivation. Additional work could investigate this further and it may be that deprivation could be included as a risk factor in place of others such as smoking and alcohol.

For those aged under 50 assessment is not recommended unless major risk factors such as previous fragility fracture, early menopause or steroid use are present.

Assessment should take the form of a bone health calculation tool such as FRAX or Qfracture. A 10 year fracture risk of 10% or greater is the approximate threshold for organising further investigation with a DXA scan. For those aged 50 and over with a fragility fracture it is not necessary to use a bone health tool and DXA scan should be arranged. Risk factors for falls should be identified and Calcium intake and vitamin D exposure evaluated. Following a DXA scan with a T score of -2.5 or less bone sparing medication such as bisphosphonate is commenced with Vitamin D supplementation, along with Calcium if intake is inadequate.

Primary prevention before any fracture occurs would be the ideal intervention but with limited resources identifying and treating such a large population is unlikely to be economically viable. 5 to 6 times as many patients would need to be identified, assessed and treated to achieve a similar fracture incidence reduction as that achieved with secondary prevention(292, 293).

Secondary prevention is effective and efficient. Half of patients with a hip fracture have sustained a previous fracture(294). Identifying and treating these patients would prevent an estimated 25% of hip fractures per year. This equates to 20,000 hip fractures in the UK per annum(295). Reduction of hip fracture rate with alendronate treatment has been shown to be significant with secondary prevention but not for primary prevention. Alendronate use following an initial non-vertebral fracture produces a significant relative risk reduction of further fracture. Along with reducing

fracture risk pharmacological therapy has been shown to improve quality of life and reduce mortality(296, 297)

In a Canadian study Majumdar et al randomly allocated distal radius fracture patients to an intervention involving patient education and the provision of evidence based guidelines to their family doctor(298). Compared to the control group osteoporosis treatment rate was three times higher six months following distal radius fracture. Cost effectiveness analysis conducted one year after initial fracture showed that for every 100 patients in the intervention group three fractures, including one hip fracture, were prevented. $26,800 was saved over a patient's lifetime and 1.1 quality-adjusted life year gained(299).

Fracture liaison services are successful and cost effective. Further fragility fractures can be reduced by 50%(95, 300). The fracture liaison service in Glasgow reported on their management of over 50,000 patients over a 10 year period(301). During this time Glasgow hip fracture rates fell by 7% whereas rates in England increased by 17%. A cost effectiveness analysis showed that for every 1,000 patients treated 18 fractures were prevented, including 11 hip fractures, and £21,000 was saved(111). If comparable services were available throughout the UK £6.3 million could be saved per year. However similar services are currently only available to 42% of the UK.

Ideally a secondary prevention program should consist of osteoporosis assessment and treatment together with a falls risk assessment, in a 'one-stop shop' setting(256). Organising and providing such services is a considerable challenge. A Fracture Liaison Service delivered by a Nurse Specialist is a cost effective, proven approach to the identification, assessment and treatment of fracture risk(80). The National Hip Fracture Database National report shows only 36% of hospitals currently provide this service(302). Presentation with a distal radius fracture provides an opportunity to implement these interventions. In the current economic climate resources are scarce and must be used prudently. Identification of those at highest risk of further fractures allows resources to be targeted to those who need them most.

Targeted outreach services to increase uptake of health services to specific groups have been shown to be effective. Roberts et al reported on a health check service

directed towards key groups including men, people of South Asian ethnicity and those from deprived areas(303). Percentage of health checks taken up amongst South Asians and those in the lowest deprivation quintiles was significantly higher than checks in primary care. They targeted people at venues such as supermarkets, mosques and bus stations. A similar cardiovascular disease risk assessment and management scheme was also able to reach more deprived patients in many areas of England including Leicestershire(304). This could easily be adapted for osteoporosis and falls prevention services.

Chapter 10 Summary

In this thesis I set out to investigate if distal radius fracture is associated with deprivation and if treatment is influenced by deprivation. A further aim was to establish the risk of hip fracture after distal radius fracture. Analysis of local and national data was performed using a variety of modelling techniques. The United Kingdom government official measure of deprivation (IMD2010) was used to investigate the influence of socioeconomic status. A prospective study was performed to identify factors responsible for the effects of deprivation on fracture incidence.

Deprivation was strongly associated with distal radius fracture in the whole population studied. Deprived patients sustained their injuries at an earlier age. Further regression modelling showed important differences between the ethnic groups which were present in both the local and national data. Increasing deprivation was an independent risk factor for distal radius fracture only in white patients. The influence of deprivation was larger in white men. Incidence rate in the least deprived quintile was a third of that in the most deprived for white men and almost half for white women. Age 50 years and over and male gender was an independent risk factor for distal radius fracture in all ethnicities. Falls risk was associated with increasing deprivation.

Deprivation was not related to any of the parameters of hospital care studied. Significant variation has been identified between hospital trusts treating distal radius fractures with a higher fixation rate seen in trusts with a smaller population. This may be exposing patients to unnecessary procedures and utilising excessive healthcare resources. Further robust research is required to provide guidance on which fractures are best treated with surgical fixation. It was identified that patients with more co-morbidities, men and patients admitted at the weekend waited longer for surgery.

Patients who suffer a distal radius fracture are an at-risk group for a subsequent hip fracture. Systematic review and meta-analysis showed that previous distal radius fracture in women was associated with an overall relative risk of hip fracture of 1.43

(CI 1.27 to 1.60) compared to those without. A similar association was demonstrated in studies looking at pooled results for men and women together (RR: 1.82 (CI 1.40 – 2.36)). Results of the four trials providing results for men only did not demonstrate a statistically significant increased relative risk (RR: 2.11 (0.93 – 4.85)). Deprivation measured by similar methods is also a risk factor for hip fracture. Effective secondary prevention after a distal radius fracture is required to prevent the catastrophic event of a hip fracture.

With the increasing size and age of the population the number of patients who sustain a distal radius fracture and require treatment will continue to increase. Poverty is rising which will cause higher levels of social deprivation and an increase in distal radius fracture rate. Fracture prevention strategies are required to combat this rise. Knowing which patients are at highest risk allows interventions to be efficiently targeted. Resources should be targeted to those at-risk patients from deprived areas and preventative strategies put in place.

Chapter 11 Future directions

In this thesis, several important findings have been demonstrated which provide the opportunity to help reduce the risk of distal radius fractures and subsequently hip and other osteoporotic fractures. Deprivation is clearly associated with distal radius fracture incidence. Probably the key result of this work is the identification of the association between increased deprivation and falls risk. It seems this is therefore the area which would be the most effective to target to reduce fracture rate. Information regarding deprivation, along with gender, age and ethnicity, of UK cities and counties is readily available. Areas of high risk can be easily identified. Other health interventions have been delivered direct to those at risk who traditionally do not access health services including those from deprived areas including Leicestershire. These methods have been shown to be effective. An assessment of bone health and falls risk along with education and falls prevention measures could be delivered directly into the communities of at risk patients. Significant funding would be required but it is likely to be effective and prove to be cost-effective overall.

Additional work should also concentrate on modification of the falls prevention programs specifically for deprived patients. These patients are younger and suffer frequent injuries outdoors compared to hip fracture patients. A shift of focus towards outdoor hazards, social support and reasons for outdoor journeys is likely to be beneficial for this group.

Other important deprivation related factors which increase falls risk include depression, polypharmacy and medications causing side effects such as light headedness. Smoking was also associated with deprivation and is known to have a negative effect on bone health. These factors are all amenable to being addressed in primary care. Screening of deprived patients for depression, regular medication reviews and specific smoking cessation advice may all help reduce fracture risk as well as improving general health and well-being.

Other aspects of interest identified include the radiographic differences of bone quality between those of different ethnicity and gender in the 50 and over age group. In this work a significant difference was demonstrated but the numbers for sub-analysis were relatively small. Further work could include larger reviews of radiographs or utilising different methods of bone health measurement such as DXA scans to investigate the ethnic differences in more detail.

Gender is another factor which requires further attention. Deprivation has a larger effect on fracture risk in men. Other studies have suggested this is due to lifestyle factors such as smoking, alcohol and risk taking behaviour. A more detailed larger, prospective assessment of lifestyle factors and mechanism of injury of men from the deprived quintiles compared to the least deprived quintiles should help answer this question.

The radiographic analysis demonstrated significant problems with intra and inter observer error for measure of intra-articular parameters. Further studies should try and develop improved measurement techniques. Relying on two points of maximum displacement is difficult and flawed. Methods measuring distance between the articular surfaces of major fragments are likely to be easier and more clinically relevant for long term functional outcome and management decisions.

Research issues identified from the analysis of the influence of deprivation on treatment include variation in fixation rate between hospital trusts, delay to treatment for men, patients with co-morbidities and with presentation at or just before the weekend. As discussed previously there is a lack of high quality studies investigating at which thresholds of displacement intervention should take place for distal radius fractures. Therefore, strong evidence based guidelines are not available leading to individual variation between units. Production of this evidence and subsequent guidelines would almost certainly reduce variation. Trusts and trauma units should aim to develop better pathways for patients with multiple co-morbidities. Appropriate pre-assessment and early anaesthetic team involvement is likely to prevent unexpected delays on the day of surgery due to medical problems.

Appendix 1 Systematic review protocol

PROTOCOL

Systematic Review – What is the risk of a subsequent hip fracture following a distal radius fracture?

Background

Wrist fractures are common and with an ageing population the incidence is rising. 6% of women in the western world will have suffered a distal radius fracture by the time they are 80. Fractures in older patients are likely to occur at lower energy usually because of osteoporosis. A patient who suffers an osteoporotic distal radius fracture is at a higher risk of sustaining a hip fracture, especially within the first year after injury . A hip fracture is a catastrophic event with an associated significant morbidity, mortality and high cost of treatment.

Review Objective – the purpose of this review is to assess the evidence regarding hip fracture after a distal radius fracture and use this to calculate the risk of a subsequent hip fracture occurring

Study Inclusion Criteria

Subjects – Men and women with a distal radius fracture

Exposure – Radiographically confirmed distal radius fracture

Outcomes –Radiographically or surgically confirmed hip fracture. Relative risk, incidence or observed/expected number of outcome events reported

Types of Study – Prospective longitudinal design

Identifying Evidence

Electronic literature review of studies published in full in Pubmed and Embase databases performed by senior clinical librarian. Further studies identified from reference lists of retrieved articles. Thesis search performed. Hand search any relevant journals which are not fully medline linked.

Study Selection and Data Extraction

Initial Screening –

Stage 1: First decision is made based on abstracts assessed against the predetermined inclusion criteria by single reviewer

Stage 2: For studies that appear to meet the inclusion criteria the full paper will be obtained and assessed against the inclusion criteria by 2 independent reviewers. Difference in assessments resolved by consensus with the advisory group.

QualityAssessment – performed using Newcastle Ottawa scale, Coleman methodology tool and domain specific tool. Risk of bias assessment carried out using Cochrane Risk of Bias tool.

Data Extraction

- Study – Type, country, study period
- Case definition
- Patients and population– Total no., age, gender, exclusion criteria applied
- Outcomes – No. of hip fractures, age, gender, time to fracture, follow up period, loss to follow up
- Results – Relative risk, confidence interval, p value, adjustment for variables, total numbers

Data Synthesis – Assessment of homogeneity and if appropriate followed by fixed effects meta-analysis to calculate pooled relative risks with 95% confidence intervals

Dissemination – Presentation at international and national conferences and publication in peer reviewed journals. Emphasis on dissemination to health professionalstreating patients who have suffered a distal radius fracture to enable preventative strategies to be put in place to prevent future hip fracture.

Appendix 2 Systematic review data collection form

Data collection form

Systematic review – risk of hip fracture after distal radius fracture

Review title or ID

Study ID *(surname of first author and year first full report of study was published e.g. Smith 2001)*

Report IDs of other reports of this study *(e.g. duplicate publications, follow-up studies)*

Notes:

1... General Information

1. **Date form completed** *(dd/mm/yyyy)*	
2. **Name/ID of person extracting data**	
3. **Report title** *(title of paper/ abstract/ report that data are extracted from)*	
4. **Report ID** *(if there are multiple reports of this study)*	
5. **Reference details**	
6. **Report author contact details**	
7. **Publication type** *(e.g. full report, abstract, letter)*	
8. **Study funding source** *(including role of funders)*	
Possible conflicts of interest *(for study authors)*	
9. **Notes:**	

Data extraction form 2013 08 12

2... Eligibility

Study Characteristics	Review Inclusion Criteria *(Insert inclusion criteria for each characteristic as defined in the Protocol)*	Yes/ No / Unclear	Location in text *(pg & ¶/fig/table)*
10. **Type of study**	Randomised trial	...	
	Non-randomised trial	...	
	Prospective longitudinal study	...	
	Retrospective cohort	... ...	
	Other design (specify):	...	
11. **Participants**		...	
12. **Distal Radius Fracture – how diagnosed?**		...	
13. **Types of outcome measures- NOF – how diagnosed?**		...	
14. **Decision:**	...		
15. **Reason for exclusion**			
16. **Notes:**			

DO NOT PROCEED IF STUDY EXCLUDED FROM REVIEW

3… Population and setting

	Description *Include comparative information for each group (i.e. intervention and controls) if available*	**Location in text** *(pg & ¶/fig/table)*
17. **Population description** *(from which study participants are drawn)*		
18. **Setting** *(including location and social context)*		
19. **Inclusion criteria recorded**		
20. **Exclusion criteria recorded**		
21. **Method/s of recruitment of participants**		
22. **Notes:**		

4… Methods

	Descriptions as stated in report/paper	**Location in text** *(pg & ¶/fig/table)*
23. **Aim of study**		
24. **Unit of allocation** *(by individuals, cluster/ groups or body parts)*		
25. **Start date**		
26. **End date**		
27. **Duration of participation** *(from recruitment to last follow-up)*		
28. **Notes:**		

5… Risk of Bias assessment

See Chapter 8 of the Cochrane Handbook. Additional domains may be required for non-randomised studies.

Domain	**Risk of bias** *Low/ High/Unclear*	**Support for judgement**	**Location in text** *(pg & ¶/fig/table)*
29. **Random sequence generation** *(selection bias)*	…		
30. **Allocation concealment** *(selection bias)*	…		

Domain	Risk of bias *Low/ High/Unclear*	Support for judgement	Location in text *(pg & ¶/fig/table)*
31. **Blinding of participants and personnel** *(performance bias)*	…	**Outcome group: All/**	
(if required)	…	**Outcome group:**	
32. **Blinding of outcome assessment** *(detection bias)*	…	**Outcome group: All/**	
(if required)	…	**Outcome group:**	
33. **Incomplete outcome data** *(attrition bias)*	…		
34. **Selective outcome reporting?** *(reporting bias)*	…		
35. **Other bias – possible confounding factors reported**	…		
36. **Notes:**			

6… Participants

Provide overall data and, if available, comparative data for each intervention or comparison group.

	Description as stated in report/paper	Location in text (pg & ¶/fig/table)
37. **Total number** *(or total pop. at start of study for NRCTs)*		
38. **Clusters** *(if applicable, no., type, no. people per cluster)*		
39. **Baseline imbalances**		
40. **Withdrawals and exclusions** *(if not provided below by outcome)*		
41. **Age**		
42. **Sex**		
43. **Race/Ethnicity**		
44. **Co-morbidities**		
45. **Other treatment received** *(additional to study intervention)*		
46. **Other relevant sociodemographics**		
47. **Subgroups measured**		
48. **Subgroups reported**		
49. **Notes:**		

7... Outcomes

Copy and paste table for each outcome.

Outcome 1

	Description as stated in report/paper	Location in text *(pg & ¶/fig/table)*
50. **Outcome name- NOF**		
51. **Time points reported**		
52. **Imputation of missing data** *(e.g. assumptions made for ITT analysis)*		
53. **Assumed risk estimate** *(e.g. baseline or population risk noted in Background)*		
54. **Notes:**		

8... Results

For prospective longitudinal/retrospective cohort studies

	Description as stated in report/paper	Location in text *(pg & ¶/fig/table)*
55. **Total period measured**		
56. **No. participants with DRF**		
57. **Mean age of participants with DRF** *(with variance measure)*		
58. **No. participants with subsequent NOF#**		
59. **Mean age of patients at time of NOF#** *(with variance measure)*		
60. **Mean time from DRF to subsequent NOF#** *(with variance measure)*		
61. **Relative risk/Hazard ratio reported**		
62. **Reanalysis required?** *(specify)*	... *Yes/No/Unclear*	
63. **Reanalysis possible?**	... *Yes/No/Unclear*	
64. **Reanalysed results**		
65. **Notes:**		

9... Applicability

66. **Have important populations been excluded from the study?** *(consider disadvantaged populations, and possible differences in the intervention effect)*	... *Yes/No/Unclear*	
67. **Is the intervention likely to be aimed at disadvantaged groups?** *(e.g. lower socioeconomic groups)*	... *Yes/No/Unclear*	
68. **Does the study directly address the review question?** *(any issues of partial or indirect applicability)*	... *Yes/No/Unclear*	
69. **Notes:**		

10. Other information

	Description as stated in report/paper	Location in text *(pg & ¶/fig/table)*
70. **Key conclusions of study authors**		
71. **References to other relevant studies**		
72. **Correspondence required for further study information** *(what and from whom)*		
73. **Further study information requested** *(from whom, what and when)*		
74. **Correspondence received** *(from whom, what and when)*		
75. **Notes:**		

Appendix 3 Modified Coleman score assessment

Modified Coleman Methodology Score

Part A

Study size	no of patients	>60	10
		41-60	7
		20-40	4
		<20	0
Mean follow-up (months)		>24	5
		12-24	2
		<12	0
Type of study	RCT		15
	Prospective cohort		10
	Retrospective cohort		0
Diagnostic criterion (DRF)	clinical only		0
	+ imaging		3
	validated scoring system		7
	imaging + validated scoring		10
Assessment of severity	clinical only		0
	Imaging		2
	Validated scoring system		3
	imaging + validated scoring		5
Description of prevention			
	Adequate (stated technique & details)		5
	Fair (stated technique only)		3
	Inadequate (not stated)		0
Description of management			
	Well described with >80% compliance		10
	Well described with 60-80% compliance		5
	Inadequate description or <60% compliance		0

Part B

Outcome criteria (NOF)		
	Outcome measures clearly defined	2
	Timing of outcome stated	2

Appendix 4 Risk of bias tool

Risk of bias tool:

Domain		**Risk of bias**
		Low/ High/Unclear
1. Random sequence generation		
(selection bias)		
2. Allocation concealment (selection bias)		
3. Blinding of participants and personnel		
(performance bias) (if required)		
4. Blinding of outcome assessment (detection bias)		
(if required)		
5. Incomplete outcome data		
(attrition bias) 6. Selective outcome reporting?		
(reporting bias)		
7. Other bias – possible confounding factors reported		
8. Notes:		

Appendix 5 Fracture risk assessment questionnaire

Wrist Injury Audit

Prospective Wrist Injury Data Collection

Study Ref:

Date of injury: / /

Surname:

Name:

Age:

Wrist injured: ☐ Right ☐ Left ☐ Both

A. **Which is your dominant hand:**
☐ **Right** ☐ **Left** ☐ **Both**

B. Where did you injure your wrist:

☐ Home ☐ Sports ground/pitch If sports please specify:

☐ Road/Street ☐ Other If other please specify:

☐ Work place

C. **Did you fall from:**

☐ **Standing height** ☐ **Above standing height**

☐ **Other** If other please specify:

D. Are you in paid employment/ self employed: ☐ Yes ☐ No

What is your Occupation:

E. **Bone Health Assessment**

Weight: kg **Height:** cm

	Yes	No
Have you had a previous fracture	☐	☐
Did any of your parents fracture their hip	☐	☐
Do you smoke	☐	☐
Do you or have you been treated with steroids in the past	☐	☐
Are you known to have osteoporosis caused by another medical condition	☐	☐
Do you drink 3 or more units of alcohol per day	☐	☐

NJ

Page 1

F. Falls Risk Assessment

	Yes	No
1. I have fallen in the past year	☐	☐
2. I use or have been advised to use a cane or walker to get around safely	☐	☐
3. Sometimes I feel unsteady when I am walking	☐	☐
4. I steady myself by holding onto furniture when walking at home	☐	☐
5. I am worried about falling	☐	☐
6. I need to push with my hands to stand up from a chair	☐	☐
7. I have some trouble stepping up onto a curb	☐	☐
8. I often have to rush to the toilet	☐	☐
9. I have lost some feeling in my feet	☐	☐
10. I take medicine that sometimes makes me feel light-headed or more tired than usual	☐	☐
11. I take medicine to help me sleep or improve my mood	☐	☐
12. I often feel sad or depressed	☐	☐

G. Previous Wrist Problems

Did you have any problems with your wrist before you injured it? Yes ☐ No ☐

Please rate the average amount of pain and stiffness you had in your wrist in the week BEFORE you injured it on a scale from 0-10. A zero (0) means you did not have any pain or stiffness and ten (10) means severe pain and stiffness.

None											Severe
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
0	1	2	3	4	5	6	7	8	9	10	

EuroQol EQ-5D

By placing a cross (☒) in one box in each group below, please indicate which statement best describes your own health state **TODAY.**

Q1 **Mobility**

- I have **no** problem walking about ☐
- I have **some** problem walking about ☐
- I am **confined to bed** ☐

Q2 **Self Care**

- I have **no** problem with self care ☐
- I have **some** problem with self care ☐
- I am **unable to wash or dress myself** ☐

Q3 **Usual Activities**

- I have **no** problem with my normal activities ☐
- I have **some** problem with my normal activities ☐
- I am **unable to perform my normal activities** ☐

Q4 **Pain/Discomfort**

- I have **no** pain or discomfort ☐
- I have **moderate** pain or discomfort ☐
- I have **extreme** pain or discomfort ☐

Q5 **Anxiety/Depression**

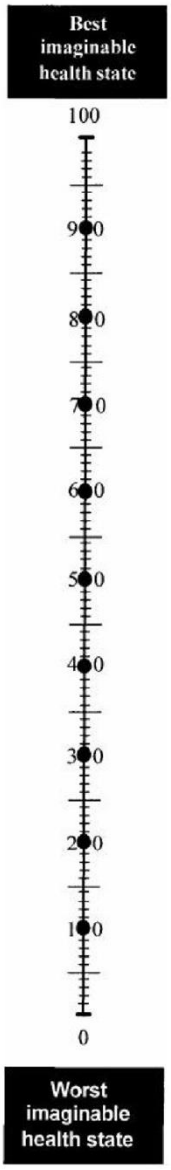
- I am **not** anxious or depressed ☐
- I am **moderately** anxious or depressed ☐
- I am **extremely** anxious or depressed ☐

Your own health state today

Think about how good or bad your own health is today.

This scale may help. The best health you can imagine is marked 100, and the worst health you can imagine is marked 0.

Please indicated, with a cross on the scale, how good or bad your own health is today.



H.This section looks at your **other illnesses**, if any.

In general, how would you describe your health:

Excellent	Very Good	Good	Fair	Poor
☐	☐	☐	☐	☐

Have you been told by a doctor that you have any of the following?
(Check all that apply to you)

Heart Disease	☐	i.e. angina, heart attack or heart failure, pacemaker etc
High Blood Pressure	☐	
Problems caused by a Stroke	☐	
Leg Pain when walking due to poor circulation	☐	
Lung Disease	☐	i.e. asthma, chronic bronchitis or emphysema
Kidney Disease	☐	
Diseases of the Nervous System	☐	i.e. epilepsy, Parkinson's disease or multiple sclerosis
Liver Disease	☐	
Cancer (within the last 5 years)	☐	
Depression	☐	
Rheumatoid Arthritis	☐	
Blood Clots in the lungs (PE) or legs (DVT)	☐	
Hepatitis (A, B or C) or **HIV** or **AIDS**	☐	
Kidney problems needing Dialysis	☐	
Diabetes	☐	**If you have Diabetes, how is it treated?** Diet Controlled ☐ Tablets ☐ Insulin ☐

Do you consider yourself to have a disability? Yes ☐ No ☐

Do you suffer from any other disease for which you are having treatment? Yes ☐ No ☐

If yes, please write details below:

Agreement:
I would be happy to be contacted again in the future for further research purposes.

Name (please use block capitals)	Signed

Name: _____ Date: _____

PATIENT RATED WRIST EVALUATION

*The questions below will help us understand how much difficulty you have had with your wrist in the past week. You will be describing your **average** wrist symptoms **over the past week** on a scale of 0-10.* Please provide an answer for **ALL** questions. If you did not perform an activity, please **ESTIMATE** the pain or difficulty you would expect. If you have **never** performed the activity, you may leave it blank.

1. PAIN

Rate the **average** amount of pain in your wrist over the past week by circling the number that best describes your pain on a scale from 0-10. A zero **(0)** means that you **did not** have any pain and a **ten (10)** means that you had the **worst pain you have ever experienced** or that **you could not do the activity because of pain.**

RATE YOUR PAIN: Sample Scale ☞	0 No Pain	1	2	3	4	5	6	7	8	9	10 Worst Ever
At rest	0	1	2	3	4	5	6	7	8	9	10
When doing a task with a repeated wrist movement	0	1	2	3	4	5	6	7	8	9	10
When lifting a heavy object	0	1	2	3	4	5	6	7	8	9	10
When it is at its worst	0	1	2	3	4	5	6	7	8	9	10
How often do you have pain?	0 Never	1	2	3	4	5	6	7	8	9	10 Always

2. FUNCTION

A. SPECIFIC ACTIVITIES

*Rate the **amount of difficulty** you experienced performing each of the items listed below - over the past week, by circling the number that describes your difficulty on a scale of 0-10. A **zero** (0) means you did not experience any difficulty and a **ten** (10) means it was so difficult you were unable to do it at all.*

Sample scale ➡	0 No Difficulty	1	2	3	4	5	6	7	8	9	10 Unable To Do
Turn a door knob using my affected hand	0	1	2	3	4	5	6	7	8	9	10
Cut meat using a knife in my affected hand	0	1	2	3	4	5	6	7	8	9	10
Fasten buttons on my shirt	0	1	2	3	4	5	6	7	8	9	10
Use my affected hand to push up from a chair	0	1	2	3	4	5	6	7	8	9	10
Carry a 10lb object in my affected hand	0	1	2	3	4	5	6	7	8	9	10
Use bathroom tissue with my affected hand	0	1	2	3	4	5	6	7	8	9	10

B. USUAL ACTIVITIES

*Rate the **amount of difficulty** you experienced performing your **usual** activities in each of the areas listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. By "usual activities", we mean the activities you performed **before** you started having a problem with your wrist. A **zero** (0) means that you did not experience any difficulty and a **ten** (10) means it was so difficult you were unable to do any of your usual activities.*

Personal care activities (dressing, washing)	0	1	2	3	4	5	6	7	8	9	10
Household work (cleaning, maintenance)	0	1	2	3	4	5	6	7	8	9	10
Work (your job or usual everyday work)	0	1	2	3	4	5	6	7	8	9	10
Recreational activities	0	1	2	3	4	5	6	7	8	9	10

Appendix 6 STEADI falls risk assessment

Check Your Risk for Falling

Circle "Yes" or "No" for each statement below			Why it matters
Yes (2)	No (0)	I have fallen in the past year.	People who have fallen once are likely to fall again.
Yes (2)	No (0)	I use or have been advised to use a cane or walker to get around safely.	People who have been advised to use a cane or walker may already be more likely to fall.
Yes (1)	No (0)	Sometimes I feel unsteady when I am walking.	Unsteadiness or needing support while walking are signs of poor balance.
Yes (1)	No (0)	I steady myself by holding onto furniture when walking at home.	This is also a sign of poor balance.
Yes (1)	No (0)	I am worried about falling.	People who are worried about falling are more likely to fall.
Yes (1)	No (0)	I need to push with my hands to stand up from a chair.	This is a sign of weak leg muscles, a major reason for falling.
Yes (1)	No (0)	I have some trouble stepping up onto a curb.	This is also a sign of weak leg muscles.
Yes (1)	No (0)	I often have to rush to the toilet.	Rushing to the bathroom, especially at night, increases your chance of falling.
Yes (1)	No (0)	I have lost some feeling in my feet.	Numbness in your feet can cause stumbles and lead to falls.
Yes (1)	No (0)	I take medicine that sometimes makes me feel light-headed or more tired than usual.	Side effects from medicines can sometimes increase your chance of falling.
Yes (1)	No (0)	I take medicine to help me sleep or improve my mood.	These medicines can sometimes increase your chance of falling.
Yes (1)	No (0)	I often feel sad or depressed.	Symptoms of depression, such as not feeling well or feeling slowed down, are linked to falls.
Total _____		Add up the number of points for each "yes" answer. If you scored 4 points or more, you may be at risk for falling. Discuss this brochure with your doctor.	

This checklist was developed by the Greater Los Angeles VA Geriatric Research Education Clinical Center and affiliates and is a validated fall risk self-assessment tool (Rubenstein et al. J Safety Res; 2011: 42(6)493-499). Adapted with permission of the authors.

Appendix 7 R packages

ggplot2	graphs
gplots	plots of group means with confidence intervals
ICC.Sample.Size	ICC power calculation
lme4	linear mixed effects models
MASS	negative binomial regression
meta	meta-analysis
mgcv	generalized additive models
mice	multivariate imputation by chained equations
pbkrtest	Kenward Roger approximation
psych	ICC calculation
sandwich	robust standard errors

Appendix 8 National regression model results

Under 50

IRR of fracture rate for deprivation quintiles are compared with quintile 1 (most deprived), ethnic groups are compared to white patients and male gender with female gender

Factor	IRR	95% CI lower limit	95% CI upper limit	P value
Quintile 2	0.84	0.82	0.86	p<0.001
Quintile 3	0.77	0.75	0.79	p<0.001
Quintile 4	0.81	0.79	0.83	p<0.001
Quintile 5	0.75	0.73	0.77	p<0.001
Asian	0.18	0.17	0.20	p<0.001
Black	0.10	0.09	0.12	p<0.001
Other	0.45	0.42	0.49	p<0.001
Male	1.35	1.33	1.37	p<0.001

50 and over

IRR of fracture rate for the gender/ethnicity deprivation quintiles are compared with quintile 1 (most deprived), ethnic group results for men are compared to results for women of the same ethnic group

Factor	IRR	95% CI lower limit	95% CI upper limit	P value
Quintile 2 - White women	0.94	0.92	0.96	0.002
Quintile 3 - White women	0.86	0.84	0.88	p<0.001
Quintile 4 - White women	0.90	0.88	0.92	p<0.001
Quintile 5 - White women	0.90	0.88	0.92	p<0.001
Quintile 2 - Asian women	0.68	0.59	0.77	0.003
Quintile 3 - Asian women	0.80	0.70	0.92	0.112
Quintile 4 - Asian women	0.77	0.66	0.91	0.11
Quintile 5 - Asian women	0.79	0.67	0.93	0.146
Quintile 2 - Black women	1.03	0.78	1.38	0.904
Quintile 3 - Black women	1.81	1.33	2.48	0.057
Quintile 4 - Black women	2.78	1.96	3.94	0.004
Quintile 5 - Black women	4.32	3.08	6.07	p<0.001
Quintile 2 - Other women	1.13	0.95	1.36	0.489
Quintile 3 - Other women	1.67	1.39	1.99	0.004
Quintile 4 - Other women	1.64	1.36	1.98	0.009
Quintile 5 - Other women	2.22	1.86	2.66	p<0.001
Quintile 2 - White men	0.82	0.78	0.86	0.008
Quintile 3 - White men	0.73	0.70	0.77	0.001
Quintile 4 - White men	0.69	0.66	0.73	p<0.001
Quintile 5 - White men	0.72	0.68	0.76	p<0.001
Quintile 2 - Asian men	0.63	0.56	0.72	0.003
Quintile 3 - Asian men	0.69	0.60	0.79	0.112

Quintile 4 - Asian men	0.70	0.59	0.82	0.11
Quintile 5 - Asian men	0.71	0.60	0.84	0.146
Quintile 2 - Black men	0.97	0.73	1.29	0.904
Quintile 3 - Black men	1.56	1.14	2.13	0.057
Quintile 4 - Black men	2.50	1.76	3.55	0.004
Quintile 5 - Black men	3.89	2.77	5.46	p<0.001
Quintile 2 - Other men	0.82	0.68	0.98	0.489
Quintile 3 - Other men	0.73	0.61	0.88	0.004
Quintile 4 - Other men	0.69	0.57	0.84	0.009
Quintile 5 - Other men	0.72	0.60	0.86	p<0.001
White men	0.23	0.23	0.24	p<0.001
Asian men	2.51	2.27	2.79	p<0.001
Black men	2.13	1.69	2.70	0.001
Other men	1.45	1.26	1.67	0.007

Appendix 9 Surgical fixation rate in Leicestershire

Factor	IRR	95% CI lower limit	95% CI upper limit	P value
Quintile 2	1.79	1.43	2.24	0.009
Quintile 3	1.17	0.91	1.51	0.529
Quintile 4	1.07	0.84	1.37	0.775
Quintile 5	1.43	1.15	1.78	0.106
Age under 50	0.57	0.48	0.68	0.001
Male	0.84	0.68	1.03	0.391
White	1.74	1.40	2.15	0.01
Intra-articular DRF	1.56	1.24	1.97	0.057
Injury outdoors	1.57	1.22	2.03	0.075
Quintile 2 - Intra DRF	0.76	0.57	1.01	0.334
Quintile 3 - Intra DRF	1.30	0.96	1.78	0.393
Quintile 4 - Intra DRF	1.61	1.20	2.16	0.105
Quintile 5 - Intra DRF	0.82	0.62	1.08	0.477
Under 50 - Outdoors	2.72	2.22	3.33	p<0.001
Male - Intra DRF	1.51	1.26	1.82	0.024
Male - Outdoors	1.18	0.96	1.43	0.414
White - Outdoors	0.72	0.56	0.92	0.188

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