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The influence of femoral head size following total hip replacement and hip resurfacing on hip biomechanics during walking, stair use and sit-to-stand

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The influence of femoral head size following total hip replacement and hip resurfacing on hip biomechanics during walking, stair use and sit-to-stand

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ABSTRACT

Due to geometrical features, it is claimed that larger femoral heads in total hip replacement (THR) are superior in achieving normal biomechanics than smaller ones; and that hip resurfacing (RSF) is superior to THR. This has not been conclusively proven. Most studies have investigated level walking, which may not be demanding enough to highlight what could be small biomechanical differences between implants. Few biomechanical studies have compared more demanding tasks and not with patients with different femoral head sizes or RSF.

This thesis aimed to address these omissions by investigating level walking, stair descent and sit-to-stand (STS) biomechanics between three groups (32mm THR, 36mm THR and RSF). Twenty-six osteoarthritis patients were recruited and tested pre-operatively, then three and twelve months post-operatively. Demographic differences between groups were expected due to patient considerations for different implants, so a study was performed to determine whether level walking biomechanics alter progressively during the aging process with a group of 63 healthy participants. Three matched sub-groups were extracted from this group as controls.

There was no suggestion that gait deteriorates progressively with age. Hip reconstruction, irrespective of head size, can allow patients to return to the biomechanical levels of controls during level walking. Stair descent differences remained 12 months post-operatively in cadence (p=0.042) and peak hip power generated (p<0.001) compared to controls. The 32mm group exhibited vertical ground reaction force (vGRF) asymmetry pre-operatively (p<0.001) and 3 months post-operatively (p=0.013); and impulse asymmetry (p<0.001) pre-operatively during STS. The 36mm group exhibited impulse asymmetry (p=0.05) three months post-operatively.

This thesis is the first biomechanical analysis of stair descent and STS of two THR groups and a RSF group. It has demonstrated stair descent differences at 12 months post-operatively and overloading of the healthy limb in some THR patients. The latter could be problematic for the healthy limb.

Publications arising from the research

Peer reviewed journals

Ewen AM, Stewart S, St Clair Gibson A, Kashyap SN, Caplan N. Post-operative gait analysis in total hip replacement patients-A review of current literature and meta-analysis. Gait and Posture 2012.

Ewen AM, Caplan N, Stewart S, Lees C, Shankar N. A comparison of level walking and stair use gait between two age groups. Gait & posture 2009; 30: S107-S108.

Conference presentations

Ewen AM, Kashyap S, Banaszkiewicz P, St Clair Gibson A & Caplan N. Sit-to-stand ground reaction force changes after hip resurfacing or total hip replacement: a pilot study. In Proceedings of the 23rd International Society of Biomechanics Congress, (July 3-7, 2011; Brussels, Belgium).

Ewen AM, Caplan N, Stewart S, Kashyap SN. The design and constructionof an instrumented staircase for use in clinical assessment of gait. Presented at the 18th Annual meeting of the European Society for Movement Analysis in Adults and Children, (September 17-19, 2009: London, UK).

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Acknowledgements

Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinion, ideas and contributions from the work of others. The work was done in collaboration with the Queen Elizabeth Hospital, Gateshead.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by Newcastle & North Tyneside 1 Research Ethics Committee on 7th August 2009.

Name:

Signature:

Date:

Glossary of Key Terms

Abduction/adduction   An anatomical movement which tends to move a segment away from (abduction) or towards (adduction) the midline

Anterolateral   A surgical approach to the hip joint in which the incision is predominantly to the front of the body and is made between the anterior superior iliac spine and the greater trochanter of the femur

Cadence   Walking pace expressed in terms of steps per unit time

Double support time   Duration during walking gait cycle where both feet are in contact with the ground expressed in seconds

Flexion/extension   An anatomical movement which tends to decrease (flexion) or increase (extension) the angle between two segments

Moment   A force which tends to cause rotation defined as the product of the force applied and the perpendicular distance between the point of force application and the centre of rotation

Posterolateral   An approach to the hip joint in which the incision is made predominantly to the rear of the body and is between the posterior superior iliac spine and the distal portion of the greater trochanter

Single support time   Duration during walking gait cycle where only one foot is in contact with the ground expressed in seconds

Stance phase   Period during which a limb is in contact with the ground

Stance phase duration	Duration of the stance phase expressed in time units
Stride length	Distance covered from foot contact of one limb to the next foot contact with the same limb
Swing phase	Period during which a limb is in motion between stance phases
Swing phase duration	Duration of the swing phase expressed in time units
Valgus	An anatomical alignment between two segments in which the more distal segment deviates laterally
Varus	An anatomical alignment between two segments in which the more distal segment deviates medially

List of Abbreviations

ADLs	Activities of daily living
ASIS	Anterior superior iliac spine
CoG	Centre of gravity
CoM	Centre of mass
CoP	Centre of pressure
HHS	Harris Hip Score
KADs	Knee alignment devices
NHS	National Health Service
OA	Osteoarthritis
OHS	Oxford Hip Score
PIS	Patient Information Sheet
QEH	Queen Elizabeth Hospital
RFID	Radio Frequency Identification
ROM	Range of motion
RSF	Hip resurfacing
SbS	Step-by-step
SoS	Step-over-step
STS	Sit-to-stand
THR	Total hip replacement
vGRF	Vertical ground reaction force
WOMAC	Western Ontario & McMaster Universities Arthritis Index

1 Introduction

The hip joint is a ball and socket joint with a ball (femoral head) at the proximal end of the femur articulating with a socket (acetabulum) on the pelvis. Ball and socket joints allow for rotational movement around all three axes, and in the hip joint this enables the femur to flex and extend, abduct and adduct, and to rotate around the long axis of the bone with respect to the pelvis. The femur is prevented from disengaging from the pelvis through a combination of the articular capsule, which extends from the pelvic girdle to the femur, and ligaments which cross the joint [1, p.269]. Both the femoral head and the acetabulum have a layer of articular cartilage covering the bone which provides smooth articulating surfaces. A thin film of synovial fluid between the femoral head and the acetabulum provides lubrication to reduce the friction at the joint [1, p.256].

Movement of the femur relative to the pelvis is enabled by muscles which cross the joint. These muscles do not generally operate in isolation; rather they are used in combinations to provide the desired movements. The main muscle responsible for hip extension is the gluteus maximus while the iliopsoas group provides most of the flexion capability. Adduction of the hip is provided by the adductor group of muscles and the gluteus medius and gluteus minimus are responsible for hip abduction. Another group of muscles, the lateral rotator group, is responsible for externally rotating the hip, while internal rotation of the hip is provided by a range of muscles, most notably the gluteus medius, gluteus minimus and tensor fasciae latae [1, p.352].

A normally functioning hip joint provides a large range of movement in all three planes which is vital for a number of tasks including ambulation, stair use and rising from a

sitting position. When normal function is compromised, such as by injury or disease, difficulties may be encountered which prevent some tasks from being performed or from being performed to the desired level [2].

Osteoarthritis (OA) is a degenerative disease of the cartilage of the synovial joints which can cause pain and joint mobility problems [3]. Patients with OA will show signs of cartilage defects on the articulating surfaces, the severity of which will influence the required clinical management [3]. Early stage treatments for OA, such as analgesics, walking aids and lifestyle changes, aim to ease the pain and limit further damage [3]. If degeneration of the cartilage continues, the associated pain and resulting mobility problems can have a serious influence on daily living [2]. When the condition has reached this stage, surgery is a course of action which can be considered, with total hip replacement (THR) and hip resurfacing (RSF) being two of the options [4] (Fig 1.1).

Figure 1.1 Radiograph showing (a) a total hip replacement in situ and (b) a resurfaced hip.

Total hip replacement has been a routine procedure for about 30 years, with 52,964 procedures performed in the financial year 2009-2010 by the National Health Service (NHS) in England and just 5,629 THR revision procedures performed in the same period [5]. This revision rate (approx. 10%) compares well with those quoted in research studies from other European countries [6, 7]. Following the procedure, marked reductions in pain levels are quoted by patients and after some specialist rehabilitation, they can resume an active and healthy life [8-10]. Patient satisfaction with the procedure is reported as being 80% or above [11-13].

In the last 15 years, an alternative to THR has become available. Metal-on-metal hip resurfacing conserves more bone stock than THR by retaining the femoral head and capping it with a metal cap after removal of the diseased cartilage [14, 15]. One of the benefits of this is that the first revision procedure at the end of the components' life can be carried out more easily, compared to a revision of a THR [14]. This has made resurfacing very popular with younger OA patients who are expected to outlive the life of the components [15]. In addition to this, the use of a femoral cap of close to anatomical size is said to more closely replicate the original geometry of the hip joint and, therefore, more closely reproduce the anatomical biomechanics compared to the smaller femoral head sizes generally used in THR procedures [16, 17]. This, in turn, is said to be more conducive to an active lifestyle [18]. The popularity of RSF is evidenced by the rising numbers of such procedures being carried out on a year-to-year basis. In the last ten years the number of RSF procedures performed in England rose from 901 in the reporting period 2000-2001 [19] to 7,798 in the reporting period 2009-2010 [5]. In the reporting period 2009-2010, the number of revision procedures carried out following RSF was 218. This revision rate 2.8% compares favourably to those

quoted for the United Kingdom [20], North America [21] and Australia [22] in the literature.

With each new advance, manufacturers and practitioners alike, require data regarding the *in vivo* function of the implanted component. In modern times, this has increasingly been collected using gait analysis techniques [23]. These techniques have been accepted as a reliable and useful means of determining and comparing gait patterns between individuals or groups of individuals [24-26] as evidenced by the vast amount of published work which use this technique. Gait analysis offers an accurate means of measuring small differences in the movement and loading of the lower limb and as such can be used to determine if different procedures and implant hardware give noticeably different results. Additionally, it allows comparison between patient populations and healthy populations to investigate differences in gait between these two groups at various stages throughout the course of a condition and following a specific intervention.

Previous studies have compared different femoral head sizes [27-31] and THR versus RSF [10, 14, 18, 32-35] using gait analysis and other techniques; however, this has not been performed in a consistent manner. Studies have measured different parameters, using different patient populations and methods, making it difficult to compare the results across studies or to determine the influence of uncontrolled factors. Some results have also been contradictory. Most of the previous gait analysis studies investigating THR or RSF patients have examined patients post-operatively and only limited information is available about patient function prior to surgical intervention [23].

The relatively undemanding nature of level walking has been used to explain contradictory findings or the inability of some studies to find differences between groups; and there have been suggestions that more demanding tasks be investigated [18, 35-37]. Few studies have investigated stair use gait with the hip reconstruction population. There appears to be only one study which compares THR patient with RSF patients [38] and none which have compared different femoral head sizes in THR patients. It is generally considered that rising to a standing position from a seated one, sit-to-stand (STS), is second only to walking in importance among activities of daily living (ADLs) [39-42], however, few studies have used STS to compare the outcome of different hip reconstruction interventions. No studies have been found which have compared STS performance of patient groups with different hip reconstruction implants with a view to determining whether benefits exist.

The aim of this thesis was to determine the influence of THR with a small femoral head, THR with a large femoral head and RSF on patient function before and after surgery using level walking, stair use and STS as the functional task. It is structured in to the following chapters:

Chapter 1: Introduction

This chapter provides a brief rationale for the thesis.

Chapter 2: Literature review

This chapter presents a comprehensive review of the literature in relation to the influence of hip reconstruction on patient function following surgery.

Chapter 3: Method

This chapter give details of the equipment used, the experimental protocol and the participants included in the study.

Chapter 4: Influence of age on gait in the healthy population

The majority of studies investigating the influence of age on level walking gait compare a young group to an old group. Due to the typically younger age of RSF patients, it was important to understand how gait changes across the entire lifespan to allow appropriate comparison of patient gait to that of healthy controls. This first experimental chapter presents gait data for healthy controls ranging in age from 18-75.

Chapter 5: Clinical outcome measures and expectations

It was expected that there would be age and gender differences between the groups and this could lead to differences in levels of everyday function and expectations from surgery. The use of validated orthopaedic outcome measures in this study would give a measure of patient reported function and the use of a self-designed expectations questionnaire would highlight participant perceived disability and what they hoped to achieve from the surgery. These would allow the objective data to be put into context of the patient ability and motivation. This chapter presents outcome and expectation data for the three groups collected immediately prior to surgery and three and twelve months post-operatively.

Chapter 6: Level walking gait analysis

Level walking is an important everyday task and is often used to determine between interventions in the hip reconstruction population. This chapter presents level walking gait data for the three groups collected at the three time points.

Chapter 7: Stair use gait

Stair use is not a necessity for everyday living, although it is a function which many people require to function in their daily life. It is also more demanding than level walking and may highlight differences between the groups which level walking does not. This chapter presents stair use data for the three groups at three time points.

Chapter 8: Sit-to-stand

Sit-to-stand is an important indicator of independence and is a demanding task which hip OA and reconstruction patients have difficulty with. Given its demanding nature it may show differences in function between the groups which less demanding tasks may not. This chapter presents data for the three groups during STS performance at the three time points.

Chapter 9: Conclusions

This final chapter summarises the findings and draws the thesis to a close.

2 Literature Review

2.1 Background

In the UK, OA affects around 8 million people [43]. Early stage treatment will be conservative in nature including education, physiotherapy and analgesics [3]. When the symptoms become severe, however, surgery may be the preferred option [4]. Total hip replacement for OA sufferers is one of the most successful elective surgery procedures currently performed. During the reporting period for 2009-2010, 52,964 THR procedures were performed in England and Wales in the NHS with only 5,629 revision procedures in the same period [5]. Lifespans of the implants are relatively long [6], although there may still be a need for implants to be removed at some point and replaced [44]. These revision procedures are reported to be less successful than the primary procedure [45, 46]. This is a problem for younger OA sufferers who are expected to require at least one revision over their lifetime [17, 47].

An alternative to THR has become available in the last 15 years for younger more active hip reconstruction patients [48, 49]. Metal-on-metal hip RSF conserves more bone stock than THR by retaining the femoral head [14, 17, 32, 47, 49, 50] and capping it with a metal cap after removal of the diseased cartilage [32]. One of the benefits of this procedure is that the first revision procedure at the end of the component's life can be carried out more easily, compared to a revision of a THR [16, 49, 51]. In addition, the use of a femoral cap of close to anatomical size more closely replicates the original geometry of the hip joint and, therefore, is said to more closely reproduce the anatomical biomechanics compared to the smaller femoral head sizes generally used in THR procedures [16, 17, 32, 48-50]. This popularity is evidenced by the rising numbers

of such procedures being carried out on a year-to-year basis. During the reporting period

for 2009-2010, 7,798 RSF procedures were performed [5]. Following RSF and THR

procedures, marked reduction in pain levels are described by patients who, after some

specialist rehabilitation, can resume an active, healthy lifestyle [8-10].

2.2 Hip Reconstruction

Sir John Charnley's work in the 1960's was the catalyst which lead to THR being one

of the most successful of elective surgery procedures [12, 17, 24, 52-56]. From a total of

5,500 procedures being performed by Charnley's group in the first 9 years of modern

THR [57] there are now close to 58,000 procedures being carried out per year in

England and Wales alone [5]. Despite this, however, reports suggest that patients who

have undergone THR exhibit gait deficiencies compared to the healthy population [8,

10, 14, 24, 58-60], even 10 years post-operatively [52]; although, not all researchers

agree as to what these gait deficiencies are [23, 26]. Even within studies where different

study groups have undergone different interventions, there are differences between

groups within the study [25, 54]. There are many possible reasons why these

deficiencies are exhibited. It has been suggested that pre-operative gait, post-operative

implant protection, implant geometry and orientation [24] and operative characteristics

[54] could be involved in the deficiencies identified. Patient reported satisfaction with

the procedure is 80% or better [11-13].

It has been suggested that gait patterns similar to the healthy population are more likely

to be achieved by using larger diameter femoral heads, which are closer in size to the

original anatomy, since the pre-operative biomechanics can be achieved [10, 14, 18, 31-

33, 61]. Early implants used an ultra-high molecular weight polyethylene (UHMWPE)

acetabular component and a metal femoral head [62]. Large heads gave higher values of friction [57] and this has been shown to give greater volumetric wear rates [63, 64] leading to a reduction in the life span of the component, therefore, there was a limitation on the diameter of the femoral head to enable the implants to provide a useful life span.

Small diameter femoral heads, however, have been associated with higher dislocation rates [27, 65] as a result of the geometrical features of the femoral and acetabular component combination [46]. In theory, the incidence of dislocation could be reduced by using larger diameter femoral heads [65]. Small diameter femoral heads have a small ratio between the diameter of the head and that of the neck of the femoral component (head/neck ratio) which will limit the range of motion (ROM) before contact is made between the neck of the femoral component and the acetabular cup [55]. Once contact is made, any further movement against the point of contact could lead to dislocation of the joint. Modelling [46, 66, 67], cadaveric [68] and clinical [27, 65, 69] studies have shown the influence of the head/neck ratio on the ROM of prosthetic hip joints with larger diameter heads providing a greater ROM than smaller sizes. Having a larger femoral head, therefore, could allow a greater ROM which may allow the patients to return to normal gait patterns. This has only been possible in recent years due to advances in material sciences [48].

Over the years since the development of THR techniques, the development of highly cross-linked polyethylene (XLPE) with a greater resistance to wear than UHMWPE [27] allowed the use of larger diameter femoral heads without the associated levels of wear [70]. A further development in the 1990s which also allowed the use of larger femoral heads was the introduction of the metal acetabular cup combined with a metal

femoral head [56]. This allowed the shell of the cup to be much thinner than polyethylene cups [14, 48]. These developments permitted a substantial increase in the diameter of the femoral heads which could be used. While Charnley limited the femoral head diameter to approximately 22mm (7/8"), most manufacturers' current standard range has heads of up to 36mm diameter. In their Magnum M2a metal-on-metal THR system, Biomet (Biomet UK Ltd, Swindon, UK) provide femoral heads up to 60mm diameter.

Developments in hip replacement surgery have lead to it being offered to younger patients than it had previously offered to [24, 56]. This raised several issues; the life span of the implant compared to the expected life span of the patient, and the activity levels of the younger patients and their expectations post-operation [71]. It can generally be expected that younger patients will outlive the implants and will require a revision procedure [17, 47]. The THR revision procedure may cause further damage to the already distressed femur if the components are well fixed [72]. Additionally, the revision procedure is less successful than the primary procedure [45, 46]. Many elderly patients undergoing hip reconstruction surgery are fit and active, although there will be those who are less active. Younger patients are more likely to have an active lifestyle and to be involved in sporting or leisure activities requiring greater performance levels from the prosthetic hip. They are likely to have greater expectations of the outcome of the surgery, perhaps expecting to return to their chosen sport or leisure activity to a higher level than for elderly patients [50, 56, 73].

Hip resurfacing was developed in the late 1990s [48] to meet the demands of patients such as these [18, 56, 71]. This is a bone conserving procedure whereby the majority of

the bone stock on the femur is preserved and a metal cap is fitted over the resected femoral head [48, 50]. Revision surgery of a resurfaced hip can be performed with more ease than that for a primary THR [10, 16, 33, 48], which should lead to a better outcome compared to revision of a THR. As the cap used in the resurfacing procedure has a diameter closer to the anatomical femoral head compared to the diameter range generally available for femoral heads used in THR, the geometry and biomechanics of the reconstructed joint should be similar to those of the original joint [50, 71]. Additionally, the use of a large diameter head should provide a large ROM [18, 48] due to the larger head/neck ratio. These could enable the patient to achieve the gait abilities of the healthy population [14, 18, 33, 48]. Choice of patient is important, however, as metal on metal implants are not suitable for everyone. As a result, resurfacing accounts for around 10% of all hip reconstruction procedures [48].

2.3   Gait Analysis Studies – Walking

Advances in THR and RSF technology continue to be made and manufacturers, practitioners and patients require data regarding the validity and reliability of the implant components. In recent times, such data has increasingly been collected using gait analysis techniques [23]. These techniques have long been recognised as a reliable and accurate means of determining and comparing gait patterns between individuals or groups of individuals [24-26]. Patient satisfaction and orthopaedic scores have their place, however gait analysis allows investigators to highlight small discrepancies in the joint angles, loadings which are out of the normal range and signs of improvement in function in THR patients.

Gait analysis is a technique whereby accurate objective data regarding spatiotemporal, kinematic and kinetic parameters can be collected during walking and other dynamic activities [74]. Much useful data has been collected in cadaveric and simulation studies, however, these are artificial, whereas gait analysis studies can provide data on the performance of hip implants as the patient carries out tasks in the environment, and under conditions for which the replacements were designed [26]. The data produced from such studies have been vital to the progress of hip implant technology [24]. Using gait analysis techniques, it is possible to highlight small discrepancies in the joint angles and loadings which are out of the normal range or signs of improvement in function of THR or hip resurfacing patients over the course of the rehabilitation process.

A number of studies have evaluated gait in the hip reconstruction population using these techniques; however, they have not been performed in a consistent manner. Studies have measured different gait parameters, using different patient populations, aims of the study and differing methodologies, making it difficult to compare the results across studies [23]. As part of this study, a review was carried out to identify areas of consensus within the community regarding methodologies and expected gait deficiencies following THR. The review aimed to address these issues by identifying studies which have used gait analysis to determine and compare post operative gait of THR patients with that of a healthy control.

To enable meaningful comparisons between studies, a set of inclusion criteria were decided upon. It is reported that by six months post-operation the majority of gait rehabilitation has been achieved [60], therefore, it was decided only to include studies which performed gait analysis at least six months post-operatively to ensure that a

suitable level of rehabilitation had been achieved. Due to the differences in the methods used and possible inconsistencies in data collection techniques between investigators, only studies which compared a patient group to a control group were accepted for inclusion. Only studies where OA was the primary indication for surgery in the majority of cases were included to avoid possible confounding factors arising from complications due to other conditions which could necessitate THR surgery. There is divided opinion as to whether gait velocity during testing should be controlled or not [75], since velocity influences gait patterns. It was decided, therefore, that included studies should report kinematic or kinetic data which were collected simultaneously with spatiotemporal data, to allow valid comparisons between studies.

Following an extensive search in June 2009 of The Cochrane Library, CINAHL, ProQuest and PubMed, 2398 studies were identified for further investigation. Removal of duplicates and irrelevant studies left 99 studies which required more detailed investigation. After reading the abstracts of these 99 studies a further 42 studies were rejected and full text papers of the remaining 57 studies were obtained. Of these 57, eight studies were identified which met the inclusion criteria [8-10, 14, 25, 52, 59, 60]. Following a review of the references of these papers, one additional study which met the inclusion criteria was discovered [54] giving a total of nine papers included in the review.

All of the studies collected spatiotemporal, kinematic and kinetic data with the exception of Bennett et al. [52] which did not collect kinetic data and Loizeau et al. [59] which did not collect kinematic data. Across the nine studies, 57 different parameters were reported (11 spatiotemporal, 21 kinematic, 25 kinetic). No single parameter was

reported by all of the studies and most of the parameters (49) were reported by just one or two studies. In order to determine whether there was agreement in the effects on gait of THR, only those parameters that were reported by at least three studies were investigated in more detail.

Walking Velocity

Seven of the studies [9, 10, 25, 52, 54, 59, 60] asked the participants to walk at their self selected normal pace and one study [14] did not specify what instructions were given. In the remaining study [8] the participants were asked to walk at a self selected natural speed, but also at self selected slower and faster speeds. Irrespective of whether it was a slow, normal or fast trial, the trial closest to 1m/s was selected for analysis. Two studies [8, 25] did not report their patients' walking velocity. This is understandable since one [8] controlled walking pace and the other [25] stated that all "subjects" walked at approximately 1m/s. Of those that did report this parameter, four [14, 52, 59, 60] reported values for their patient group which were significantly lower than that for their control group. Across the studies, the mean velocity for the patient and control groups ranged from 0.707-1.31m/s and 0.895-1.34m/s, respectively.

Cadence

Only three studies reported walking cadence [52, 54, 60]. These ranged between 109.1-115.2 steps/min in the patient group and 112.8-117.2 steps/min for the controls. Madsen et al. [54] found that patients had a higher cadence than the control group, but this was not significant. Only Perron et al. [60] found a significant difference in cadence.

Stride Length

Stride length ranged from 0.87m-1.28m. The upper value is the same as the mean for the control groups across the studies (range of values for controls; 1.156-1.37m). Six studies reported this parameter [10, 25, 52, 54, 59, 60]. All six studies found that patients had a shorter stride length than controls. Four of the studies [25, 52, 59, 60] reported a significant reduction in stride length, although Hodge et al. [25] reported that a second patient group (a valgus group) had the same stride length as the control group.

Stance Phase Duration

Three studies reported stance phase duration [9, 52, 59]. No significant difference was reported by Bennett et al. [52], Loizeau et al. [59] reported a significant increase and Götze et al. [9] stated that a significant difference was found, but it was not possible to determine whether this was an increase or decrease in duration from the data provided. Loizeau et al. [59] reported longer stance phase durations for both the patient and control groups than the other studies.

Hip Flexion/Extension Kinematics

Three studies [9, 52, 54] reported similar hip flexion/extension angles for the control group (around 46º) and similar patient group values (30.4º-39.9º). Two of these studies [52, 54] reported these reductions as significant, the other study did not comment on significance. Two other studies [8, 25] reported this parameter, but did so graphically, finding lower values of hip ROM in the sagittal plane for the controls (≈30º and ≈.40º respectively) and significantly lower values for the patient group (≈ 25º for both).

Hip Flexion/Extension Kinetics

Only Mont et al. [14] presented values for hip flexion/extension peak moment. The other studies which reported this parameter did so graphically [8, 10, 25, 60]. All of these studies normalised the data for body mass; however, two studies [8, 25] also normalised the data for height. There was no consensus between these two studies as to what constituted normal peaks for flexion and extension moment. Nor did they report similar values for the patient groups. There was more similarity in both control and patient peak values shown in the other three studies [10, 14, 60]. Mont et al. [14] gave values of peak extension moment for each subject (range 0.348-1.172Nm/kg) and this wide range encompassed the values reported in the other two studies [10, 60]. It also encompassed the values given for the controls. Hodge et al. [25] found significant differences in the peak flexion and peak extension moments between the control group and one of their patient groups (a varus group).

Hip Abduction/Adduction Kinetics

Five studies reported on the peak hip abduction and adduction moments [8-10, 14, 25, 60]. Only Mont et al. [14] reported values for their findings, two [9, 25] gave no values at all and two [8, 60] presented their results graphically. Foucher et al. [8] normalised the data for subject height and mass and in Perron et al. [60], the scale of the graph was too small to extract meaningful data. As a result, only two studies [8, 14] allowed values to be extracted, however, these were given in incompatible units (%BW*height and Nm/kg) so could not be compared.

Three of the studies [8, 14, 60] reported significant reductions in this parameter compared to control data. Götze et al. [9] reported a reduction, but made no comment on

the significance and Hodge et al. [25] found no differences. Of the three studies which noted significant differences, two [14, 60] noted differences only in the peak abduction moment, while the other study [8] found a significant difference only in the peak adduction moment.

Based upon the studies reviewed here, it is clear that gait adaptations do occur following THR. Patients are likely to walk with a slower velocity [14, 52, 59, 60] with a shorter stride length [25, 52, 59, 60] than healthy individuals of the same age.

Patients may also show reduced range of hip flexion/extension compared to the healthy population [8, 25, 52, 54] although this can be influenced by the implant orientation [25] or the approach used [54]. All five studies which reported hip flexion/extension range agreed that the patient group had a reduced range compared to the controls [8, 9, 25, 52, 54], although one did not state the significance level [9]. Two of these studies [25, 54], however, had two patient groups that were given different interventions, finding that only one of their patient groups walked with a reduced range of hip flexion/extension. Madsen et al. [54] investigated the effects of two different surgical approaches, the anterolateral (A-L) and the posterolateral (P-L). Their findings showed the P-L group to have a normal range of hip flexion/extension while the A-L group had a significantly lower range. Similarly, Hodge et al. [25] found that their valgus group had normal hip flexion/extension ranges; whereas, those in the varus group showed a significant reduction.

It is also likely that THR patients will exhibit a reduced peak value for the hip abduction moment [14, 60] than that of the healthy population. Four studies [8, 9, 14, 60] found a

reduction in the peak values of the hip abduction/adduction moment, with three of these reductions being significant [8, 14, 60] compared to the controls. Two of these, however, found only the hip abduction moment to be reduced [14, 60], while the remaining one found only the hip adduction moment to be reduced [8].

Two of the parameters which have been discussed here are related; having a reduced range of hip flexion/extension could cause a reduction in the stride length [8, 9, 25, 52, 54]. One of the aims of hip reconstruction is to achieve as much of the ROM in all three planes as would be expected from a healthy hip. Walking does not utilise the full range of hip flexion, however, THR patients may have a ROM in the sagittal plane which is lower than what is required for healthy walking [8, 9, 25, 52, 54]. This could be due to pain [52], muscle weakness [54, 76], un-recovered soft tissue damage [54] or a physical barrier to further movement, (e.g. impingement) [55], and these will each be addressed below.

Level of pain is often recorded using clinical outcome measures. Unfortunately, only two of the studies which found a significant reduction in the range of hip flexion/extension or stride length also reported clinical scores (Harris Hip Scores (HHS)) [77] that contained an element related to pain. Neither study, however, reported scores specific to the pain element of the measure. Götze et al. [9] presented individual elements of the HHS as well as reporting a reduced hip ROM (although the significance was not stated). They tested their patient groups before and after the procedure and found that both groups experienced an increase in score for the pain element, from 8.7 (+/- 5.1) to 38.9 (+/- 8.9) for one group and from 10 (+/- 8.2) to 42.1 (+/- 1.9). This result suggests that these patients experienced little or no pain at about four years

following surgery. Given that Bennett et al. [52] tested patients around ten years post-surgery, pain would not be expected to be a problem for these patients, yet they still showed a reduced hip flexion/extension range and a reduced stride length.

Osteoarthritis is a progressive disease for many sufferers [78-80] with associated reduced lower limb function [78, 80, 81] and levels of activity [82] compared to the healthy population. There is evidence to suggest that end stage sufferers of hip OA exhibit significant muscle atrophy and weakness compared to the healthy population [83] and the unaffected limb [54, 76, 84]. Given the evidence and no indication of pre-op activity levels or lower limb function in the studies reviewed, some degree of muscle weakness could be present in the study participants prior to surgery.

Muscle weakness could be responsible for the observed reduction in stride length and hip flexion/extension given the association between OA and gluteus maximus atrophy, and its role in hip extension [76]. Studies have shown significant improvements in muscle strength following THR at 24 weeks [85] and at one year [86] although around 20% below values exhibited by the unaffected limb. Even at two years post-surgery there is evidence of muscle weakness compared to the unaffected side [87].

There are two factors which could lead to a reduction in the peak abduction/adduction moments at the hip. One of these is muscle strength, which has been discussed previously and linked to soft tissue damage [54]. The second is the perpendicular distance between the point of action of the abduction force and the centre of rotation of the hip. This is not the femoral offset, although the two are connected. There is still some disagreement as to whether restoring the original anatomical geometry during

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surgery leads to closer to normal gait pattern [88, 89]. If the geometry has been altered such that the femoral offset is much smaller than in the original anatomy, as is the case for smaller head sizes, then a situation will arise where more force is needed to produce the peak abduction moment found in the control group. Two studies reported that their patient groups exhibited a reduced hip abduction moment [14, 60]. Mont et al. [14] gave full details of pre and post-operative femoral offsets. They reported that their patient group had similar pre-operative and post-operative femoral offsets. This would suggest that the reduction was due to a muscle deficiency.

Gait analysis in which kinematic, kinetic and spatiotemporal data are collected can provide researchers with a vast number of parameters that can be analysed, however, this review has highlighted a possible lack of focus given that 57 parameters were investigated over the nine studies reviewed with half of those giving no significant differences between patient and control groups and 34 parameters were reported by fewer than three studies. Three dimensional computerised gait analysis has been performed on hip reconstruction patients for many years, however there still seems to be much time spent investigating parameters which seem little affected by hip reconstruction.

One of the most commonly overlooked confounds is the time between the operation and the gait analysis data collection. There was a vast range of operation to testing periods, ranging from six months to ten years. Only Foucher et al. [8] performed pre-operative gait analyses to show within patient improvement. According to previous authors, rehabilitation follows an inverse exponential pattern with the majority of recovery taking place within the first six months post-operatively [10, 32, 60, 90-92]. There

seems to be general agreement within the community that 12 months post-operation is a likely end point of further recovery [93], therefore, the results obtained from the gait analysis may vary depending on the time after surgery. Many research studies have used six months as the minimum post-operative period before testing.

The benefits and detriments of the lateral and posterior approaches is a common topic for research with the posterior approach believed to cause less hip abductor muscle damage [94, 95]. This should allow for improved post-operative gait compared to the lateral approach, particularly in hip abduction [54, 94-96]. For an issue which could influence gait, there were variations in how it was addressed. Four of the studies [9, 25, 59, 60] did not specify which approach was used and another had a group which included both approaches [8]. In order for results to be meaningful, researchers must restrict inclusion to a single approach and specify the approach used.

Following THR, differences in gait of the patients compared to controls were found in walking velocity [14, 52, 59, 60], stride length [25, 52, 59, 60], range of hip flexion/extension [8, 25, 52, 54] and peak abduction moment [14, 60]. Control of confounding factors such as surgical approach and number of surgeons varied over the studies and these could produce conflicting results and an inability to state with confidence what features contributed to the observed gait adaptations [23]. There is also the suggestion that researchers in this field may not fully understand what differences from the norm should be expected following THR, given the large number of parameters investigated by one or two studies.

2.4 Gait Analysis Studies - Stair Use

Stair use is a hazardous activity with reports that it accounts for over 10% of all fatal falls [97]. Stair use is also more demanding than level walking and requires greater moments applied across the hip joint, with descent being the more demanding of the two [98-100]. Stair descent is more functionally demanding than stair ascent, requiring greater joint ROM and balance control [101, 102], however, it is likely that the greater demand is due to stair descent requiring eccentric loading compared to the concentric loading required in stair ascent. It has been reported that demand on the muscles reaches isometric capacity during stair ascent, but that it exceeds it during stair descent [99]. Given the additional burden of stair use compared to level walking, it is no surprise that the elderly population report stair use as a difficult activity [103]. A previous study reported that 57% of OA sufferers reported difficulties with stair ascent, while 54% reported difficulties with stair descent [103]. The elderly (65 years and above) account for 66% of all primary THR patients and in 90% of these patients, THR procedures are performed with OA as the primary indicator [104]. The additional disability brought about by OA on a population which already has difficulty with stair use can only exacerbate the problem.

Stair use may not be a vital activity for some OA sufferers, but for others it may be a major concern; especially as they may have to cope with the condition for a number of years before hip reconstruction is performed [3, 105, 106]. The importance of stair use, however was shown in one study of 31 THR patients which reported that during a 24 hour period they climbed 344 steps, representing about 4% of the time spent walking [107]. Further evidence of the difficulties with stair negotiation for sufferers of OA is reflected by its inclusion in all of the major hip related OA orthopaedic questionnaires;

including the Oxford Hip Score (OHS) [108], HHS [77], Western Ontario & McMaster Universities Arthritis Index (WOMAC) [109], Hip Disability & Osteoarthritis Outcome Score [110], Iowa Hip Score [111] and Mayo Hip Score [112].

Andriacchi et al. [98] performed one of the first studies to investigate the biomechanics of stair ascent and descent in which they defined the ROM for the hip, knee and ankle joints. They also presented joint forces and moments, finding that during stair descent joint moments were higher than during ascent, with the knee showing the greatest increase in moment compared to level walking. They also presented data collected while ascending and descending the stairs while using a handrail on the left side of the staircase. They found no significant differences in joint moments between the handrail and no handrail conditions, although there were generally lower values at the hip joint in the sagittal plane when the handrail was used. There were some flaws in the methods of this study which could have had an influence on the results. The handrail was not instrumented and thus there is no measure of how much of the load was taken by the handrails. Despite not being stated, it appears that the data collected while ascending the staircase were from the right limb and from the left while descending. Given that there may be a bias for one side or another, it cannot be assumed that left and right limbs would be comparable [113]. Kinetic data were collected from the bottom step; however, participants did not make foot contact with the force plate directly. Instead, a section of the step was separate from the remainder and was in contact with a force plate embedded in the floor. No detail was given as to whether the step section was free to move relative to the force plate as this could be a potential source of error. Their participant group was healthy and younger (20-34 years) than the typical OA patient which means that the data are not directly comparable to an older or an unhealthy

population, however, they did present data comparing ascending or descending from one step to another to ascending from the floor to the first step and descending from the last step to the floor. They found that the joint moments were lower when descending from a step to the floor compared to descending from one step to another as both feet end up at the same level. From this they suggested that patients, such as those with OA, can make significant reductions in the joint moments by descending stairs in a step-by-step (SbS) fashion where both feet are brought onto each step.

Kirkwood et al. [114] investigated stair ascent and descent in a healthy participant group with an age range (55-75 years) more akin to the typical OA patient population. They reported lower hip joint moments than the younger participants in the study by Andriacchi et al. [98], however, several of the parameters from the Kirkwood et al. [114] study had much lower values than would be expected in comparison to those quoted by Andriacchi et al. [98]. Participants in the study by Kirkwood et al. [114] wore running shoes during data collection although it was not stated whether these were the participants' own or standardised footwear supplied for testing. Footwear use could have an influence on gait kinematics and kinetics [115-117]. In addition, not all of the participants performed the stair ascent and descent tasks. Due to the large bank of tests included in the study, participants only performed level walking and another three or four tasks from a bank of 13 tasks which included stair ascent and descent. Only eight of the 30 participants, therefore, performed the stair descent task and the authors did not give demographic data for each of the sub-groups. Another problem with the comparison was that different units were used by the two studies. The mean group body mass reported by Andriacchi et al. [98] was used to estimate normalised data to allow it to be compared to that from the Kirkwood et al. [114] study, however, this estimation

would not account for some of the large differences observed. Full details of the stairs used were not given, although the step height (riser) was similar to that used in the Andriacchi et al. [98] study, nor was the matter of handrails raised. Given that the age range of the participants had an upper limit of 75 years, it could be possible that some of the participants required the use of the handrails to negotiate the stairs. Additionally, this was not a study into the biomechanics of stair use, but rather an investigation into tasks which could generate the required load to encourage bone growth. If one or two handrails were used to aid ascent and descent, this could remove much of the load on the lower limbs, resulting in the data presented. Another reason for wariness of the results from the Kirkwood et al. [114] study is that while Andriacchi et al. [98] reported hip flexion moments for stair ascent which were similar to those for level walking and 1½ times greater for stair descent compared to level walking, Kirkwood et al. [114] reported significantly lower hip flexion moments for stair ascent and descent compared to level walking.

One of the first studies to compare stair use biomechanics of the THR population with the healthy population determined the hip joint contact forces [118]. Three groups of participants had data collected during stair ascent and descent. They were an all male THR group, a healthy male control group and a healthy female control group all between the ages of 40 and 60. The mean post-operative time for the THR group was around 18 months. There were two limitations with this study; the participants wore their own choice of flat-soled shoes and the small group sizes (two groups of five and a group of six), however, they identified the pattern of hip joint contact as generally having two peaks occurring at about 20% and 80% of the stance phase during stair ascent and descent. With few exceptions, they found that the magnitude of these peaks

was larger for both of the healthy groups compared to the THR group, although only one result was significant. They did find, however, that the THR group had a significantly reduced cadence for stair ascent and descent compared to both of the healthy control groups. They concluded that the lower joint loading and the reduced cadence are directly connected.

A later study investigated stair climbing biomechanics of the THR population from the point of view of the forces subjected upon the implant during the task [119]. Interestingly, this study attempted to collect data pre-operatively but was presented with the problem that the majority of their patient group were unable to perform stair ascent. They also experienced a similar dilemma one year post-operatively. Twenty- eight patients were recruited into the study, but only 15 could perform stair ascent one year after surgery. This group of 15 constituted the study group in addition to a group of 15 control participants. A limitation in the study was the diversity of the study group. Two different implants (6 cemented and 9 uncemented) were used in the patient group and the homogeneity of the group was further diluted by two different approaches being used (10 posterior and 5 lateral). From the figures quoted it can be seen that the implant types and approach used are also intermixed. There may be little difference in performance between the implants, but it has been well reported that the posterior approach causes less damage to the hip abductor muscles and could lead to better hip abduction function post-operatively [54, 94, 95, 120]. Having a study group where more than one approach was used is likely to introduce a confounding factor into the results, especially when reporting hip frontal plane moment data. They suggested that abductor muscle weakness could be the reason for two of their significant findings, reduced hip adduction and external rotation moments compared to the control group. The limitation

suggested may not have been present had there not been five patients who had surgery by the lateral approach which requires splitting the gluteus medius [121] and could reduce hip abductor function [120]. They also noted a significant increase in the hip extension moment which they also suggested could be a result of hip abductor weakness, although they did present data confirming this.

Studies have compared hip resurfacing with total hip replacement during level walking using modern motion analysis techniques [10, 14, 18, 32-35], although few studies using similar techniques have compared the stair negotiation abilities of patients with these two forms of hip reconstruction. The first such study appears to be a 2009 study by Shrader et al. [35]. Testing was carried out three months post-operatively, which most experts would agree is not long enough to expect the participants to be sufficiently rehabilitated [93]. Data were collected pre-operatively, although no pre-operative data were reported for stair negotiation, only for level walking and clinical outcome scores. No comment was made regarding this omission, although it could be speculated that the patient groups were unable to perform the tasks. Neither was any comment made about post-operative ability to perform the tasks, however, it must be assumed that all 14 patient participants were able to perform the task in the step-over-step (SoS) manner required by the protocol. This is contrary to what would be expected given that age itself is a factor which could limit a person's ability to negotiate stairs in addition to the adverse effects of OA and surgery [103]. There was a notable gender difference between the control group (1m, 6f) and the patient groups, particularly the RSF group (5m, 2f). There are known differences in level walking gait parameters between healthy males and females [122, 123], but no study which compared males and females during stair negotiation was found. Higher joint contact forces have been identified in females

compared to males during stair negotiation [118] and another study noted gender differences in kinematic and kinetic parameters during stair ascent and descent [99], however, Shrader et al. [35] did conclude that hip resurfacing patients were able to perform stair negotiation with closer to normal biomechanics compared to those who had a 36mm femoral head THR procedure, although they did conceded that the study lacked statistical power.

Two further conference presentations were located which compared hip resurfacing and THR during stair negotiation [37, 38]. Like Shrader et al. [35], Wells et al. [38] had small group sizes (14 participants in two study groups). The other study by Wells et al. [37] had slightly more participants (20 participants in two groups). Neither of these studies compared the two patient groups to a control group and only Wells et al. [38] specified the post-operative time (3 months). The belief is that the larger sized head used in the resurfacing procedure would result in benefits in function, however, this was not shown by Wells et al. [37]; whereas Wells et al. [38] suggested that resurfaced hip may perform slightly better.

Lamontagne et al. [105] and Lamontagne et al. [124] are the highest quality studies found which have investigated stair use biomechanics of the hip reconstruction population. Lamontagne et al. [124] compared lower limb biomechanics between THR patients and a control group. Lamontagne et al. [105] compared stair negotiation abilities between two groups of THR patients who had hip reconstruction procedure by two different approaches. Both of these studies had study groups of 20 participants each which would likely give the study sufficient statistical power. Participants were tested at a post-operative period long enough for sufficient rehabilitation to have

occurred, although there were a wide range of post-operative times. The main finding from these studies was that THR patients did not achieve normal lower limb joint biomechanics in either the operated or non-operated limb during stair ascent or descent following surgery [105, 124]. During stair ascent, they found deficiencies to be more prevalent at the hip. This included lower support moments and reduced hip power generated. During stair descent, they also reported lower support moments and reduced hip flexion. There was also a suggestion that those operated on with the anterior approach had a better stair climbing outcome than those operated on with the direct lateral approach [105].

No other studies were found which compared stair negotiation biomechanics between hip resurfacing and THR post-operatively and only two others which have investigated stair negotiation biomechanics for any hip reconstruction procedure post-operatively [125, 126]. Considering the reported importance of stair negotiation [107], it would be expected that more studies would have been performed. The evidence presented here points to stair negotiation as being an important activity and one which is a cause for concern for the OA population, however, few studies have investigated stair use in this population using modern gait analysis methods and fewer have used stair negotiation to compare THR with resurfacing.

2.5 Sit-To-Stand

Sit-to-stand (STS) is a transition to an upright position during which the centre of mass (CoM) moves from a stable position to a more unstable one, supported by the lower limbs in an extended posture [127]. This is a complex [128] and demanding [129]

activity requiring movements of many body segments in order to accomplish it [128]. Rising to a standing position involves displacing the body centre of mass anteriorly and upwards [128] against gravity [130]. These movements must be performed in the correct sequence and to the correct degree [128].

The STS movement is initiated when the hips are flexed to produce forward rotation of the pelvis and trunk initially [131]. This generates momentum in the upper body which contributes to the anterior and upward motion [130-132]. Following this, the knees and hips extend to continue the upward motion until steady standing is achieved [131].

Sit-to-stand is one of the most important activities of daily living (ADLs) [40, 128, 132-134]. It is often performed prior to walking [128, 130, 132, 134] and is performed many times per day [39, 130, 134]. The ability to rise from a sitting position is seen as being of such importance that it is used as an indicator of functional independence and is a known risk factor for falls [40, 128-130, 134]. Despite requiring similar patterns of movement, returning to a sitting position from standing it is not regarded as being as demanding since it has been shown that individuals who are unable to perform STS are capable of returning to a sitting position [130]. Part of the reason could be due to gravity, as the stand-to-sit is performed with the aid of gravity while the STS task works against gravity [130]. It has been reported that elderly persons have hesitancy in beginning the stand-to-sit action. Once initiated, the descent is swift, but with little control, although it is rarely a danger [130].

As we age our ability to perform the STS task reduces due to the demands of the task [129]. This difficulty has been reported to be due to muscle weakness or atrophy [128, 129, 135]. Since these are also traits which affect the hip OA and reconstruction

populations [54, 84] it is not unexpected that similar difficulties in performing STS are found in this population [136, 137]. Despite STS being more demanding than level walking and the suggestion that more demanding tasks be used to compare different interventions in the hip reconstruction population [37], it is seldom used in research with this population. This could be due to a number of issues. These include there being no commonly used protocol, the variation in performance of the task both within and between individuals [132, 134] and the different equipment used. Differences in protocol used have involved chair design [45, 129, 138, 139], arm involvement (e.g. as normally used [140], discouraged [141], on waist [45] and across chest [139]), starting position (e.g. no restriction [142], ankles below knees [45], shank at 20° to the vertical [139], 90° hip and knee angle [140]) and the start and end points of the task [128, 131, 132].

Previous work has shown the link between the height of a seat and the ease of rising to a standing position from it [134]. When the seat is too low relative to the lower limb length the task becomes very difficult or impossible to perform [134]. The increased flexion of the hips and knees requires greater moments at these joints for successful completion [143]. Another study reported that a higher seat produced lower vertical GRFs compared to a lower seat [41], however, this study would have been more meaningful had each participant been tested on a seat of optimal, higher and lower heights rather than all been test at the same three height. Armrests are not only an issue of chair design, but of how the arms are dealt with. When no kinetic data are being collected, it may be acceptable to allow the use of the armrests [144], but there will be a contribution when kinetic data is being collected which will reduce the contribution from the lower extremities [145]. If the arms are allowed to move freely the position of the CoM can be altered [146] and could contribute to the momentum generated [132,

146]. When armrests are not used, therefore, the arms have to be kept stationary in a position which will not aid the STS task. This should exclude placing the hands on the knees, it is possible for the arms to aid the STS task [132, 142].

It has been reported that initial foot position has an influence the performance of the STS task [41, 143, 147]. Farquhar et al. [143] reported that hip extensor moments were reduced when individuals are allowed to choose their preferred initial foot positions compared to when the position was constrained to give 90º of knee flexion. Gillette et al. [147] and Kawagoe et al. [41] both reported that when the feet were placed in a posterior position the STS task was less demanding, however, researchers still constrain the position of the feet as a means of limiting performance variations. This is also the case with arm use. It is normal for people, both young and old, to use arm assistance during STS when available [148] and this will change the contribution of the lower limbs [145], but researchers will often constrain the involvement of the arms to limit variation. Data can be collected from the armrests regarding the contribution of the upper extremities, but if the aim of the study is to investigate the kinetics of the lower limbs, then the protocol should ensure the minimum contribution from the upper extremities.

The basic requirements for investigating STS are similar to those for level walking gait analysis, a motion capture system and force plates, although different setups with additional equipment may be required and this could preclude some researchers from being able to analyse the task. Some studies have used a single force plate to collect GRF data [132, 138, 149], although two are required if separate data are desired from each limb. Requiring two force plates may not be a limiting factor in itself, however, they must be side-by-side which may not be the case in many gait laboratories.

Additionally, in some protocols which have been used, an additional force plate is required on or beneath the seat to detect the seat-off event [138, 140, 145, 150, 151]. Simpler protocols use a switch or sensor to detect the seat off event [139]. It is possible to carry out analysis of STS without the equipment described, but there will be limits on the data which can be collected. The aims of the study, however, will determine the nature of the equipment which would be required.

To rise from a chair requires adequate strength in the muscles, range of joint motion and balance ability [40, 128, 136]. As we age we lose strength and balance and this makes performance of the STS task more difficult [128, 135]. Since muscle weakness and atrophy are likely to be features also present in the hip OA and reconstruction population [54, 76, 84], in addition to pain [3, 52], it can be supposed that such patients will also have difficulties performing STS both before and for some time after hip reconstruction surgery. Little research has been carried out with the hip reconstruction population performing STS, although it has been reported that it is demanding for those with a physical impairments in general [136, 137]. Joint replacement patients may have difficulty with the STS task, although they may still be able to perform it by off-loading the affected limb, however, this would place more stress on the unaffected side and in the long term this could increase the risk of that limb suffering the same fate [143].

Few studies appear to have investigated STS with the hip reconstruction population using movement analysis techniques. Those which have, investigated the effects of a training programme on the kinematics of THR patients [141], loading symmetry following THR [139] and loading symmetry differences between THR and hip revision [45].

In the study by Talis et al. [139], a group of THR patients performed STS from a height adjusted seat. Kinetic data were collected from two force plates, one foot being placed on each. A contact switch on the seat was used to indicate the point when the buttocks left contact with the seat. The arms were folded across the chest and the feet were positioned with the heels 10cm apart and the shanks at an angle from the vertical of 20º. They found that the THR group showed a significantly greater asymmetry than the control group, and that this asymmetry off-loaded the operated limb. These patients were on average 19 months post-operation.

The other study which investigated loading symmetry [45] was performed in a similar manner to the Talis et al. [139] study. The chair was adjusted to achieve a knee flexion angle of 90º and the ankles were positioned directly below the knees. Participants were instructed to place their arms at their waist and not to use them during the task. Each foot was positioned on a separate force plate for the collection of kinetic data. The study had no control group so it is not possible to know how the performance of the two groups compared to the healthy population, however, they found no difference in the loading symmetry between the primary THR group and a revision THR group. This study [139] found a greater degree of asymmetry (78.1%) than the Boonstra et al. [45] study (83%), however, the formula used to determine loading symmetry was not stated by Talis et al. [139] and may not have been the same as that used by Boonstra et al. [45].

It is clear that there is scope for further work in STS with the hip reconstruction population. Considering the range of interventions which are available to hip

reconstruction surgeons it would be useful to know how they influence one of the most important ADLs.

2.6 Conclusions

This review has found that much research has been carried out with the hip reconstruction population using modern motion analysis techniques. Most of this has involved level walking, with only a small number investigating higher demand tasks such as stair use and STS. Those studies which have investigated biomechanical differences between patients with different sizes of femoral head or RSF have found conflicting results and this could be as a result of different protocols being used.

Previous studies which have compared THR patients with controls have agreed that patients are likely to walk more slowly and with a shorter stride length than healthy individuals. They are also likely to use a reduced range of hip flexion/extension and have a reduced peak value for the hip abduction moment. Studies which have compared RSF to THR have suggested that RSF patients exhibit larger flexor and abductor moments compared to THR patients. Other studies have compared large diameter femoral heads with RSF and some have suggested that no noticeable differences are present, and that patients with both interventions exhibit close to normal gait biomechanics. Other studies, however, have observed better performance in hip range of motion for RSF compared to patients with a large headed THR.

There have been few studies which have used stair use to compare different hip reconstruction interventions. Differences in hip flexion and abduction moments were suggested between RSF and THR, with the RSF fairing slightly better. Reduced

cadence, lower joint contact forces, reduced hip abduction moment and reduced external rotation moment have been reported in THR patients compared to controls. During stair descent lower support moments and reduced hip flexion have also been reported.

There have only been a few studies which have investigated STS in the hip reconstruction population, however, it has been reported in one study that THR patients off-load the operated limb resulting in loading asymmetry compared to controls, although no difference has been found between THR and RSF in another study. Previous studies have performed biomechanical analyses comparing RSF to large and small head THR during level walking, although studies of stair use and STS are few in number. In addition, many of these studies have failed to adequately control possible confounding factors. As a result, studies have reported contradictory findings.

This thesis aims to perform a three-way comparison between RSF, large diameter femoral head THR and small diameter femoral head THR during level walking, stair descent and STS using a protocol with few confounding factors in an attempt to clarify whether the claims of better performance with RSF or large head THR are justified.

3 Materials & Method

3.1 Preliminary Work

This study was carried out at Northumbria University (the "university") in collaboration with the Gateshead Health NHS Foundation Trust (the "trust"). The healthcare of all patients was provided by the staff of the Orthopaedics and Trauma department of the trust. All of the surgical procedures were performed by one of two experienced surgeons at the North East Surgery Centre of the Queen Elizabeth Hospital in Gateshead (QEH).

Prior to carrying out the study, ethical approval was sought and granted by the Newcastle & North Tyneside 1 Research Ethics Committee. Approval from the Research & Development Department of the trust was also sought and granted for the study. Within the university, the School of Life Sciences Ethics Committee were informed that the study was subject to NHS ethical approval and the notification of approval was submitted to the committee when granted prior to the study commencing. A risk assessment for all laboratory testing was carried out by the author and this was approved by the trust Risk Manager. To support the studies, normal control data were required for comparison to the patient data. It was decided to recruit these participants through the university. Since this did not involve NHS staff, patients or premises, it was not subject to NHS ethical approval and ethical approval for the collection of control data was sought and granted through the university.

3.2 Equipment

<u>General laboratory set-up</u>

All gait analysis testing took place in the Gait Laboratory within Sports Central at Northumbria University in Newcastle upon Tyne. This laboratory is a purpose designed and built lab for collecting movement data in the clinical and sport sciences domains (Figure 3.1).

Figure 3.1 The Gait Laboratory at Northumbria University showing the general layout.

To ensure patient confidentiality and privacy, the internal laboratory windows had Venetian blinds and curtains which could be closed during participant testing. It also had one external window which had a blind which was lowered for privacy and to prevent external light from interfering with the data during testing. Entry to the laboratory was via a radio frequency identification (RFID) card which only authorised

persons are issued with. As a further aid to privacy, signs stating that participant testing was underway were placed on the door and over the RFID card reader.

Two mounting rails (diameter = 50mm) ran around perimeter of the laboratory at 275mm and 2500mm from the floor. Additional camera mounting rails were suspended from the ceiling. Ten vertical poles (diameter = 50mm) with clamps could be positioned anywhere around the perimeter of the laboratory and attached, top and bottom, to the two perimeter rails. Cameras could be attached onto these vertical poles as well as directly to the perimeter rails and to the additional ceiling mounted rails. A pit in the floor of the laboratory, capable of housing up to six force plates, was located centrally in the laboratory. These features gave the laboratory great flexibility for the collection of numerous different types of movement data.

Kinematic Data Collection Equipment

Kinematic data were collected using a Vicon MX optical motion tracking system (Vicon Motion Systems, Oxford, UK) with 12 T20 T-Series near-infrared cameras positioned around a 7m level walkway and a staircase (Fig 3.2). These were connected to two Vicon MX Giganet core processor units which were in turn connected to a Dell Precision T7500 workstation (Dell UK, Bracknell, UK) running the Microsoft XP Professional operating system (Microsoft Corp., Redmond, WA) and Vicon Nexus version 1.7 software. The T20 cameras had a resolution of 2 Megapixels and they were set to collect data at a frame rate of 200Hz.
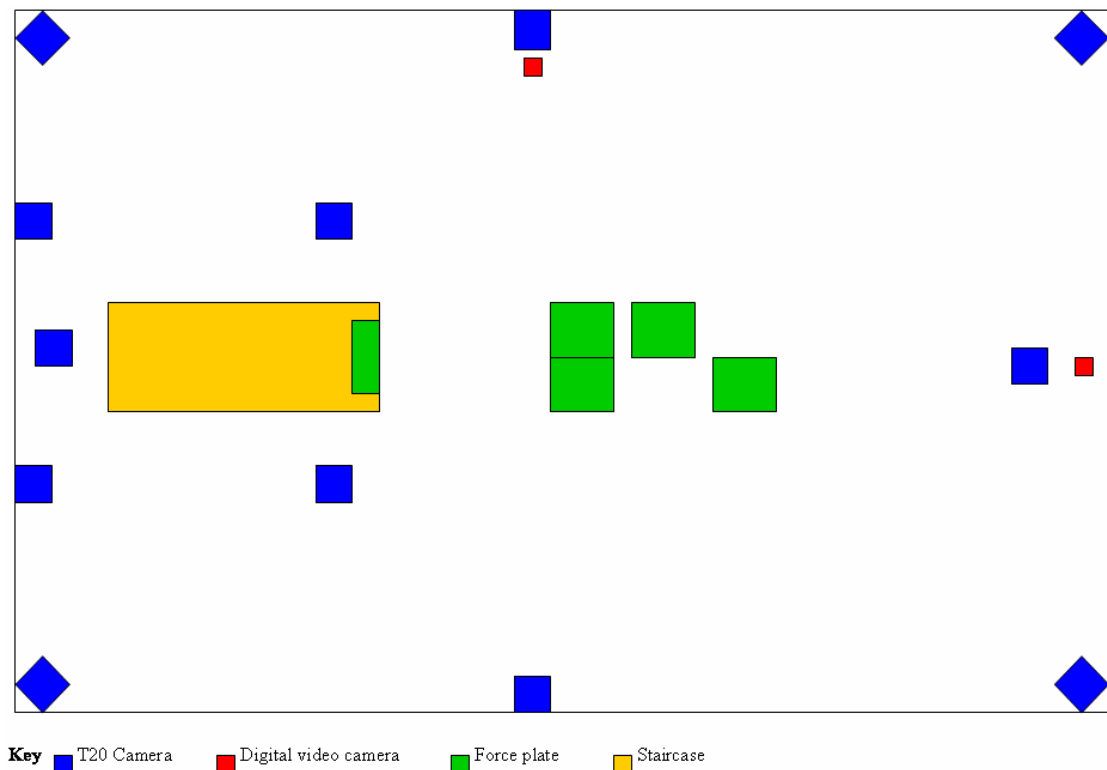
Figure 3.2 Layout of the gait laboratory showing the positions of the cameras relative to the staircase and force plates.

Calibration of the System

Before data could be collected, the system had to be calibrated. This was performed in two stages, dynamic and static. The dynamic stage of the calibration was carried out using a calibration wand (Fig 3.3) which was waved around the space where the recordings were to take place. The calibration wand had five 14mm reflective markers attached to it at specific locations relative to one another. It was important that no other reflective markers were visible to the cameras when the calibration process was performed. It was also possible to create a camera mask which blanked out pixels on each camera where unavoidable reflections were located. During dynamic calibration, the T20 cameras collected data and when each camera had collected 2000 frames of data in which the calibration frame was visible, the system began to process the data automatically. At this point the calibration wand was placed on the point chosen to be

the capture volume origin and orientated to reflect the axis system required. The processing involved calculating image errors for each camera and determining the location of each camera relative to the others. On completion, the image error values were displayed on screen. These were checked and if any value was above 0.2 the calibration was rejected and the process repeated.
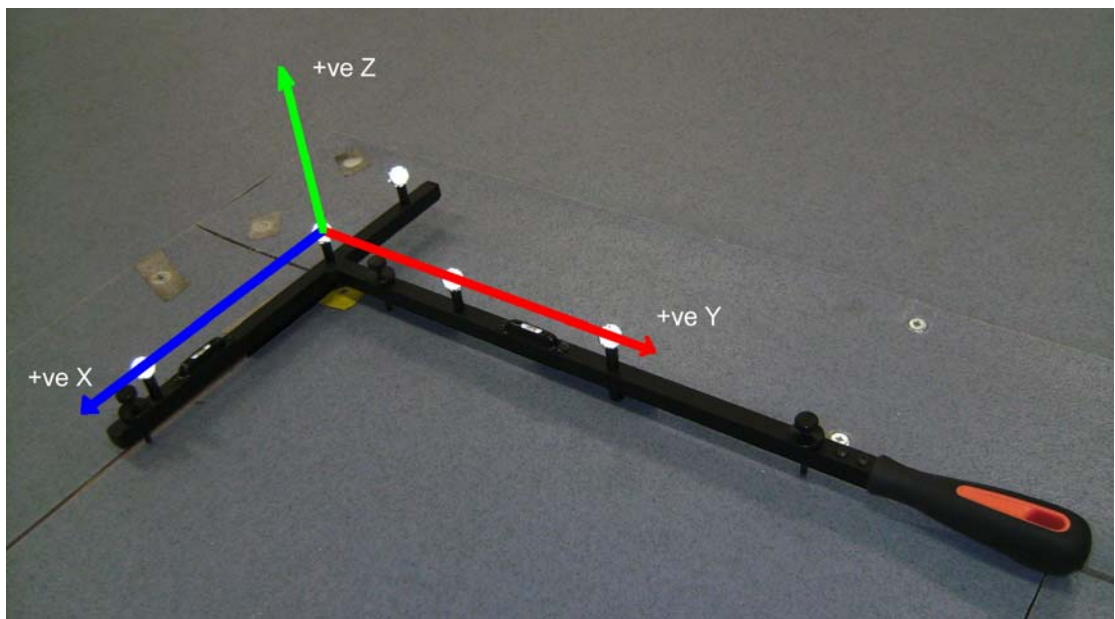
Figure 3.3 The calibration wand showing the x, y and z axes orientations

The camera positions had been determined at this point, however, they were not orientated or positioned correctly relative to the user defined 3-D co-ordinate system and origin. This was the role of the static calibration stage. The cameras captured a few frames of data and those cameras whose fields of view contained reflections from the five markers on the calibration wand were used to re-orientate and reposition all of the cameras. The system referred to the data stored in the calibration file regarding the positions of the markers on the wand being used and from this was able to set the capture volume and axis system. This completed the calibration of T20 cameras.

Kinetic Data Collection Equipment

Kinetic data were collected using four floor mounted force plates (OR6-7, AMTI, Watertown, MA.) and a smaller step force plate (MC818, AMTI, Watertown, MA.). Each force plate was connected to a digital strain gauge amplifier (MSA-6, AMTI, Watertown, MA.) with each of the three dimensions of force and moment amplified according to the gains shown in Table 3.1. The amplified signals were subsequently connected to the one of the MX Giganet units via a patch box. The force plates had a stated linearity of $\pm0.2\%$ and a stated hysteresis of $\pm0.2\%$.

Table 3.1 Amplifier gains

Force plate	Excitation voltage	Fx	Fy	Fz	Mx	My	Mz
1	9.996	3986.7	3957.4	3987.1	3973.9	3986.3	3989.6
2	9.995	3987.1	3985.9	3979.5	3983.5	3979.9	3985.5
3	9.994	3993.6	3966.2	3981.9	3977.1	3972.3	3988.3
4	9.995	4002.0	3988.3	3992.8	3997.2	3992.8	3974.3
Step	9.995	3986.7	3964.2	3960.6	3992.8	3973.5	3968.2

High speed video equipment

Two high speed digital video cameras (Pilot pi640-210gc, Basler AG, Arhensburg, Germany) were connected directly to the Dell workstation by ethernet cables for data transfer and to one of the MX Giganet units for control and synchronisation. These cameras had a resolution of 0.3Mp and were set to capture images at 50Hz. Both were mounted on tripods with one positioned to view the action in the saggital plane and was positioned to view the area of the floor mounted force plates. The other viewed the frontal plane and was positioned to view along the walkway towards the staircase. The tripods were set at heights of 635mm (saggital plane) a 975mm (frontal plane). Their positions in the laboratory are shown in Fig. 3.2.

These cameras were primarily used to check the data. Video footage from the cameras was reviewed for each level walking trial to check foot position on the force plates to ensure that no trial where the foot was not fully within the boundaries of the force plates were used in the analysis. During the processing of the stair use data the video footage was reviewed to confirm that the handrails were not used and also ensure that the task was performed in the required manner.

Instrumented Staircase

Data were also collected for stair negotiation. A standard physiotherapy training staircase unit (Physio-Med Services LTD, Glossop, UK) was modified to accept the MC818 force plate in place of the first step (Fig 3.4). The first step was removed and the side panels were modified to reduce marker occlusion during stair use by the participants. This unit had an overall length of 1950mm, a height of 600mm and was 670mm wide. Each end of the unit had a different staircase, differing in gradient. One end had a rise of 145mm and a pitch of 45°, while the other was steeper with rise and pitch of 195mm and 65° respectively. Both ends conformed to BS 5395-1:2000 [152] recommendations for private staircases as per sub-section 3.1.1. Height adjustable handrails were fitted for support and safety.

Figure 3.4 The instrumented staircase showing the MC818 force plate.

A decision was made to use the side of the staircase with the greater rise and pitch to tax the participants more during testing. At just 79.2mm in height, compared to the rise of 195mm of the steeper end of the staircase unit, the MC818 force plate was too low to be used on its own. To overcome this, a bespoke pedestal was designed onto which the force plate could be secured which would raise it to the required height of 195mm. Other design requirements were that the pedestal had be rigid to enable accurate data to be collected without vibrations, that it be adjustable in height if it was decided to use it with the other (shallower) end of the unit and be portable since the gait laboratory was used for other movement analysis projects not involving stair use.

Initially, a fabricated design was considered since this would be a light construction that could be moved easily, however, this design was rejected for the following reasons. Firstly, it was felt that the distortion due to the heat during welding would prevent the accuracy required being met. Secondly, it was felt that a pedestal fabricated from square tube may also be lacking in the rigidity required to allow accurate data to be captured. It

was decided to go with a pedestal constructed from solid mild steel sections. This would greatly increase the mass of the pedestal, but it would also provide much more rigidity and a more accurate product. An assembly drawing and part drawings were produced using AutoCad LT 98 (Autodesk, San Rafael, CA.) (Appendix 1). To reduce the mass of the pedestal it was decided not to go for a solid base. Instead, a plate, onto which the force plate would sit, would be supported by three solid blocks the same depth as the plate. The materials used in the construction of the pedestal are listed in Table 3.2. An assembly drawing showing how the finished components and the force plate were fitted together is shown in Figure 3.5 and the pedestal assembly is shown in situ in Figure 3.6.

Table 3.2 List of materials used in the construction of the step force plate pedestal.

Item	Qty	Material	Dimensions	Description
1	1	Mild steel plate	630x209x12mm	cut to size and flash ground
2	6	Cold rolled mild steel □ section	50x50x200mm	cut to length
3	1	Cold rolled mild steel plate	457x260x5mm	cut to size
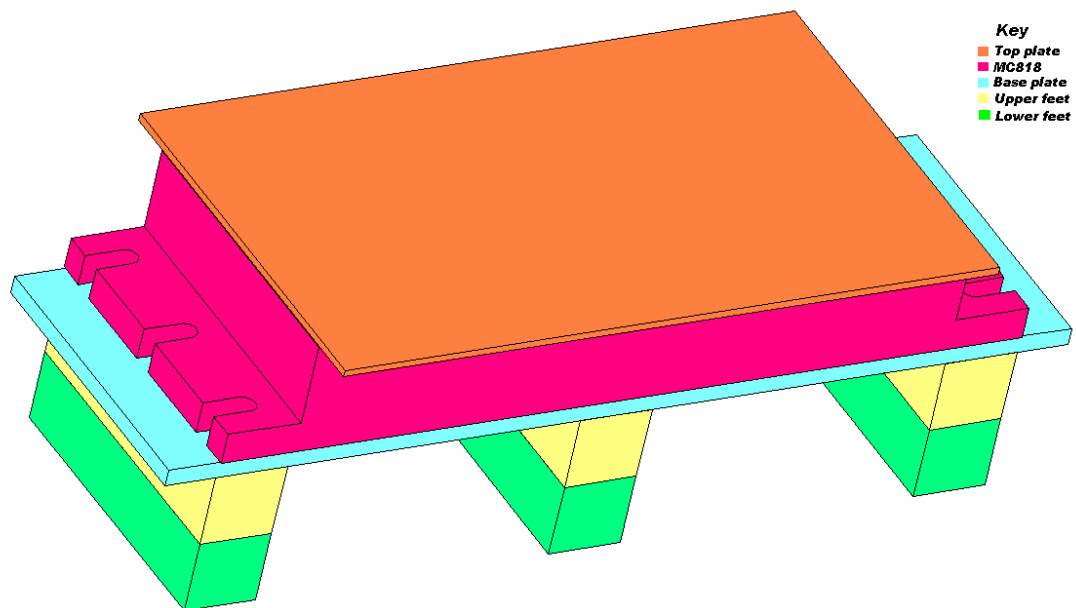
Figure 3.5 Step pedestal and MC818 force plate assembly

Item 1 formed the base plate onto which the force plate was to be attached. Its dimensions were selected with reference to the force plate and the staircase. To ensure that the force plate - staircase combination was always set up in the same relative positions, the width of the plate was slightly less than the internal width of the staircase side panels into which it would be placed. Its depth was chosen to be slightly larger than that of the force plate and its thickness was determined in conjunction with the other components of the assembly to achieve the correct overall height.

This base plate was marked off and drilled as per the component drawing (Appendix 1). The pitch of these holes was constrained by mounting slots of the force plate, although the three in the centre of the plate were positioned midway along the plate. These latter three were countersunk since they would be under the flat base of the force plate. Those at each end of the plate, in addition to securing the feet to the plate, also secured the force plate to the mounting plate.

Item 2 would form the feet of the pedestal. Each foot would be constructed from two of these blocks. Standard square sections of cold rolled mild steel were selected for these items to minimise the machining requirement. Using 50mm sections also corresponded to the 50mm difference in rise between the shallow and the steep sides of the staircase. If the force plate was to be used with the shallow side of the staircase, the pedestal could be modified to suit by removing the upper three blocks, one from each foot. Since these blocks were supplied cut to length (sawn), no great accuracy could be expected, therefore it was decided to have them cut to 200mm, to ensure that they did not project from the plate to interfere with any of the staircase structure.

These blocks were to be of two different designs, since three would effectively be spacers to increase the overall height. Those which were to be spacers had plain through holes drilled, while the remainder had blind holes drilled and tapped. All six blocks were marked off and machined in accordance with the drawings (Appendix 1).

Item 3 was to be secured to the top face of the force plate to increase the surface area of the force plate. The width of the force plate was less than the width of the original step (457mm compared to 630mm), however, it was felt that this would be sufficient since it covered the central section. Its depth, though, was around 60mm less than the tread of the steps on the staircase (203.2mm compared to 260mm) and it was felt that this could cause health and safety and data collection issues. It was designed, therefore, to have the same width as the force plate, but the same depth as the step tread. Its thickness was determined to achieve a height equivalent to the rise of the stairs.

This plate was marked off and machined in accordance with the drawing (Appendix 1). Plain holes were drilled and countersunk to allow the plate to be secured to the top face of the force plate.

Following machining, the components were assembled using threaded fasteners of suitable size and type (Figure 3.6). To finish off the assembly, a piece of anti-slip flooring material (2mm thickness) was cut to 260x457mm and secured to the top surface of the assembly with heavy duty double sided carpet tape. In addition to providing safety through its non-slip properties, this material also added some comfort for the participants as it isolated the bare feet from the cold metal.

Figure 3.6 Step pedestal shown in position in the staircase.

<u>Safety handrails</u>

Handrails were provided which ran the full length of the walkway. These consisted of two pairs of floor mounted parallel bars (Physio-Med Services LTD, Glossop, UK) which spanned the sections from the start of the designated level walkway to the force plates and from the force plates to the staircase (Figure 3.1). The stands for these handrails had holes in the bases to allow fixing to the floor, although it was not possible to attach them directly to the floor. An alternative method of ensuring that the handrails were stable and would provide the necessary support was needed. This problem was solved by using sheet metal plating as a strap.

Four plates (1760 x 245 x 6mm) were drilled and countersunk as per the component drawing (Appendix 2). Two of the handrail stands were bolted to each of the straps. Once the handrails were fitted to the stands, they were put in place along the walkway

with the straps running across the walkway and the handrails themselves running parallel to it. These straps did cause a secondary problem; since they could not be placed over the force plates they had to be positioned on either end of the central force plate area in the walkway. There was only 185mm of the handrail projecting beyond where they were attached to the stands, leaving a gap which had to be filled. This was filled using suitable lengths of mild steel round tube of similar outside diameter to the handrails to form two extensions bars. Each of the handrail ends adjacent to the force plate section of the walkway had their plastic end caps removed. Four sleeves were made which would fit inside the ends of the extensions bars and handrail ends. These were inserted into each of the ends of the extension bars with half their length protruding. These protrusions were then positioned into the open ends of the handrails and the handrail constructions were moved to butt the handrail ends to the tubing ends (Fig. 3.7). The handrail layout can be seen in Figure 3.8.

Figure 3.7 The handrail end, sleeve and handrail extension piece.

Figure 3.8 The handrails in position in the laboratory showing the free standing handrails and the extension bars covering the force plate area.

3.3 Method

Gait analysis sessions (all participants)

In the course of this study two groups of participants were tested, hip reconstruction patients and healthy controls. For both of these groups, the same data collection protocol and laboratory setup, as described above, were used during the gait analysis sessions.

On the day of testing participants were asked to read and complete the Informed Consent form (Appendices 3 and 4). This was also signed by the author as a witness. Since normal vision, as well as near infrared, video was to be collected, all participants had to complete a consent form agreeing to have video footage collected and possibly used for research dissemination purposes. Other paperwork required completion, but since this differed between the groups it will be discussed more fully in the relevant sections. With the paperwork completed, participants were directed to the changing rooms where they would change into a pair of shorts and a tee shirt.

Modelling in Vicon Nexus requires a number of measurements to be taken, including mass (kg), height (mm), leg lengths (mm), knee widths (mm) and ankle widths (mm). These measurements were taken as follows. Participants were asked to step onto a clinical scale and stadiometer (Seca 220, Seca United Kingdom, Birmingham, UK) where height and mass were measured. Measurements of the leg lengths where taken with the participant lying in a supine position on a treatment bed. Firstly, the right anterior superior iliac spine (ASIS) was located and the end of a tape measure was held on it with the measured value being taken from there to medial malleolus of the right ankle. This was repeated for the left leg. Measurements of the joint widths were taken with the participant standing using a bicondylar caliper (Holtain, Crymych, UK). The knee widths were measured at the distal end of the femur between the lateral and medial condyles. The ankle widths were measured between the lateral and medial malleoli. Additionally, a note made of which limb was to be operated upon (or which was the dominant limb for control participants) to allow comparisons between operated and non-dominant sides to be made. For matching between the study group and the control group, date of birth, gender and ethnic origin were also noted.

One of the inherent inaccuracies in the method of gait analysis used is that the markers are attached to the skin and therefore follow the skin movements rather than the underlying anatomy [74, 153]. To reduce this error, markers were located on specific bony landmarks. Sixteen retroreflective markers were attached to bony landmarks of the pelvis, legs and feet according to the Vicon Plug-in Gait (PIG) marker set [154]. Twelve of the markers were 14mm spherical markers on a circular base with the remaining four (for the thigh and tibia) being on wands of around 70mm length. Wands were used at these locations to accentuate the axial rotation of the limb. Double sided toupé tape was used to secure the markers to the anatomical locations described below. The 16 markers were located at the following locations on the left and right sides (Figure 3.10):

- RASI, LASI   Anterior superior illiac spine
- RPSI, LPSI   Posterior superior illiac spine
- RTHI, LTHI   Lateral thigh
- RKNE, LKNE   Flexion/extension axis of knee (lateral side)
- RTIB, LTIB   Lateral tibia
- RANK, LANK   Lateral malleolus
- RHEE, LHEE   Calcaneous
- RTOE, LTOE   Second metatarsal head
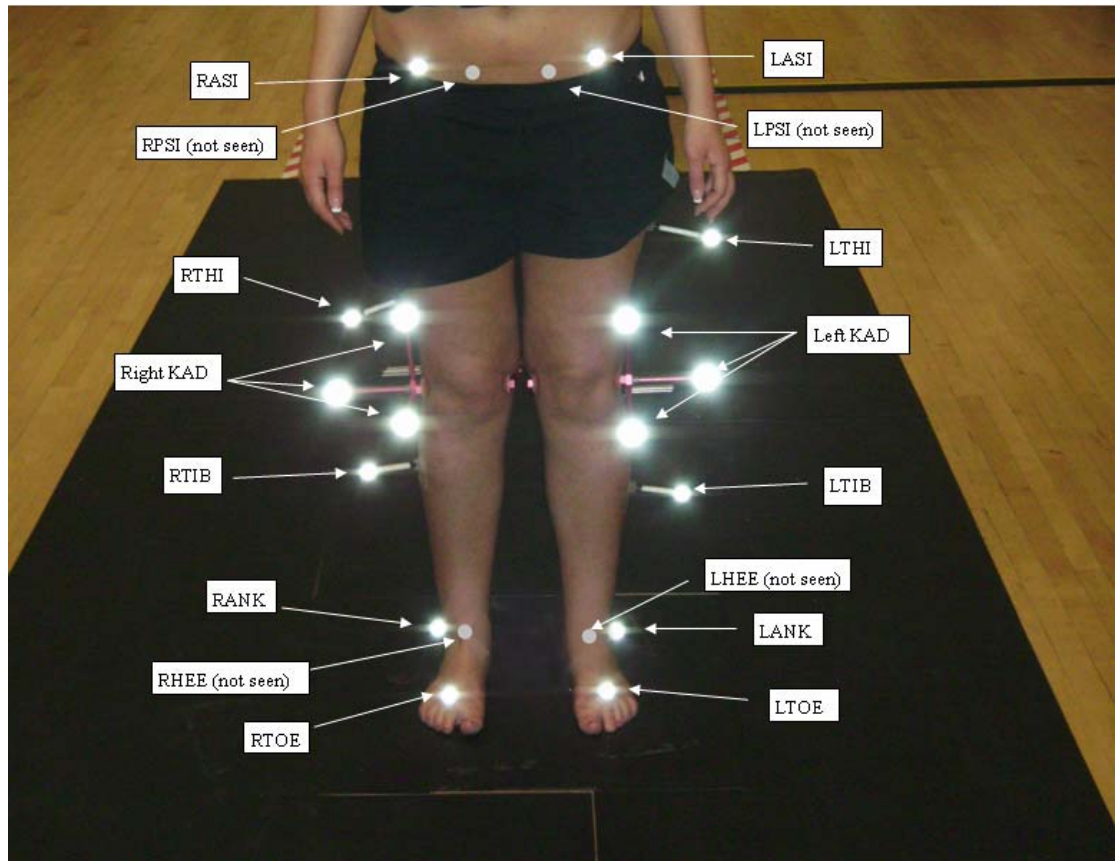
Figure 3.9 Anterior view of a participant with the markers attached during the static trial with the knee alignment devices fitted.

All session tasks were performed barefoot, with the participants wearing shorts and a tee shirt to allow the markers to be accurately attached to the skin at the bony landmarks and tracked accurately by the cameras. Where necessary, the tee shirt was rolled up to avoid occlusion of the pelvic markers. Initially, the left and right knee markers were not attached. Care was taken to locate a position where skin movement was minimal [154]. This was carried out with the participant sitting on the treatment bed with their lower legs hanging freely over the edge. The author flexed and extended one of the knee joints and the flexion/extension axis was located. Then by observation, a position was determined were the movement of the skin was deemed to be minimal. With the participants' consent, a small mark was made at this point with a makeup pencil. This procedure was repeated for the opposite limb.

On completion of the marker attachment, participants were asked to stand in the centre of the walkway. Two knee alignment devices (KADs) were placed on the flexion/extension axes of the knee (Figure 3.11) (Motion Lab Systems, Baton Rogue, LA). These spring loaded devices were placed, one on each knee, with one clamp pad on the mark previously made on the knee joint. Three metal rods (each mutually perpendicular to each other) projected from the device with a 25mm marker attached at the free end. In situ, one of these rods projected predominantly horizontally from the knee joint. The KADs were adjusted for position and orientation so that this rod became an extension of the flexion/extension axis of the knee, in both the frontal and transverse planes.
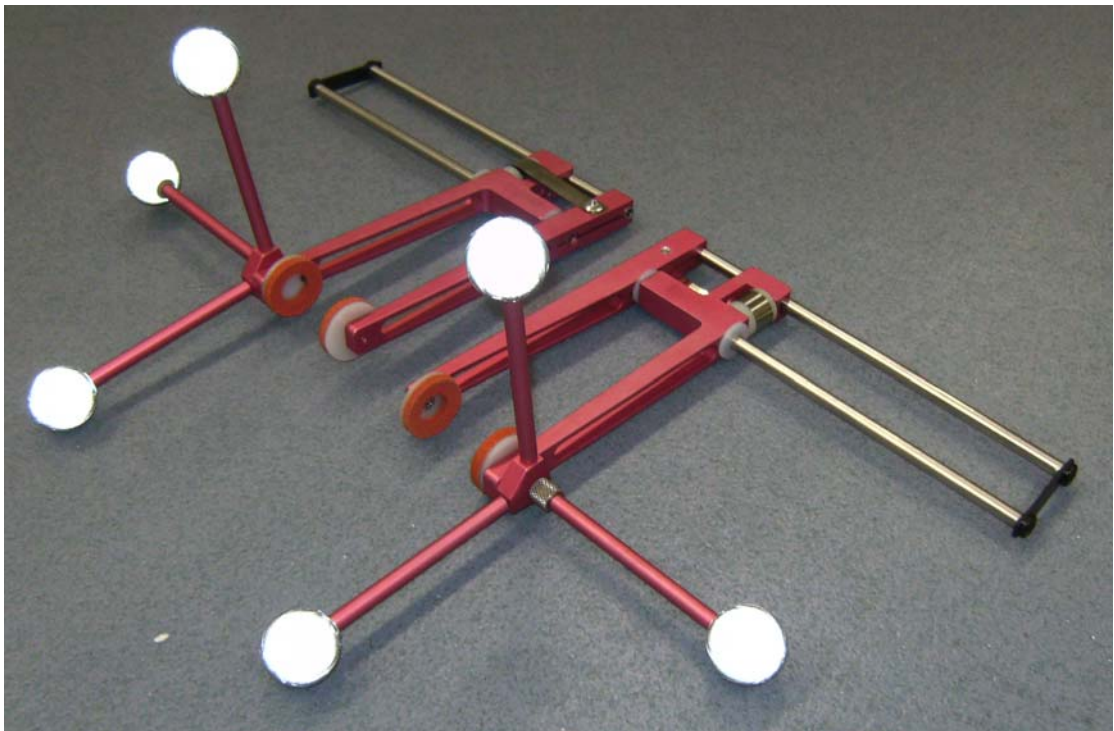
Figure 3.10 The knee alignment devices.

A short static trial was captured with the participant wearing the KADs and standing in the standard anatomical position with the feet pointing forward. Since there were no markers on the upper body, there was no need to assume the full anatomical position

and the arms were left at the side of the body to avoid obscuring any markers (Figure 3.10). These data were checked to ensure all markers were clearly visible. If this was satisfactory, the KADs were removed and two standard markers were put on the knees on the marks previously made.

Prior to collecting data, the participants were informed of the tasks to be carried out and detailed instructions of the level walking and stair use task were given. Detailed instructions for the other tasks were given prior to these tasks being performed. Participants were asked to stand at the start of the walkway and walk from there along the walkway to the top of the stairs. They were then asked to turn around and descend the stairs and walk back to the start of the walkway. This gave the participant a chance to practice the task, but also allowed adjustments to be made to the starting position of each participant to ensure that the force plates were struck cleanly, with the entire foot landing within the boundary of the force plate, and that the staircase was reached as part of a natural stride. Participants were not informed that this was the case, nor were they told that they had to strike the force plates. They were asked to perform the tasks as naturally as possible and without using the handrails, if possible. Participants were told, however, that for health and safety reasons they could use the handrails during both level walking and stair use at any time if they felt insecure or unstable. A minimum of six trials were collected with the participant performing the level walk followed by stair ascent and another six of stair descent followed by level walking. Initially, they were asked to start walking or start descending the stairs with the right foot first, but when sufficient required data had been collected, they were asked to then start with the left foot first. This was done to obtain three trials with the right foot stepping up on the step force plate, three with the left foot stepping up, three with the right foot stepping down

from the step force plate and three with the left foot stepping down. During these trials level walking data were also collected from the four ground mounted force plates. Again three clean right and left force plate strikes were required, however, in some patients, additional trials were collected to achieve the required number of successful force plate strike during level walking.

Within the walkway two of the four force plates were positioned adjacent to each other. A clinical stool (Nottingham Rehab Supplies, Ashby de la Zouch, UK.), fixed at a height of 540mm, was placed within the walkway such that it was behind these two force plates in a central position (Figure 3.12). In this position, participants would be seated with each foot on one force plate. Participants were asked to sit on the stool with their arms crossed over their chests and hands clasping the opposite shoulder (Figure 3.13). They were then asked to rise to a standing position, then after a pause, asked to sit back down again. Following this trial run, three similar trials were collected.
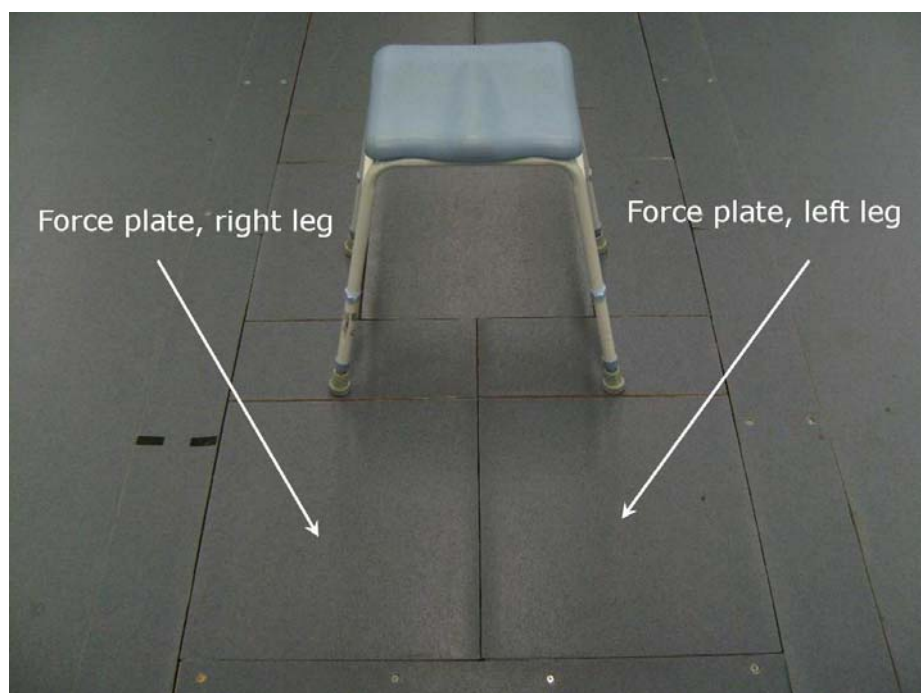
Figure 3.11 The stool in situ for sit-to-stand testing.

Figure 3.12 The starting position for the sit-to-stand task

At the end of the testing session, all markers were removed and the participants were directed back to the changing rooms.

3.4   Hip reconstruction participant method

All participants were recruited from the Joint Care Clinics of two orthopaedic surgeons from the QEH. During these clinics, suitable patients were identified by the surgeon and were told about the study. In order to be suitable for inclusion, patients had to be between the ages of 18 and 75 inclusive and be scheduled for a primary total hip replacement or hip resurfacing procedure as a result of primary osteoarthritis of the hip. They had to have had no previous surgery to either of the lower limbs, and a reasonably well preserved joint on the opposite side to exclude those scheduled for bi-lateral hip surgery, or who would be requiring a second hip on the other side within the timescale of the study. Patients would also be excluded if any of the following list of exclusions applied to them:

- Inflammatory arthritis of the hip such as rheumatoid arthritis, gout, pyrophosphate, enteropathic and psoriatic arthropathy

- Inadequate x-rays

- Infection of the hip joint

- Body mass index of greater than 35

- Unable to comprehend the study and its implications

- Severe vascular insufficiency of the affected limb

- Marked bone loss around the hip

- Unable to walk without assistance (sticks, crutches, etc.) as a result of the condition

- Any physical disability which would prevent them from performing the tasks safely

- Unwilling to take part

Potentially suitable patients were informed of the study by their consultant and if they showed an interested, had the study was fully explained to them by the author. Those who wished to take part in the study were given a copy of the Participant Information Sheet (PIS) (Appendix 7) to take away which gave full details of study, what they would be expected to do and contact details for the author. They were also given a provisional gait analysis testing appointment at least 48 hours after the joint care clinic, although no consent was taken at this point. This was done so that the patients would not feel pressurised into taking part in the study and to give them time to read over the PIS, discuss the study with others, ask questions of the author and make an informed decision whether to take part or not. Patients who provisionally decided to take part in

the study where given maps and instructions to direct them to the place where the gait analysis was to be performed.

Three study groups were investigated which included two THR groups and a RSF group. These were 32mm femoral heads, 36mm femoral heads and hip resurfacing. In total 32 patients were recruited in to the study between December 2009 and January 2011. Two patients had their surgery postponed indefinitely and were removed from the study. One patient withdrew from the study at the three month post-surgery stage and was removed from the study. Three patients scheduled for a total hip replacement with a 32mm femoral head had a 28mm head fitted on clinical grounds. These two patients continued in the study, although their data were not used in the analysis. This gave a total of 26 eligible patients for analysis in the study with a breakdown of 10 resurfacing, seven 36mm femoral heads and nine 32mm femoral heads. All surgery was performed using the Hardinge or Modified Hardinge anterolateral approach. A complete breakdown of all the participants recruited is shown in Table 3.3.

Table 3.3 Data for the patient participants included in the study categorised by study group showing, at the time of recruitment, age (years), mass (kg) and height (m) and their means and standard deviations (sd) together with gender and operated side.

Resurfacing group					
	Age	Gender	Side	Mass	Height
1	59.6	M	R	95.0	1.630
2	43.9	M	R	94.6	1.785
3	68.2	M	L	87.9	1.646
4	34.9	M	L	87.9	1.753
5	66.9	M	L	74.8	1.643
6	42.7	M	R	128.6	1.791
7	54.0	M	R	86.2	1.842
8	38.9	F	R	60.6	1.577
9	54.9	F	L	83.0	1.687
10	59.4	F	R	71.1	1.585
Mean	52.3			87.0	1.694
(sd)	(11.7)			(18.2)	(0.093)

32mm femoral head group					
	Age	Gender	Side	Mass	Height
1	58.5	F	R	107.6	1.618
2	57.9	F	R	88.9	1.567
3	59.7	F	R	75.0	1.582
4	65.5	F	R	77.8	1.656
5	74.7	F	R	63.9	1.662
6	65.6	F	R	75.5	1.563
7	61.1	F	L	116.3	1.655
8	57.8	F	L	94.5	1.569
9	62.8	F	R	71.6	1.567
Mean	62.6			85.7	1.604
(sd)	(5.5)			(17.5)	(0.043)

36mm femoral head group					
	Age	Gender	Side	Mass	Height
1	53.2	M	R	93.1	1.878
2	59.7	M	R	91.4	1.696
3	71.4	M	R	84.0	1.604
4	59.8	M	L	84.0	1.772
5	63.1	M	R	76.7	1.653
6	63.3	M	R	81.4	1.654
7	75.9	M	L	114.5	1.795
Mean	63.8			89.3	1.722
(sd)	(7.7)			(12.5)	(0.097)

Patients were telephoned on the day prior to their provisionally scheduled gait analysis testing appointment to ensure that they were still willing to take part. On arrival at the laboratory they were asked to complete three lower limb questionnaires; the HHS, the OHS and the WOMAC. These were chosen for several reasons, firstly the participants would be familiar with them from the hospital, secondly they are often quoted in the literature and thirdly they can be scored online (http://www.orthopaedicscore.com/). In addition to these, the participants were asked to complete a bespoke expectations questionnaire (described in more detail in Chapter 4). It was felt that people of different ages and who had different levels of activity prior to end stage osteoarthritis may have different expectations from the surgery. In the expectations questionnaire, participants were asked about how active they had been and what they hoped to be able to do after

surgery and rehabilitation that they could not do at that time. At subsequent gait analysis sessions they were asked to complete a slightly altered expectations form which asked about which of their expectations had been met.

Participants in this group returned for two further gait analysis sessions at three months and one year after their surgery. These sessions followed exactly the same pattern as the first session. All three of the orthopaedic questionnaires selected for use in this study were administered to all patients on three occasions corresponding to the three time points for testing. In this study part 2 of the HHS was not used and thus 91 was the maximum score available. Part 2 was omitted since the HHS is normally a clinician administered questionnaire, but was being used as a self administered questionnaire, therefore those parts which require direct clinician involvement were omitted.

At each of the testing points, the patients were asked to complete the relevant expectations questionnaire (Appendix 8). Prior to surgery, they were asked to rate their general activity and their sporting and leisure activity levels before they started being troubled by osteoarthritis. They were also asked to rate how active they thought they were presently for both of the activity types. Finally, they were asked select the activities from a list which they hoped to achieve after surgery and rehabilitation. At the two post-operative testing points, they were again asked to rate their current activity levels generally and in sporting and leisure activities and to what degree they felt that they had achieved their general and sport/leisure activity levels. They were again asked to indicate which, if any, of the list of activities that they still hoped to achieve.

The section relating to activities of daily living contained a list of nine activities. Patients were asked to tick all activities that they hoped to be able to perform following surgery and rehabilitation. It was decided to analyse these data by analysing the number of activities that had been checked where a lower number of expectations ticked would suggest that the patient had less that they still wanted to achieve. It could also be taken as a measure of satisfaction.

At the three and 12 months post-operative testing points, patients were asked to indicate to what level they had achieved both their general and sport/leisure activities compared to where they wanted to be. There were five possible responses from "I have achieved none of my expectations" through to "I have achieved all of my expectations". In the analysis, the five responses were given a rank from 1 to 5, with five being awarded when all expectations had been achieved and one being awarded when no expectations had been achieved.

All forms were checked before the patient left the laboratory and if any questions were unanswered, the patient was asked to give a response to ensure that no forms had to be discarded due to being incomplete.

Due to time constraints, it was not possible to include all of the participants in the 12 months post-operative analysis. As a result sub-groups of the RSF, 36mm and 32mm groups were used. Table 3.4 shows the demographic data for these sub-groups. Table 3.5 shows the data regarding timing of the testing sessions relative to the date of operation.

Table 3.4 Data for the patient participants included in the 12 months post-operative analysis categorised by study group showing, at the time of recruitment, age (years), mass (kg) and height (m) and their means and standard deviations (sd) together with gender and operated side.

Resurfacing group					
	Age	Gender	Side	Mass	Height
1	59.6	M	R	95.0	1.630
2	43.9	M	R	94.6	1.785
3	68.2	M	L	87.9	1.646
4	34.9	M	L	87.9	1.753
5	66.9	M	L	74.8	1.643
Mean (sd)	54.7 (14.7)			88.0 (8.2)	1.961 (0.072)

32mm femoral head group					
	Age	Gender	Side	Mass	Height
1	58.5	F	R	107.6	1.618
2	57.9	F	R	88.9	1.567
3	59.7	F	R	75.0	1.582
4	65.5	F	R	77.8	1.656
5	74.7	F	R	63.9	1.662
Mean (sd)	63.3 (7.1)			82.6 (16.6)	1.617 (0.043)

36mm femoral head group					
	Age	Gender	Side	Mass	Height
1	53.2	M	R	93.1	1.878
2	59.7	M	R	91.4	1.696
3	71.4	M	R	84.0	1.604
Mean (sd)	61.4 (9.2)			89.5 (4.8)	1.726 (0.139)

Table 3.5 Mean (sd, range) days prior to operation of the first testing session and mean days (sd, range) before or after the 3 month and 12 month post-operative date of subsequent testing session.

Time point	RSF	36mm	32mm
Pre-op	12.1 (19.0, 1-62)	6.1 (4.5, 2-14)	3.7 (2.2, 2-8)
3 months	9.2 (12.8, -3-39)	0.3 (5.1, -9-7)	11.3 (15.8, -7-38)
12 months	3.4 (12.3, -9-21)	5.3 (10.7, -7-12)	0.4 (11.3, -17-13)

3.5 Control participant method

A cohort of healthy adults was recruited, primarily, as control participants for the clinical gait study. In total 63 control participants were recruited into the study. From this group three cohorts were selected as matched controls to the study groups and were matched as closely as possible for age, gender, mass and height. The Shapiro-Wilk test showed that the patient and control ages, heights and masses were normally distributed. Student's t-tests were performed to test the degree of matching between the patient and control groups. Only one difference was found which was the mass of the 32mm group compared to their control group (p=0.003). This was unavoidable due to the relatively small number of control participants from which to choose.

Since the age range of the study groups was from 18-75, a number of different recruitment sources were required to cover the age range. Control participants were recruited from members of staff and students of the university, their family and friends, a local retired persons club, the spouses of recruited participants and via local media. Due to the differences in demographic data between the three patients groups and that comparisons were to be made between the groups, the decision was taken to have three control groups; one matched to each patient group. The breakdown of the control group participants used as matched controls are shown in Table 3.6.

Table 3.6 Data for the matched control participants included in the study categorised by study group showing, at the time of recruitment, age (years), mass (kg) and height (m) and their means and standard deviations (sd) together with gender and dominant limb.

Resurfacing control group						32mm femoral head control group					
	Age	Gender	Side	Mass	Height		Age	Gender	Side	Mass	Height
1	49.1	M	R	81.5	1.855	1	56.1	F	R	77.4	1.579
2	48.2	M	R	68.8	1.739	2	56.8	F	R	62.2	1.677
3	53.3	F	R	70.6	1.692	3	59.9	F	R	63.8	1.718
4	33.4	M	R	77.1	1.728	4	62.2	F	R	49.9	1.552
5	59.9	F	R	63.8	1.718	5	58.9	F	R	62.7	1.660
6	29.4	F	L	73.0	1.629	6	61.4	F	R	59.4	1.480
7	49.6	M	R	65.2	1.836	7	75.2	F	R	63.7	1.585
8	65.6	M	L	85.3	1.686	8	65.8	F	R	74.6	1.580
9	67.9	M	R	67.8	1.648	9	65.6	F	R	65.4	1.678
10	61.9	M	R	75.4	1.746						
Mean	51.8			72.9	1.728	Mean	62.4			64.3	1.612
(sd)	(12.9)			(7.0)	(0.073)	(sd)	(5.9)			(8.1)	(0.076)

36mm femoral head control group					
	Age	Gender	Side	Mass	Height
1	64.9	M	R	73.5	1.682
2	48.2	M	R	68.8	1.739
3	60.9	M	R	95.6	1.773
4	76.8	M	R	88.3	1.816
5	64.6	M	R	82.2	1.768
6	61.9	M	R	75.4	1.746
7	71.2	M	R	66.2	1.660
Mean	64.1			78.6	1.741
(sd)	(8.9)			(10.7)	(0.054)

To be considered eligible to take part, potential participants had to be within the ages of 18 and 75 inclusive. They must have had no lower limb surgery, condition or injury which had or could affect their walking ability, be able to perform the tasks without support and have no physical impairments which could prevent them from performing the tasks safely.

Prospective participants were given a copy of the PIS either in person, by mail or electronically and, if willing to take part, were offered a time for a testing session. On arrival at the laboratory on the testing day, they were asked to complete three documents. Two of these were the consent forms discussed previously (Appendices 4 and 6) and the other was a screening questionnaire which was used to ensure that the potential participant was indeed suitable to take part (Appendix 9).

After completion of the gait testing session as described for the hip participants, these participants were issued with a Participant Debriefing Sheet (Appendix 11) which ensured them that they had not been deceived during the session, gave details of how they could withdraw and recapped the details of the study.

Control data were dealt with in two ways. Firstly suitable participants were selected as healthy controls to the patient groups; and secondly for the study of age related changes in gait. The control data had the level walking, stair use and STS data analysed. The remainder of the healthy participants had only the level walking data analysed. Data were processed as described for the patient participants with the dominant limb replacing the operated limb.

3.6 Data Analysis

During the data collection sessions three good trials of each task were collected. For level walking this required one or both feet making contact within the boundary of one of the floor mounted force plates. For stair use this required three trials where the right foot made contact with the step force plate and three with the left. The STS task simply required the participant to perform the task in the required manner.

These data were processed as follows. Firstly, the static trial for each participant and session was reconstructed and labelled as per the PIG marker set within the Nexus software (Figure 3.10). The anthropometric data (mass, height, leg lengths, knee and ankle widths) were entered and the PIG static model was run. This model, which was used in conjunction with the KADs, created two virtual markers at the knee. The static trial was re-labelled with the two virtual markers labelled as the right and left knee markers, and the static PIG model was re-run in addition to the Static Subject Calibration routine. The former of these took as input the marker locations and the anthropometric data, and determined joint centres and defined segment lengths and axis systems [154]. The latter creates a template which the enables automatic labelling of dynamic trials.

Each of the selected trials was reconstructed and auto-labelled. Trials were cropped within Nexus to include only the section of interest and these cropped versions were saved with all further processing performed on that copy. If gaps were found in the trajectory data which were greater than 10 frames in length, the trial was discarded and another trial was selected. Otherwise, any gaps were filled manually using a cubic spline routine and unlabelled markers were deleted. For level walking trials, heel strike and toe off events were marked for both sides to delineate two full strides (left heel

strike to left heel strike and right heel strike to right heel strike), irrespective of whether there was a force plate strike for one or both feet. A similar procedure was adopted for stair use trials to delineate two full steps, one for each foot. For the STS trials, heel strikes were marked at the start and end of the STS task. This was done to enable the trials to be normalised to a common number of data points in Polygon 3.1 (Vicon Motion Systems, Oxford, UK).

A Butterworth filter was applied to the data from the force plates (4th order zero lag with a 300Hz cut off frequency), the trajectories were filtered with a Butterworth filter (4th order zero lag with a 6Hz cut off frequency), the dynamic PIG model was run, the model output data were filtered using a Butterworth filter (4th order zero lag with a 6Hz cut off frequency) and the trial was saved. The dynamic PIG model uses the parameters created during static modelling and applies these frame by frame to calculate the joint angles and kinetic data. The ground reaction force data from the force plates were used, in conjunction with the joint angles, to calculate joint moments and powers using inverse dynamic techniques. By saving the trials, all the marker trajectories and model outputs were converted into c3d files which were used for further processing.

Further processing was carried out in Polygon. Three processed trials of the same task by the same participant were imported into Polygon in order to determine the means of all of the parameters from the three imported trials. In addition to this, Polygon also normalised the trials between the gait cycle events previously marked in Nexus such that all trials had the same number of data points. This is vital to account for the difference in the time taken to perform the task from trial to trial and from participant to

participant. These single data sets were exported from Polygon in a format which could be opened by a spread sheet package.

These output files were opened and the relevant data were extracted and inserted into SPSS 20 (IBM Corp., Armonk, MY) for statistical analysis. All data were checked with the Shapiro-Wilk test for parametricity and statistical tests relevant to the data were used to test the hypotheses. Details of the tests used during the study are given in each of the experimental chapters.

4 Orthopaedic Questionnaires and Expectation

4.1 Introduction

Orthopaedic questionnaires are a commonly used measure of disability in the clinical setting [155-157]. They are generally relatively quick to complete and many can be completed by the patients themselves. Questionnaires such as these are often quoted in research literature as a means of determining the efficacy of one intervention over others, even as the only outcome measure [155, 158]. Many such questionnaires have been developed over the years to cover various joints and causes of disability. They are subjective in nature, although they have been proven to reliably distinguish between degrees of disability [155].

During the initial stages of this study, it was understood that since patients were to be placed into one of the three groups based on clinical need, there could be differences in the demographics between the groups. One of the groups consisted of hip resurfacing patients who tend to be younger male patients, whereas older females tend to have a smaller femoral headed component implanted. In addition to this, the potential age range for the patients in the study was 18 to 75 (although the youngest patient recruited was 34) and this could have some influence on the objective outcome measures between the groups with older patients possibly being less active or having lower expectations of the surgery. For these reasons, it was decided to administer an expectations questionnaire which would give a measure of activity levels as well as an indication of what the patients' expectations for the surgery were (Appendix 8). This could highlight such differences and could be used to help explain differences in the objective data between the groups.

4.2 Method

<u>Orthopaedic Questionnaires</u>

In this study it was decided to use orthopaedic questionnaires to give the patients' perspective on the success of the intervention. Gait analysis will give specific objective data regarding the kinematics and kinetics of the movements investigated, however, this may not mirror what the patient perceives. Gait analysis may highlight features of motion which are different from what would be expected in the healthy population, but if the patient is free from pain and able to maintain a healthy lifestyle, then the procedure must be seen as successful from the patient's point of view. By using commonly reported questionnaires in this study, the results can be compared with the results from other similar studies.

It was decided to use three of the commonly reported orthopaedic questionnaires in this study to allow comparison with a larger number of other studies without over burdening the patients. Those selected were the HHS [77], which has been reported by a number of similar studies to this one investigating hip replacement surgery in the OA population using gait analysis as the primary outcome measure [23]; the WOMAC [109], which is recognised as a reliable outcome for measuring the efficacy of hip replacement surgery [159] and the OHS [108], which was designed specifically for use following hip replacement [160], which is not true of the HHS and the WOMAC questionnaires.

All three of the questionnaires selected allow a total score to be calculated from the responses given by the patient. In addition, the HHS and the OHS also stratify the scores into degrees of disability or health. The WOMAC questionnaire is divided into four sections covering symptoms, stiffness, pain and function and has a maximum score of 100 representing full function, no pain or stiffness and no symptoms. There is no

indication with this questionnaire as to what score represents where disability changes to healthy. Instead, pre and post intervention scores must be analysed statistically to determine if there is a significant increase in the score as a result of the intervention.

This is not the case with the HHS where four score bands representing differences in health have been developed [161] (Table 4.1). There are two sections to the HHS questionnaire; a questionnaire section covering pain, support and activities of daily living and a clinical examination of the range of movement in the limb under investigation. Like the WOMAC index, the HHS has a maximum score of 100, but the score can be identified directly with degree of health. This grading system also gives an indication of what increase in score (20 points), pre and post intervention, would be thought of as a successful outcome.

Table 4.1 Score stratification for the Harris Hip Score.

Score range	Indication
90 - 100	Excellent
80 - 89	Good
70 - 79	Fair
< 70	Poor

Like the HHS, the OHS also has four grades of severity of the condition (Table 4.2), although the maximum score at 48 is lower than that of both the HHS and the WOMAC questionnaires. This questionnaire has a single 12 question section covering pain, limping and activities of daily living.

Table 4.2 Score stratification for the Oxford Hip Score

Score range	Severity
40 – 48	Satisfactory
30 – 39	Mild to moderate
20 – 29	Moderate to severe
0 – 19	Severe

Expectations Questionnaire

A specification was drawn up for an expectations questionnaire, in addition to questioning patients about their expectations of the surgery; it should also question them about their activity levels. Since there were three time points at which testing was to be performed, the questionnaire was designed to reflect this.

To date, there are no standardised measurement tools for determining expectations from a clinical intervention, although some tools have been developed for specific conditions and interventions [162]. One study of hip replacement patients did develop a series of questions which were asked of a cohort of patients post-operatively to investigate correlations between patient satisfaction and prior expectations [163]. Unfortunately, this tool did not meet the requirements specified for the expectations questionnaire required for this study, nor were there any other expectations questionnaires for hip reconstruction surgery. It was decided, therefore, that a questionnaire specifically for this study would have to be developed.

Each of the orthopaedic questionnaires selected for use in this study contain questions on the ease with which activities of daily living can be performed. Walking, stair use, using a car or public transport, rising from sitting and putting on/taking off socks are common to two or more of these questionnaires, so it was deduced that these were activities that were important for osteoarthritis and hip replacement patients and that they should be included in the list of expectations in the form. Bath use only features in the WOMAC questionnaire, but it was felt that this was a task which could prove difficult for the OA patient group and a possible expectation, so it was also included in the list. Younger OA patients and healthier older ones may also wish to resume a

sporting or leisure activity and it was felt that this expectation should be included as one of the options.

There is some evidence to suggest that pre-operative function has an influence on post-operative function [159] and since it was expected that participants in this study would present with a wide range of pre-operative function, it was felt that pre and post-operative function should be recorded. These data could be used to help explain any differences in kinematic and kinetic data. Two types of activity were identified, general activity, such as activities of daily living, and sporting/leisure activity, such as participation in sports and hobbies. For each of these it was important to determine, not just the current levels of activity, but the levels of activity prior to OA causing disability. By comparing the patients' pre-disability activity levels with those after surgery some measure of the success of the surgery could be determined. Additionally, comparing the actual activity levels pre-operatively with those post-operatively could show the progress of the rehabilitation process between the three groups. A five point Likert scale was used to measure these activity levels ranging from 'very active/sporty' to 'not active/sporty at all'.

Using this specification, a three part expectations questionnaire was developed (Appendix 8). Part one was for use pre-operatively and would ask the patient about their general and sporting/leisure activity levels at the time of testing and before the onset of disability due to OA. It would also question the patients on their expectations following surgery and rehabilitation. Parts two and three were to be used at three and twelve months post-operatively respectively. These two parts are predominantly the same and question the patients on their current general and sport/leisure activities and to what

degree they have met their general and sport/leisure expectations. It would also question them on any expectations they still hope to achieve.

Orthopaedic scores and expectation data were analysed using Kruskal-Wallis tests for between group differences with post-hoc Mann-Whitney U tests. Within group analysis was performed using Wilcoxon signed-rank tests. A 95% confidence level was used throughout.

4.3 Results

Orthopaedic Questionnaires

Table 4.3 shows the descriptive and inferential statistics for the HHS at the three time points. There were no significant differences between the HHS results at the pre-operative testing point. This gives some evidence that patients in the three groups were all equally disabled prior to surgery. This is useful to know as if any differences between the groups are found post-operatively in any of the outcome measures they can be attributed to the intervention, rather than as a result of differences in ability before surgery. The Kruskal-Wallis values, however, also show that there were no significant differences between the groups at either of the post-operative testing points. The surgical intervention caused an increase in the average score in all three groups when comparing the pre-operative score with that at three months post-operatively. In all cases this proved to be significant as evidenced by the Wilcoxon signed-rank values, however, only the RSF group continued to improve between 3 months and 12 months post-operatively, although this proved not to be significant.

Table 4.3 Statistical results for the Harris Hip Score for the three groups at the three time points (* = significant).

	Time points								
	Pre-op			3 months			12 months		
	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm
Mean (SD)	44.00 (9.19)	50.57 (14.28)	37.00 (10.20)	64.40 (18.31)	73.71 (21.57)	66.11 (16.98)	84.80 (7.29)	73.67 (28.31)	63.50 (2.12)
Range	34-57	36-75	25-51	31-88	41-91	32-83	74-91	41-91	62-65
Kruskal-Wallis	p=0.075			p=0.337			p=0.359		
	RSF			36mm			32mm		
	Pre-op vs 3 months		3 months vs 12 months	Pre-op vs 3 months		3 months vs 12 months	Pre-op vs 3 months		3 months vs 12 months
Wilcoxon signed-rank	p=0.032*		p=0.138	p=0.028*		p=0.180	p=0.008*		p=0.343

Table 4.4 shows the descriptive and inferential statistics for the OHS. The Kruskal-Wallis values indicate that neither group had a score significantly higher than any of the others at any time point. Wilcoxon signed-rank tests revealed significant improvements for all groups by 3 months following surgery, but only the RSF continued to show a further improvement by 1 year post surgery.

Table 4.4 Statistical results for the Oxford Hip Score for the three groups at the three time points (* = significant).

	Time points								
	Pre-op			3 months			12 months		
	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm
Mean (SD)	18.50 (5.93)	21.86 (7.60)	15.13 (5.30)	36.60 (8.72)	40.71 (10.80)	35.89 (10.52)	45.80 (2.95)	40.00 (13.86)	42.60 (5.55)
Range	34-57	13-34	6-23	19-46	18-48	17-48	41-48	24-48	34-48
Kruskal-Wallis	p=0.195			p=0.293			p=0.708		
	RSF			36mm			32mm		
	Pre-op vs 3 months		3 months vs 12 months	Pre-op vs 3 months		3 months vs 12 months	Pre-op vs 3 months		3 months vs 12 months
Wilcoxon signed-rank	p=0.007*		p=0.042*	p=0.018*		p=0.102	p=0.017*		p=0.197

Table 4.5 shows the percentages of scores in each of the recognised categories for the OHS 3 months post-surgery. These results show that at 3 months post-surgery, 54% of

the total cohort scored 40 or greater in the OHS representing "...satisfactory joint function". In terms of the individual groups, the majority of THR patients had a satisfactory result; whereas fewer than half of the RSF patients did. Additionally, the RSF group had more scores in the 30-39 grade (mild to moderate) than the THR groups.

Table 4.5 Percentage of Oxford Hip Scores for each group in each of the four grade bands at 3 months post-surgery.

	<20	20-29	30-39	40-48
RSF	10	10	40	40
36mm	14	0	14	71
32mm	11	11	22	56

Table 4.6 shows the descriptive and inferential statistics for the WOMAC scores. The Kruskal-Wallis score again highlighted no significant differences between the groups at any of the testing points. Like the HHS and the OHS, the WOMAC scores increased significantly between the pre-operative and 3 months post-operative time point. The Wilcoxon signed-rank values also show that the RSF group was also the only group which showed a significant increase in the scores between 3 months and twelve months.

Table 4.6 Statistical results for the WOMAC score for the three groups at the three time points (* = significant).

	Time points								
	Pre-op			3 months			12 months		
	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm
Mean (SD)	43.25 (12.63)	45.76 (16.88)	37.00 (10.67)	79.80 (12.81)	86.90 (16.72)	77.00 (18.38)	94.08 (5.80)	82.03 (27.15)	88.60 (8.73)
Range	21.1-65.6	25.8-78.9	21.8-55.8	57-96	51.6-100	43-96.1	84.4-98.4	50.8-100	74.2-96.9
Kruskal-Wallis	p=0.487			p=0.831			p=0.516		
	RSF		36mm		32mm				
	Pre-op vs 3 months	3 months vs 12 months	Pre-op vs 3 months	3 months vs 12 months	Pre-op vs 3 months	3 months vs 12 months			
Wilcoxon signed-rank	p=0.005*	p=0.043*	p=0.018*	p=1.000	p=0.012*	p=0.588			

Expectation Questionnaires

Table 4.7 shows descriptive and inferential statistics for the general activity levels element of the expectations questionnaire. Kruskal-Wallis tests showed significant differences in activity levels between the groups prior to onset of OA. The results of the Mann-Whitney U, post-hoc, tests highlighted a significant difference prior to onset of OA between the RSF and 32mm groups (p=0.017) and between the 36mm and 32mm groups (p=0.016) at the same time point. No other significant results were noted between the groups.

Table 4.7 Statistical results for the general activity levels for the three groups at the three time points (* = significant).

	Time points											
	Prior to onset			Pre-op			3 months			12 months		
	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm
Mean (SD)	4.70 (0.48)	4.86 (0.38)	3.56 (1.01)	2.20 (1.03)	2.43 (0.98)	1.78 (0.67)	3.20 (0.63)	3.43 (1.40)	2.89 (1.27)	3.80 (1.00)	4.00 (2.52)	3.20 (0.84)
Range	4-5	4-5	2-5	1-4	1-4	1-3	2-4	2-5	1-5	3-5	3-5	2-4
Kruskal-Wallis	p=0.007*			p=0.371			p=0.662			p=0.698		

The Friedman ANOVA showed significant within group differences in general activity levels for RSF (p=0.008) and 32mm (p=0.022) groups. Wilcoxon signed-rank tests (Table 4.8) found significant differences within these two groups. These results showed a significant reduction in general activity levels pre-surgery and 3 months post surgery compared to how active the patients felt they had been before developing OA in the RSF group and a significant increase at 3 months post surgery compared to pre-surgery. The 32mm group showed a significant increase in general activity levels at 3 months post surgery compared to pre-surgery.

Table 4.8 Results from within group analysis of general activity using Wilcoxon signed-rank test for the RSF and 32mm groups (*=significant).

	RSF			32mm		
	Prior	Pre	3 months	Prior	Pre	3 months
Pre	0.006*			0.011		
3 months	0.010*	0.015*		0.332	0.028*	
12 months	0.102	0.066	0.180	0.317	0.041*	1.000

Kruskal-Wallis analysis of sport/leisure activity levels between the three groups showed significant differences prior to onset of OA, at pre-surgery and at 3 months post-surgery (Table 4.9). Post-hoc analysis on these three significant results highlighted significantly higher levels of activity for the RSF group compared to the 32mm group prior to onset (p=0.013) and three months post-operatively (p=0.028). In addition there was a significantly higher level of sport/leisure activity for the 36mm group compared to the 32mm group, prior to onset (p=0.012), pre-operatively (p=0.031) and three months post-operatively (p=0.042).

Table 4.9 Statistical results for the sport/leisure activity levels for the three groups at the three time points (* = significant).

	Time points											
	Prior to onset			Pre-op			3 months			12 months		
	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm	RSF	36mm	32mm
Mean (SD)	3.90 (0.88)	4.14 (0.90)	2.22 (1.30)	1.50 (0.71)	2.29 (1.11)	1.11 (0.33)	2.90 (1.10)	3.00 (1.41)	1.56 (1.01)	3.80 (0.45)	2.00 (1.00)	1.60 (0.55)
Range	3-5	3-5	1-4	1-3	1-4	1-2	1-4	1-5	1-4	3-4	1-3	1-2
Kruskal-Wallis	p=0.011*			p=0.030*			p=0.037*			p=0.214		

Within group analysis for sport/leisure activities was carried out using the Friedman ANOVA test and found a significant difference within the RSF group over the time points (p=0.006), but in no other groups. The Wilcoxon signed-rank test was used to further investigate the RSF group in detail (Table 4.10). This analysis determined that there was a significantly lower sport/leisure activity level in the RSF group at pre-

operation and 3 months post-operation compared to their perceived sport/leisure activity level prior to OA onset. Their pre-operative sport/leisure activity level was significantly lower than that at 3 months and 12 months post-operatively. There was also a significantly lower activity level at 3 months post-operatively compared to that at 12 months post-operatively.

Table 4.10 Results from within group analysis of sport/leisure activity using Wilcoxon signed-rank test for the RSF group (*=significant).

	RSF		
	Prior	Pre	3 months
Pre	0.004*		
3 months	0.026*	0.014*	
12 months	0.317	0.041*	0.046*

Statistical data for the expectations element of the questionnaire, administered at 3 and 12 months following surgery are shown in Table 4.11. No significant effects were found using the Kruskal-Wallis test at either 3 or 12 months between the groups, therefore no post-hoc testing was performed.

Table 4.11 Descriptive and inferential statistics for the general and sport/leisure activities achievement of expectations between groups.

	Time points					
	3 months			12 months		
	RSF	36mm	32mm	RSF	36mm	32mm
	General activity					
Mean (SD)	3.40 (0.97)	3.86 (1.35)	3.56 (0.88)	4.40 (0.89)	4.33 (1.15)	4.60 (0.55)
Range	2-5	2-5	2-5	3-5	3-5	4-5
p	0.582			0.697		
	Sport/leisure activity					
Mean (SD)	2.80 (1.03)	3.57 (1.62)	3.11 (1.62)	3.60 (0.55)	4.00 (1.73	4.60 (0.55)
Range	1-4	1-5	1-5	3-4	2-5	4-5
p	0.534			0.209		

Wilcoxon signed-rank tests were performed on the general and sport/leisure expectations achieved within the groups between 3 and 12 months post-operatively

(Table 4.12). Only one significant result was found, the 32mm group rated their general achievement of expectations higher at 12 months post-operation compared to 3 months post-operation.

Table 4.12 Results from within group analysis of general and sport/leisure expectations using Wilcoxon signed-rank test (*=significant).

	General			Sport/Leisure		
	RSF	36mm	32mm	RSF	36mm	32mm
p	0.180	0.108	0.046*	0.157	1.000	0.157

Table 4.13 shows descriptive and inferential statistics for the overall general expectation scores. No significant between groups differences were identified by the Kruskal-Wallis test and the Friedman ANOVA test identified no significant differences within groups, therefore no further analyses were performed.

Table 4.13 Statistical analysis of general expectations scores.

	Time points								
	Pre-op			3 months			12 months		
	RSF	36m	32m	RSF	36m	32m	RSF	36m	32m
Mean (SD)	6.30 (3.09)	7.1 (2.27)	8.33 (0.71)	4.20 (3.05)	2.57 (3.78)	4.00 (3.55)	2.80 (3.56)	1.00 (1.00)	2.60 (3.44)
Range	1-9	3-9	7-9	1-9	0-9	0-8	0-9	0-2	0-8
Kruskal-Wallis	P=0.598			P=0.266			P=0.479		
	RSF			36mm			32mm		
Friedman Anova	P=0.135			P=0.150			P=0.082		

4.4 Discussion

This study found no significant differences between the three study groups pre-surgery in any of the three orthopaedic scores questionnaires, which indicates that the groups were equally symptomatic at the baseline condition. One of the criticisms of non-randomised studies of hip replacement interventions is that the groups are biased [17,

164, 165]. This is unavoidable if the best interests of the patient and ethical considerations are put to the fore. This study is no different and the groups do follow patterns with the 32mm group being exclusively female, the 36mm group being exclusively male and the RSF group being predominantly male and younger than the other two groups. The results presented here, however, show that, despite the differences in the groups, they were equally matched in terms of disability prior to surgery. Another positive feature of the groups is that there were no significant differences in the mean age between the groups. This allows the groups to be compared from an even baseline.

This study aimed to determine if there were significant differences in the effectiveness of three different hip replacement implants for OA. The fact that there were no significant differences in the three orthopaedic questionnaires at either of the two post-surgery time points indicates that neither intervention was significantly better than the others at restoring function and removing pain according to patient perception. These results should not have too much weight put on them. Questionnaires such as these may not have the sensitivity to identify the small differences in function which could be present between the three groups. In general, these questionnaires are used to determine if an intervention has made an improvement in the level of pain and function, approaching those expected of the asymptomatic population. They were not designed to identify the subtle differences between two or more symptomatic groups. The Oxford Hip Score, for example, was specifically designed to assess patients undergoing hip replacement surgery [108] and, given the success of such surgery, scores would be expected to reach the higher levels unless there were major complications following the procedure. It has been suggested that the HHS is not suitable for use with hip replacement patients as it exhibits ceiling effects which commonly occur with such

patients [166]. In studies where two or more groups are compared, orthopaedic scores tend not to identify differences between intervention methods post-operatively and are used simply to confirm that the intervention has delivered a successful outcome [9, 10, 18].

To this end the questionnaires showed that the interventions had a significant positive benefit to of the patients. All three groups showed a significant increase in all three orthopaedic scores at 3 months post-operatively compared to that pre-operatively. There is also evidence that further improvements were made between 3 and 12 months post-operatively. The OHS and the WOMAC scores suggest that the RSF group improved significantly over this time period. This is partly due to the RSF group reporting lower mean scores at 3 months post-operatively compared to the 36mm group on all three questionnaires and also by the RSF group having higher means scores at 12 months post-operatively than the other two groups. These results support the belief that RSF patients are better placed than THR patient to have a more successful outcome due to their younger age and higher activity levels [14, 16, 17, 49].

It was for this reason that the additional expectations questionnaire was used. These results show that both the RSF and 36mm groups had a higher level general of activity than the 32mm group. The RSF patients were younger than the THR patients, although they were not more active than one THR group, the 36mm group. The 36mm group, however, exhibited no within group effects over the four time points. This suggests that this group remained relatively active throughout the disease and recovery stages. The other two groups, on the other hand felt that they were less active at the time of surgery compared to how active they were before OA became a problem. All groups returned, at 12 months, to similar activity levels they believed they had prior to onset.

Both the RSF and the 36mm groups were more active in sport and leisure prior to onset than the 32mm group. Like general activities, the 36mm appeared to maintain a similar level of sport/leisure activity throughout the disease and recovery stages. An example of this is that one of the patients in this group reported at the pre-operative testing session that they were still playing golf. As a result, they were also more active than the 32mm group in sport/leisure pre-operatively and at 3 months post-operatively. The RSF group were the only group which exhibited within group differences at any of the time points. The only non-significant difference between the time points was between the score for prior to onset and at 12 months post-surgery. The suggestion here is that the RSF group were the only group that felt that the disease and recovery stages had an impact on their enjoyment of sport and leisure activities.

At each time point, patients were asked to select from a list of nine expectations those which they would like to achieve. If they selected the item "Resume a sporting, outdoor or leisure activity", they were asked to state what this/these activity or activities were. Six out of the nine 32mm group members selected this item, although only three of the activities specified could be classed as strenuous (swimming, hiking and gym work). The patient who wished to return to gym work had achieved this expectation by 3 months post-surgery, while the other two patients had still to achieve these expectations. Neither of these two patients was included in the 12 months post-operative analysis.

All, but one of the 36mm patients expressed a desire to return to sporting, outdoor or leisure activity. The one who did not was also the oldest participant recruited. Only three of the eight patients stated an activity which could be classed as strenuous (gym

work, swimming and cycling and swimming). The patient who wished to return to swimming and cycling did so 12 months post-surgery, but not at 3 months post-surgery. The other two patients, who were not included in the 12 months post-operative analysis, had still to achieve their expectation at 3 months post-operatively.

All of the RSF group patients selected the "Resume a sporting, outdoor or leisure activity" expectation. In all instances these were strenuous in nature and included swimming, golf, jogging, cycling and gym work. None of these patients had achieved their expectations in this area at three months post-operatively and only two of the five included in the 12 months post-operative analysis had reached their achievement at 12 months post-operatively.

Some of the results from the expectations questionnaires do not support the theory of RSF patients having characteristics which make them more likely to have a successful outcome [14, 33, 48]. The 36mm THR group were as active in sport and leisure as the RSF group prior to the onset of OA according to the activity levels reported. In fact, apart from having an older mean age, the 36mm group had more similarities to the RSF group than the 32mm group. In addition to the gender difference, they were more active and their preferred activities were more strenuous than those in the 32mm group. This study has highlighted very different characteristics between the two THR groups. This could suggest that across the range of THR patients there are a wide range of characteristics which means that they should not be treated as a homogenous group.

There is a suggestion in the data presented, however, that the RSF group may be more demanding than the 36mm group. The sport/leisure activity levels appear to show the

36mm group to be as active as the RSF group, although when expectation achievements are included in the analysis, differences seem to be present. The RSF group were generally involved in more strenuous activities and since they had generally not achieved their sporting aims post-operatively, there is a suggestion that they want to perform better in those activities before they are satisfied. Further evidence of this could be that the RSF group had mean scores on all of the orthopaedic questionnaires which were slightly lower than those of the 36mm group pre-operatively and at 3 months post-operatively. This could be an indication that they perceived their function to be low compared to their expectations, whereas the 36mm group perceived that they were closer to their expectations and felt less disabled by OA. The 32mm group were less active and had lower expectations of what they hoped to achieve following surgery than the 36mm and RSF group.

Like other studies which have used HHS, OHS and WOMAC questionnaires, the current study found that patients showed an improvement post-operatively compared to their pre-operative scores. The expectations questionnaire was bespoke, although other studies have measured expectations of hip reconstruction patients. It has been reported that active younger males are more likely to have higher post-operative activity levels [56]. This study [56] also suggested that pre-operative activity, gender and age were greater predictors of post-operative activity than the implant used in surgery. The current study is in agreement with this suggestion to a degree. The group with the lowest pre-operative sporting activity level was the 32mm group. This was an older female group, while the all male 36mm group and predominantly male RSF group had higher pre-operative sporting activity levels. The 36mm group, however, were of a similar age to the 32mm group. In this study, the implant type itself determined the

demographics of the members of the groups and therefore it could not be said that the post-operative involvement in strenuous sports was independent of the implant. As such, the RSF group matched the demographics suggested to be predictors of better sporting activity levels [56].

Another study also suggested that age and gender were important factors in post-operative activity [13]. They noted a relationship between pre-operative activity and expectations of surgery among a group of THR and total knee replacement patients. They found that those with higher pre-operative activity levels also had the higher expectations of the surgery. They also found that these patients were younger male patients. The current study supports some of these statements. The younger and predominantly male RSF group had higher general and sporting activity levels than the older female 32mm group, however, the RSF group was not more active in general or sport than the older 36mm group. In addition, all three groups in the current study demonstrated a similar degree of having met their expectations. It should be noted that the sport and leisure expectations of the RSF group were more strenuous than those of the 32mm group and, to some extent, the 36mm group.

Another study [167] suggested that patients with poorer pre-operative function had greater expectations of surgery and rated these as more important than those with better pre-operative function. The group in the current study with the poorest pre-operative function, the 32mm group, had no greater number of expectations that they wanted to achieve compared to the two other more active groups did, either before or after surgery. These results suggest that the 32mm group have a lower threshold at which they feel an expectation has been met than the other two groups. It was also noticeable

that the sport and leisure expectations of this group were not as demanding as the other two groups. The study by Mancuso et al. [167] also reported that older males were more likely to have more expectations than patients who are younger or female. The current study does not support this finding.

Few studies of hip reconstruction use patient expectation as an outcome measure. From the clinician's point of view, hip reconstruction is performed to relieve pain and enable patients to walk and perform ADLs and these are also patient expectations of surgery [163], however, many patients may want to achieve more, such as resume a sporting activity or a less demanding leisure activity, as was the case with the patients in the current study. Many reports of patient satisfaction following hip reconstruction surgery have quoted satisfaction rates of over 80% [11-13] and a strong correlation between achieving expectations and satisfaction with surgery is present [163]. There is a possibility that some of the expectations patients have for the surgery may be un-achievable [163], however, another study [168] reported that a group of primary joint replacement patients had expectations which were on a par with those of a group of patients with previous experience of joint replacement surgery. They concluded that the expectation of the primary joint replacement group were realistic. These two studies are separated by six years and location and thus the experience of the two patient groups may not be the same. Like the patients in the current study, those in the study by Moran et al. [168] underwent a process of education prior to surgery which could have influenced their expectations, however, there is evidence from the current study that patients hope to return to activities they enjoyed prior to OA onset. In the case of these patients, those activities were not out with the realms of possibility [73].

It has been suggested that favourable results can occur when patients have preference for a particular intervention [169]. This is an issue which has been raised about RSF as patients are known to ask specifically for the intervention [170] and was the case with some of the patients in the current study. It has been found, though, that no preferential bias was present in a study of two RSF groups, patients with a strong preference for RSF and those who were randomised for an RSF procedure [170].

4.5 Summary

This study has shown that patients presenting for primary hip reconstruction surgery are functionally debilitated and that the intervention allows them to return to levels of function of the healthy population as evidenced by the orthopaedic scores. These scores also demonstrated that patients across the three groups are equally debilitated prior to surgery, however, they did not identify any differences due to the intervention at either of the two post-operative time points.

The RSF and 36mm group were more active generally and in sport/leisure activities than the 32mm group prior to onset of OA. In addition the RSF and 36mm groups were also more active in sport/leisure than the 32mm group at 3 months post-operatively. The RSF group also reported that they wished to return to more demanding activities than the 32mm group and, to some extent, than the 36mm group. Few patients who wished to return to strenuous activity had done so by 12 months post-surgery.

5 Gait and Aging

5.1 Introduction

It is well understood from common knowledge and research that gait patterns are not a constant throughout an individual's life. By the age of 3.5 - 4 years of age, children will have developed sufficiently to perform adult gait kinematics; albeit with some variations [171] and by five years of age the kinetics will be very close to those of adults, although fully mature gait will not be achieved until around nine years of age [172, 173]. In older life gait will change again as a result of neurological or muscular changes [174]. Verghese et al. [175] identified three neurological pathways to gait changes as reduced executive function, memory decline and cognitive impairment.

There have been studies which have investigated gait of the healthy elderly population compared to a group of younger adults, however, many of them have classified the participants into simply young or old. Some studies have grouped the participants into a number of age groups (usually in ten year spans). One study [176] had four groups of participants aged between 20 to 88 stratified by age, however, their aim was to study the vertical movement of the centre of mass across the age groups rather than kinematic and kinetic parameters. Studies which have stratified their participants by age and investigated gait parameters have looked at the spatiotemporal parameters only [177, 178].

One study with four study groups from 40 to 70+ reported that step length, step frequency and double support time showed a worsening trend with increasing age [177]. Another study also reported detrimental changes in step length and step

frequency with increasing age, in addition to gait velocity reduction [178] with the same groups as the other study [177]. One other study compared four groups stratified into four year bands from 70 years to 85+ [179]. They also found that many of the parameters they measured deteriorated with age, however, in these studies there was no direct or indirect relationship between the parameters and age, suggesting that there is variability between participants within the groups.

It was not possible to compare data between these studies. Two of the studies used the same group breakdowns, although one of them normalised the step length and step frequency for leg length [177], while the other did not [178]. These two studies [177, 178] grouped every participant over the age of 70 into a single group, whereas the other study discussed [179] only recruited participants over 70 years. The 70+ group in the Oberg et al. [178] study, however, had a similar walking velocity (118.2 cm/s) to the 70-74 group in the study by Hollman et al. [179] (117 cm/s). There was also slight similarity in the cadence values between these groups (1.91 steps/s compared to 1.7 steps/s), however, there was no similarity for the stride length (52.7 cm against 69 cm).

Two studies investigated a group of healthy participants across a wide age range and used regression analysis to identify age related changes in gait [180, 181]. One of these studies had a study group of 183 participants aged between 60 and 96 years [180]. The other had a study group of 190 participants aged between 32 and 93 years [181], however, they divided the group into just three age dependant groups (32-57 years, 58-78 years and 79-93 years). In addition to differences in spatiotemporal parameters, they also identified age related changes in joint ranges of motion and powers. They reported reductions in ranges of motion (ROM) at the hip, knee and

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ankle in the sagittal and frontal planes with increasing age. They also reported reducing hip power in the sagittal and frontal planes, and ankle power in the sagittal plane with increasing age.

Ankle power deficits in the elderly were also reported in another study [182]. This was a study comparing a group of over 65 year olds with a young group (18-35 years). They also reported differences in hip sagittal plane kinematics, but only in extension. There were also differences in the hip and knee moments which were age-related.

Another study also reported changes in knee moments which were due to aging [183]. This study had two groups of participants; an elderly (mean 72 years) and a young group (mean 25 years). This study, however, found no significant differences in hip or ankle power between the groups.

Previous work identified three features of the spatiotemporal gait parameters: pace, rhythm, and variability; and reported that changes in two of these features (pace and rhythm), equated to reduced executive function and memory loss respectively [175]. This could explain, to some extent, gait differences between the young and the older population.

Few studies have investigated age related gait kinematics or kinetics. Those which have, have tended to compare a young group to an older group. The one study found which had a wide range of ages from young to old divided the participants into three broad age groups [181]. No studies appear to have attempted to track gait changes in

gait kinematics, and kinetics over time as people age. This study aims to address this omission by investigating kinematic and kinetic gait parameters in addition to spatiotemporal parameters to determine whether there are any patterns of decline in gait over time.

5.2 Method

Details of the recruitment, testing and processing of the control participants are given in Chapter 3. These participants were allocated to one of six groups based upon age at the time of testing. Table 5.1 gives demographic details of the control participants.

Table 5.1 Demographic data for the control participants.

	Mean Age	Side (r/l)	Gender (m/f)	Mass (Ave)	Height (Ave)	Total
20s	24.8	7/2	5/4	73.0	1.695	9
30s	33.0	2/0	2/0	80.5	1.728	2
40s	46.0	7/0	3/4	69.7	1.718	7
50s	55.4	12/1	1/12	71.8	1.655	13
60s	64.4	18/2	8/12	65.1	1.543	20
70s	74.2	10/2	4/8	68.8	1.625	12
Total						63

After the testing and data processing, the relevant data were extracted from the output files and imported into SPSS. Data for each member of each group were grouped together for analysis. Kruskal-Wallis tests were preformed on a number of spatiotemporal, kinematic and kinetic parameters.

Based on previous studies which have reported age related differences in gait parameters between younger and older persons, the following parameters were analysed:

Spatiotemporal

- Walking velocity
- Cadence
- Stride length
- Double support time

Kinematic

- Hip sagittal plane ROM
- Hip frontal plane ROM
- Knee sagittal plane ROM
- Knee frontal plane ROM
- Ankle sagittal plane ROM
- Ankle frontal plane ROM

Kinetic

- Peak hip extension moment
- Peak knee extension moment
- Hip power
- Ankle power

5.3 Results

Spatiotemporal Parameters

Table 5.2 shows the spatiotemporal data for the six groups that were investigated. The Kruskal-Wallis analysis showed no significant differences between the groups in any of the spatiotemporal parameters investigated. Figure 5.1 shows the graphs of the spatiotemporal data. When looking at trends, double support time (Figure 5.1 (d)) appears to have a reducing trend, however, outlying values at 30 and 70 years prevent this from being a complete trend. Between the 20 year old group and 60 year old group, there was a 16% reduction in double support time from 0.23 to 0.19 seconds.

There was a noticeable drop in the mean cadence (Figure 5.1 (b)) from the 50 to 70 year old groups from 126 to 115 steps/min, a reduction of 8%, however, this was offset by the low cadence values for the younger groups. There was no overall trend in the walking velocity (Figure 5.1 (a)); however, there was a large reduction in velocity from around 1.4m/s to 1.2m/s between the 60 and 70 year old groups. Like the walking velocity, the stride length (Figure 5.1 (c)) also exhibited a large decrease from around 1.38m to 1.25m between the 60 and 70 year old groups. There was no obvious trend in the data due to variability between the groups.

Table 5.2 Results of the between groups Kruskal-Wallis analysis for walking velocity, cadence, stride length and double support time.

	Walking velocity	Cadence	Stride length	Double support time
p	0.407	0.855	0.646	0.244
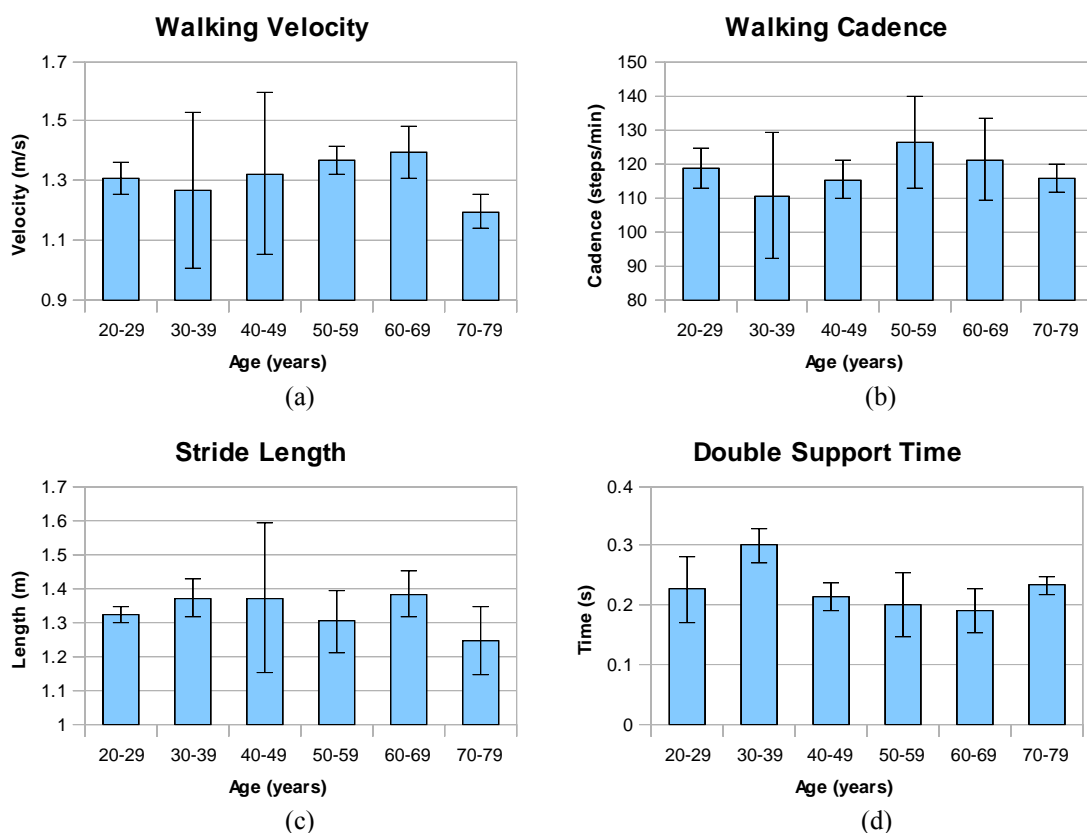
Figure 5.1 (a-d) Graphs showing means for each age group for (a) walking velocity, (b) cadence, (c) stride length and (d) double support time.

Kinematic Parameters

Kinematic data were analysed across the age ranges (Table 5.3). No differences were found in any of the parameters analysed. Figure 5.2 shows plots of each of the parameters across the ages. There appears to be a trend in the hip abduction/adduction ROM (Figure 5.2 (b)) with the range reducing with increasing age. Between the 20 year old group and the 70 year old group there was a distinct reduction in the ROM from approximately 15º to approximately 6º in the peak abduction angle, representing a 58% reduction. A similar trend was apparent in the knee flexion/extension ROM (Figure 5.2 (c)) with the range reducing with increasing age. There was a continuous reduction in the ROM from the 20 year old group to the 70 year old group, however, the difference was only around 7º which represented a 12% reduction in the range of knee flexion over 4 decades. There was a trend for the ankle inversion/eversion ROM (Figure 5.2 (f)) to increase with increasing age. This increase represented a 77% increase in ROM from around 3º to 5.25º between the 20 year old group and the 70 year old group. None of these trends was a direct linear relationship as each parameter has data which was off the trend line.

Table 5.3 Results of the between groups Kruskal-Wallis analysis for hip, knee and ankle sagittal and frontal plane ranges of motion.

	Sagittal Plane			Frontal Plane		
	Hip ROM	Knee ROM	Ankle ROM	Hip ROM	Knee ROM	Ankle ROM
p	0.842	0.184	0.331	0.081	0.240	0.194
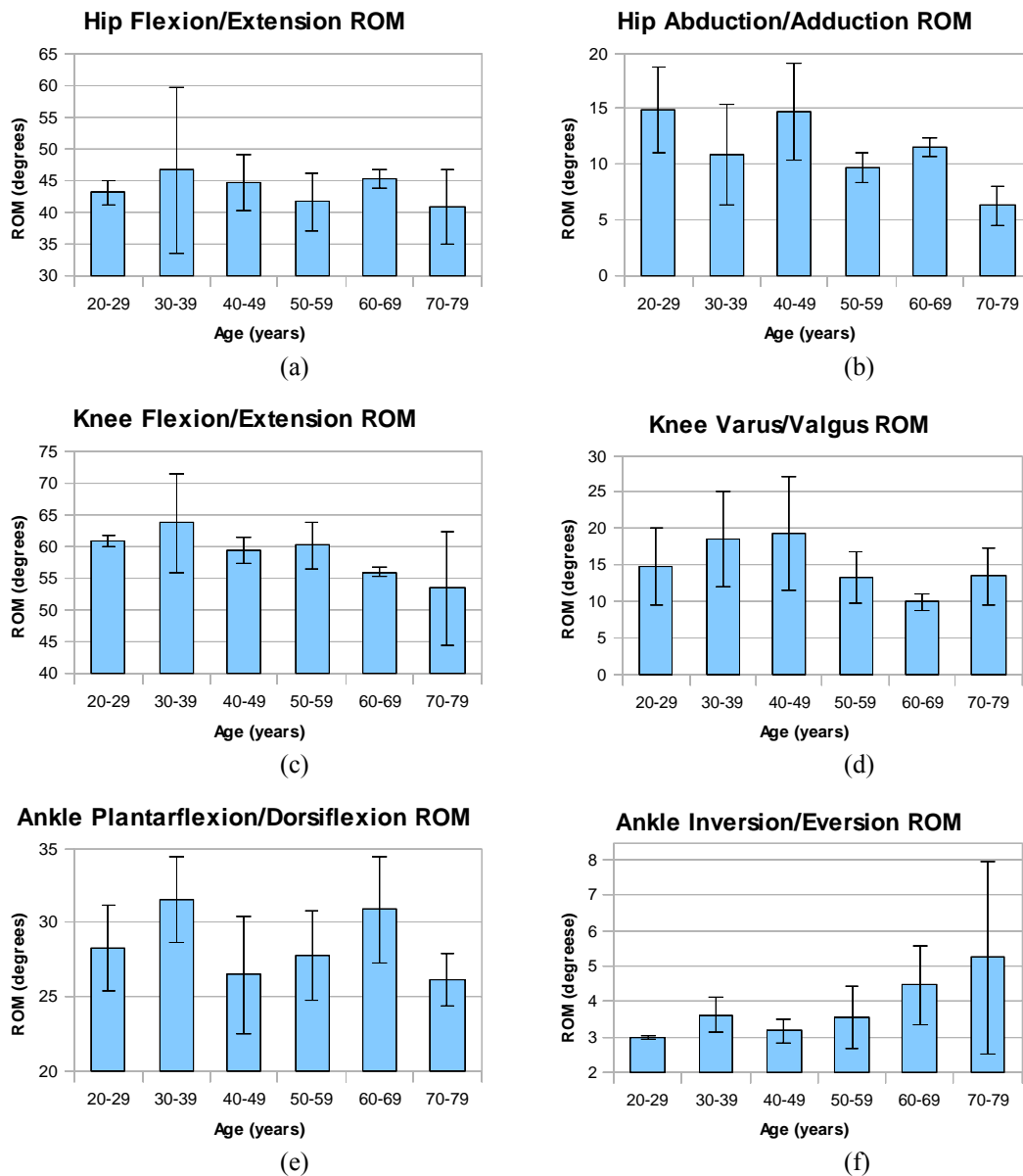
Figure 5.2 (a-f) Graphs showing means and standard deviations for each age group for (a) hip flexion/extension ROM, (b) hip abduction/adduction ROM, (c) knee flexion/extension ROM, (d) knee varus/valgus ROM, (e) ankle planterflexion/dorsiflexion ROM and (f) ankle inversion/eversion ROM.

Kinetic Parameters

Table 5.4 shows the statistical results for the kinetic parameters investigated. No age related differences were noted in these parameters. Figure 5.3 shows plots of the mean data across the groups. There were no trends in either the hip or ankle power (Figure 5.3 (c & d)). The hip extension moment (Figure 5.3 (a)) exhibited an almost constant peak value across the entire range of age groups. Between the 20 year old group and

the 60 year old group there was a trend of increasing peak knee extension moment (Figure 5.3 (b)) of around 172%, however, the 70 year old group exhibited a lower peak than the 60 year old group. If the 70 year old group are included, the increasing trend reduces to 70%.

Table 5.4 Results of the between groups Kruskal-Wallis analysis for hip and knee peak extension moments and hip and ankle peak powers.

	Hip extension moment	Knee extension moment	Hip power	Ankle power
p	0.992	0.201	0.491	0.862
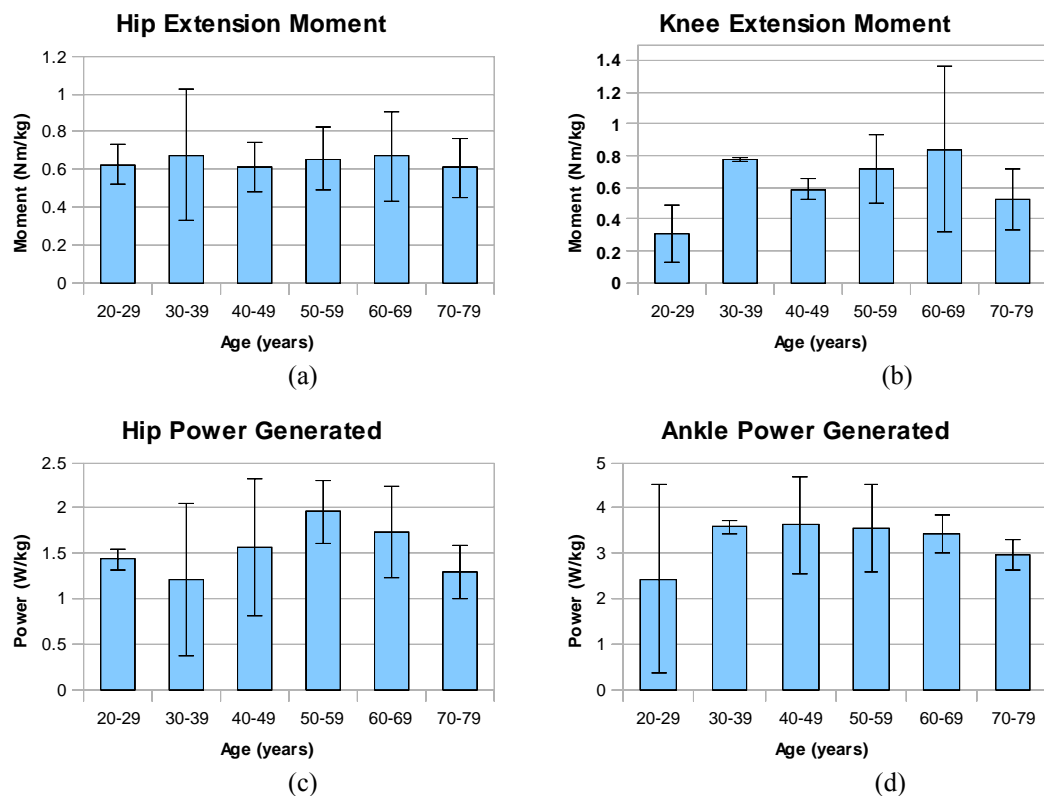
Figure 5.3 (a-d) Graphs showing means for each age group for (a) peak hip extension moment, (b) peak knee extension moment, (c) peak hip power generated and (d) peak ankle power generated.

5.4 Discussion

The analysis revealed no significant differences between the groups for any of the parameters, although there were some trends in the data. One of the parameters which

exhibited a trend was the double support time. The double support time reported in this study (0.23s) is slightly lower than those previously quoted (range 0.26s to 0.34s) [175, 184]. This study also identified that the double support time, which has been reported as increasing with increasing age [174], occurs after 60 years of age. The trend identified was a decrease in the parameter between 40 to 60 years. This goes against what would be expected. Single leg support is less stable than double leg support as the CoM lies outwith the base of support [185] and double limb support would be less hazardous to those with muscle strength, reduced balance control and neurological deficiencies associated with old age [174, 185]. It has also been suggested that double support time increase in old age could be as a result of reduced ankle power at push-off due to weakness of the plantar flexion muscles [185]. This study partially supports this suggestion due to the 70 year old group exhibiting reduced ankle power and increased double support time.

Cadence in the current study ranged from 110 to 126 steps/min with a mean of 117 steps/min, which is within the range reported by previous studies (92 to 119 steps/min) [52, 175, 179, 180, 182-184, 186]. Two studies which compared a young and an old group reported values for cadence of 107 step/min [183] and 119 step/min [182] for their young groups, which are in line with the cadence values in the current study for the 20 to 40 year old groups. In the current study, the 70 year old group had a cadence of 115 steps/min, which does not agree with previously reported data for this age group [179, 186].

It has been reported that cadence reductions with increasing age could be as a result of memory loss [175]. This could explain the sharp decline in cadence in the current study between the 50 year old and the 70 year old groups, however, there could be

other factors. Reduced muscle strength [174, 187] could reduce the ability to propel the body or the swinging limb forward. Previous work has suggested that ankle power reduces with increasing age as a result of muscle weakness [185]. This could reduce the cadence and indeed the reduction in cadence between the 50 year old and the 70 year old groups is matched by a reduction in ankle power across these groups.

A previous study identified age related changes in spatiotemporal gait parameters including a decrease in the walking velocity [174]. This study has also shown a similar reduced walking velocity occurring in the 70 year age group compared to the other groups. This study also agrees with the findings of Himann et al. [188] who reported that such changes begin to occur after the age of 63 years. Two studies reported walking velocity values of 1.2m/s for groups of 70 year olds [178, 179] which is consistent with the value reported in the current study for the 70 year old group. Another study reported slightly lower values (1.1m/s) for the same age group [186]. Only one other result for walking velocity in the current study is consistent with other age stratified data. The walking velocity for the 40 year old group of 1.3m/s agrees with the value quoted by Oberg et al. [178] for their 40 year old group. Two studies which reported data for young mixed age groups reported walking velocity values of 1.3m/s [183] and 1.4m/s [182], which are consistent with the values reported in the current study for the 20 to 40 year old groups.

It has been reported that walking speed decreases with increasing age by 0.1% to 0.7% per year [178] and that by the age of 63 the reduction increases to 12% to 16% per decade [188]. This study showed no trend for reducing walking speed between 20 year old group and the 60 year old group, therefore the figures quoted by Oberg et al. [178] cannot be corroborated. A reduction of 0.23m/s was noticed between the 60

year old group and the 70 year old group, which equated to a reduction 16%. This reduction was within the range quoted by Himann et al. [188].

The suggestion that there could be a 0.1% to 0.7% per year reduction in walking velocity appears to be applying strict criteria to an inherently variable parameter. A number of studies including this one have performed gait analysis on the elderly population and have measured widely different values for walking velocity [175, 179, 184, 186]. It should be noted, however, that in the study by Callisaya et al. [184] the participants were a random sample from the local population and thus where not without conditions which could influence their gait. For example, 44% of the participants had arthritis and 8% had Parkinson's disease. In contrast, participants in the study by Hollman et al. [179] were screened and excluded if they had a variety of conditions including Parkinson's disease. Additionally, eligible participants were grouped by age into groups spanning 5 years. They quoted 1.17m/s for the 70-74 and 1.22m/s for the 75-79 male groups respectively which shows a 4% increase rather than a decrease. In the current study, participants were volunteers and were excluded if there had any conditions which could influence their ability to walk. Having volunteered to take part, there was also the likelihood that they would be more active and healthy than some people of a similar age.

The walking velocities reported in the current study, do agree with Himann et al. [188] regarding the reduction in walking speed of 12% to 16% per decade after 60 years of age. Few other studies have stratified their participants into age bands, however one study which did showed a reduction close to the range reported (11%) between the 70 and 80 year old males groups and 13% from their female group [179].

Another study reported smaller reductions in the walking speed of 8% and 4% for males and females respectively between groups of 60 and 70 year olds [178].

Previous studies have investigated stride length across different age groups. One study reported a mean stride length of 1.38m for their two groups of participants in their eighth decade [179]. This value is the same as the value reported in the current study for the 60 year old group. The 70 year old group in the current study, by contrast, had a shorter stride length of 1.25m. Other studies with an elderly participant group have reported shorter stride lengths of around 1.1m [175, 180, 182]. Studies which have investigated younger adults report longer stride lengths. These studies have reported stride lengths in the region of 1.4m [182, 183], which are longer than the stride lengths reported in the current study for the 20 and 30 year old groups.

Stride length is one of the factors which impacts on walking velocity [180, 182]. In the elderly, there is evidence that the selection of the stride length is aimed at producing the most efficient use of available energy [180]. This would suggest that the elderly population have less available energy which would be supported by the reduced joint powers in the elderly reported in the current study and previous studies [180-182]. There is evidence, however, that additional energy is available to be called upon when required, such as when asked to walk at a faster pace [182].

According to Verghese et al. [175], reductions in pace parameters such as walking velocity and stride length with age are a function of reduced executive function. This could have an effect on the ability of an individual to plan their movements, especially when multi-tasking. In gait, this could mean a requirement to take more

time to plan the actions and result in reduced walking speed. Alternatively, it may introduce anxiety regarding the ability to perform a task safely and tentativeness could result in shortened stride length. Other researchers, however, have identified changes in the musculoskeletal system, such as muscle degeneration and joint stiffness, which could be responsible for the changes identified with advancing years [187]. It has been reported that people who tend to volunteer are more active than those without a voluntary nature [189]. Given that the majority of the older members of the study group made initial contact to volunteer for the study, the elderly participants may be more active than the general elderly population. No measures were taken to determine activity levels or muscle strength and it was out of the remit of this study to investigate the causes of any changes in gait parameters identified. It is likely that a combination of neurological and musculoskeletal factors were responsible for the changes found.

Rhythm-specific parameters, such as cadence, are influenced by memory decline [175]. All participants had to be free from conditions which could influence their ability to perform the task. This could discourage those suffering from mild dementia from volunteering to take part. In addition it has been suggested that people who volunteer for research studies may not be a representative sample of the population [190]. It is possible that these factors could have contributed to this study not finding differences in cadence between the groups.

Two studies have reported joint ROMs in the sagittal and frontal planes with participants from a range of ages [180, 181]. One of these studies had a participant group ranging in age from 60 to 96 years [180] and reported a hip sagittal plane ROM of around 40°. The other study grouped their participants, aged between 32 to 93

years, into three age specific groups and reported little difference between the groups with all values for hip flexion/extension ROMs around 40°. The current study reported greater hip flexion/extension ROMs across all the age groups. Values reported for knee flexion/extension ROM were 52° and 57° [180, 181]. One study reported an age related reduction in knee sagittal plane ROM [181]. The current study reported higher values across all the age ranges, although there was also an apparent trend of reducing knee sagittal plane ROM with age. The current study reported no trend for ankle plantarflexion/dorsiflexion ROM, whereas one study reported a reducing ROM at the ankle [181]. Again the current study generally reported higher values.

The study by Ko et al. [181] reported a trend of reducing hip frontal plane ROM with increasing age. This was also the case with the current study, although there were some values which lay either side of the trend line. The oldest group in the current study had a lower frontal plane ROM at the hip than has been reported in previous studies for similarly aged participants [180, 181]. The data in the current study do not show a linear trend in the knee frontal plane ROM data, although the younger groups in the current study (20, 30 and 40 year olds) all exhibited larger ROMs than the three older groups. This is not in agreement with previous studies which have reported values for this parameter which are generally lower than those reported in the current study and which show almost no variation across the age ranges [180, 181]. The current study indicated a slight trend for the ankle frontal plane ROM to increase with age. Another study reported no trend in the parameter [181], although it did report a lower value for the very elderly participants compared to the younger ones; as did another study [180].

The current study reported a peak knee extension moment for the 20 year old group of 0.31Nm/kg, a value which agrees with data from another study with a young group of participants (mean age 25 years) [183]. The same study, however, also reported data for an older group (mean age 72 years) which had a much lower value for peak knee extension moment (0.23 Nm/kg) compared to the current study (0.53Nm/kg) [183]. Additionally, the current study showed this parameter increasing with increasing age, whereas the other study reported a lower value for the older group [183].

A previous study reported hip and ankle power data for a young and an old group [182], finding that the peak power at the hip and ankle were greater in their younger group (18 to 35 years) compared to their older group (>65). The current study had more variation in the hip joint power between the groups and does not show a difference between the older and younger groups. The 20 year old group had a large variability in the ankle power data and had this not been the case there may have been a trend of reducing ankle power with age as reported previously [182].

Another study has identified that ankle plantarflexion power is reduced in the less functional elderly compared to the healthy elderly [191]. Power generated by the ankle in late stance provides a propulsive movement to continue forward motion during ambulation and could contribute to some of the gait differences which have been observed with increasing age [182]. This could be partly responsible for the reduction in walking speed and the reduced stride length. The current study identified a slight reduction in ankle power from 3.62 W/kg to 2.97 W/kg from the 40 year old group to the 70 year old group.

Few studies have investigated changes in gait during the aging process and many of those have investigated spatiotemporal parameters only. One early study reported kinematic, in addition to, spatiotemporal parameters using photographic methods [192]. They found no progressive changes in spatiotemporal parameter with age, but reported that the over 60 year olds had shorter step and stride lengths. Within the kinematic parameter, they found a small effect of age on reducing hip flexion/extension ROM. The current study found no significant differences between adjacent groups or between the youngest and oldest groups. The lack of differences between adjacent groups is understandable. If there was a linear degradation in gait parameters over time, any changes between adjacent groups may be too small to be significant. Another point to be considered is the inherent variation during the act of walking. A standard sequence of events and movements are required to perform the task of ambulation, although within individuals variations in these parameters will occur. Within and between individual variations could lead to overlaps between adjacent groups.

It is less understandable, however, that no difference was found between the youngest and oldest groups in the study. Part of the reason for this could lie with the participant group. All participants had to have no condition which could have a detrimental effect on the ability to perform the task. This would have excluded persons with many of the conditions which effect the elderly population which influence walking ability. In addition, all participants were volunteers, many of whom had responded to a call for participants rather than being approached. It is possible that participants recruited in this manner would to be more motivated than the general elderly population and may

be more active and healthy. These issues suggest that participants in the study may not be representative of the wider population.

Another possible reason for the lack of significant differences is the numbers involved in the study. The participants were primarily recruited as control participants for the hip reconstruction study and as such the majority of the participants are in the age range most associated with the majority of hip reconstruction patients. As a result, the younger groups are not so well represented as those 50 and older.

5.5 Summary

Age related changes in gait parameters have been reported and this study aimed to identify age related changes in kinematic and kinetic gait parameters. This study found no significant differences in gait parameters between age stratified healthy individuals. There did appear to be some apparent trends in the data with some parameters seeming to show decreasing function with increasing age. There appeared to be a trend for a reduction in both the hip abduction/adduction ROM and knee flexion/extension ROM with increasing age.

6 Hip Reconstruction – Level Walking

6.1 Introduction

Level walking is one of the primary activities of daily living and ability to perform it is one of the outcome measures often used to determine the success of hip reconstruction surgery. It is included in all of the main orthopaedic questionnaires and is often evaluated visually by health care professionals. Gait analysis of level walking is now commonly used for evaluating post-operative outcomes following hip reconstruction surgery particularly to identify small differences between the healthy population and a patient group or between two patient groups that have undergone different interventions. As a result, numerous studies have used modern motion analysis techniques to evaluate level walking gait with post-operative THR and resurfacing patient groups; however, they have not been performed in a consistent manner. Studies have measured different gait parameters, using different patient populations and methods, making it difficult to compare the results across studies [23].

Femoral head size is expected to have a major influence on the functional outcome of THR, however, considering the importance of this parameter, it is often not controlled for in gait analysis studies. There are studies which make no statements about the head size used in the study groups [8, 9, 54, 58, 60]. Even a study which aimed to compare function following THR to that following hip resurfacing failed to specify the head size used for the THR group [14].

This study aimed to investigate the level walking gait of three groups of hip reconstruction patients who have had implants with differing femoral head sizes to determine whether the larger head sizes produce more natural level gait than smaller head sizes.

6.2 Method

Chapter 3 gives details of patient and control group recruitment and a description of the testing procedure. After each participant had completed the preliminary stages (completed paperwork, had demographic and anthropometric data collected, had markers attached and static trial performed), testing began with the combined level walking and stair use task. These tasks were performed in a single trial to reduce the length of the testing session, to reduce the physical burden on the participants and also to make the stair ascent and descent task like everyday life. Stair use testing will be discussed in detail in Chapter 7.

Participants were told that they were to start at a pre-defined position at one end of the walkway, but that this may be altered. On an instruction from the author, they would begin walking along the walkway in a natural manner. The instruction to start would also state which foot to lead with. Initially, they would lead with the right foot until sufficient data had been collected, before switching to the left foot. Participants walked along the walkway to the other end were the staircase was located, continuing up the staircase, with a natural transition from walking to stair climbing, and then stopped on the top platform. Participants would then turn and position their toes on the edge of the top platform. They would then descend the stairs, again with the right foot leading initially, and continue to the other end of the walkway with a natural

transition from stair descent to level walking. Participants were then given an opportunity to practice this task before data collection began.

During these practice sessions, the author observed the foot falls over the force plates in the walkway and the transition into stair climbing. If the participant hit one of the force plates cleanly (i.e. one foot lands on a force plate with the whole foot on the force plate) and the transition from level walking to stair climbing was natural (i.e the participant did not over stride), then no alterations were made. If, however, either of these situations failed to occurr, the author would ask the participant to start from a different position prior to the next practice run.

Once an appropriate starting point had been determined and the participant was comfortable with the task, data collection would begin. Participants would perform the level walking and stair ascent task on three occasions leading with the right foot and three further occasions leading with the left foot. Similarly, the stair descent and level walking task would also be carried out six times; three leading with the right followed by three leading with the left. From these 12 trials it was hoped to achieve three sets of data each for right and left force plate data. If this was not achieved, further trials would be carried out until it was achieved.

Between three and six trials were selected to be included in the study. Preference was given to trials where there were force plate foot falls for both feet in consecutive steps. Each of the selected trials was processed as described in Chapter 3.

The author reviewed previous studies which had investigated post-operative gait patterns of THR patients and identified six spatiotemporal, kinematic or kinetic

parameters for which there was a consensus that differences were present between healthy individuals and post-surgery THR patients [23]. Data for these six parameters were extracted. Data for each parameter were averaged across all of the participants in the group. It was these averaged data which were compared. Data were analysed using one way ANOVA's with post-hoc Bonferroni corrections applied. A 95% confidence interval was used throughout.

6.3 Results

Tables 6.1(a-d) show the walking speed for the three groups and their respective control groups. All three groups exhibited a reduced walking speed prior to surgery compared to their controls, although these were only significant for the RSF and the 32mm groups (p=0.032 and p= 0.0005 respectively). Both of these groups also showed significantly increased walking speeds 12 months post-operatively compared to their pre-operative walking speeds (p=0.039 and p=0.026 respectively).   In addition, the 32mm group had a lower walking speed at 3 months compared to controls (p=0.015). There were no significant differences in walking speed when comparing the 12 months post-operative results with the relevant control group (p= 1.000, p=1.000 and p=0.812 for the RSF, 36mm and 32mm groups respectively).

Table 6.1(a-d) Walking speed data comparing within group data pre-operatively and at 3 and 12 months post-operatively and compared with the control data for (a) RSF group, (b) 36mm group, (c) 32mm group and (d) comparing between the groups at three time points and between the three control groups.

Walking speed (m/s) RSF				
Group	mean (SD, range)	p Pre	3	12
Pre	0.94 (0.23, 0.46-1.16)			
3	1.08 (0.18, 0.73-1.38)	0.918		
12	1.28 (0.07, 1.18-1.37)	0.039*	0.555	
Control	1.25 (0.23, 0.84-1.54)	0.032*	0.598	1.000

(a)

Walking speed (m/s) 36mm				
Group	mean (SD, range)	p Pre	3	12
Pre	0.95 (0.17, 0.70-1.19)			
3	1.08 (0.22, 0.82-1.50)	1.000		
12	1.25 (0.17, 1.12-1.45)	0.179	1.000	
Control	1.23 (0.16, 0.98-1.37)	0.111	1.000	1.000

(b)

Walking speed (m/s) 32mm				
Group	mean (SD, range)	p Pre	3	12
Pre	0.71 (0.24, 0.37-1.02)			
3	0.90 (0.18, 0.64-1.15)	0.417		
12	1.10 (0.07, 1.03-1.17)	0.026*	0.643	
Control	1.31 (0.19, 1.13-1.58)	0.0005*	0.015*	0.812

(c)

Walking speed (m/s) p								
	Pre		3 months		12 months		Control	
Group	RSF	36	RSF	36	RSF	36	RSF	36
36mm	1.000		1.000		1.000		1.000	
32mm	0.145	0.141	0.196	0.246	0.100	0.270	1.000	1.000

(d)

None of the groups showed any improvements at 3 months post-operatively compared to their pre-operative performance (p=0.918, p=1.000 and p=0.417 for RSF, 36mm and 32mm, respectively). Neither did any groups show increases in walking speed between 3 months and 12 months post-operatively (p=0.555, p=1.000 and p=0.643 for RSF, 36mm and 32mm, respectively), however, all groups did exhibit a trend of improving walking speed post-operatively.

The RSF and the 36mm control groups had similar walking speeds of 1.25m/s and 1.23m/s, while the 32mm control group had a higher value of 1.31m/s. Pre-operative walking speeds for the RSF and the 36mm groups were 0.94m/s and 0.95m/s respectively, while the 32mm group had a walking speed of 0.71m/s. These results show that each of the groups exhibited a similar overall improvement of 0.34m/s, 0.30m/s and 0.39m/s (RSF, 36mm and 32mm, respectively) at 12 months compared to their pre-operative walking speeds.

Further examination of the between group results (Table 6.1(d)) showed no differences between RSF and 36mm groups at any time point (p=1.000 for all comparisons). No differences were noted between the 32mm group and the RSF and 36mm groups at any time point (p=0.141 vs 36mm pre-operatively to p=1.000 vs RSF 12 months post-operatively). Table 6.1 (d) also showed no significant differences in walking speed between the three control groups (p=1.000 for all comparisons).

Tables 6.2(a-d) show lower stride lengths pre-operatively for the three groups compared to that of their respective control groups (p=0.022, p=0.003 and p=0.029 for RSF, 36mm and 32mm, respectively). No group showed any significant increase at 3 months post-operatively compared to pre-operatively (p=1.000 in all cases). Neither did any group exhibit differences between 3 and 12 months post-operatively (p=0.812, p=0.452 and p=0.695 for RSF, 36mm and 32mm, respectively), however, at 12 months post-operatively, there were no differences in stride lengths between the patient groups and their respective control groups (p=1.000 in all cases). At 3 months post-operatively, the 36mm group still had a significantly shorter stride length than the control group (p=0.040).

Table 6.2(a-d) Stride length data comparing within group data pre-operatively and at 3 and 12 months post-operatively and compared with the control data for (a) RSF group, (b) 36mm group, (c) 32mm group and (d) comparing between the groups at three time points and between the three control groups.

Group	Stride length (m) RSF mean (SD, range)	p Pre	3	12
Pre	1.08 (0.16, 0.87-1.58)			
3	1.17 (0.20, 0.80-1.50)	1.000		
12	1.31 (0.10, 1.18-1.44)	0.115	0.812	
Control	1.34 (0.14, 1.19-1.55)	0.022*	0.245	1.000

(a)

Group	Stride length (m) 36mm mean (SD, range)	p Pre	3	12
Pre	1.12 (0.10, 1.05-1.33)			
3	1.19 (0.10, 1.10-1.39)	1.000		
12	1.32 (0.13, 1.17-1.41)	0.053	0.452	
Control	1.37 (0.82, 1.28-1.47)	0.003*	0.040*	1.000

(b)

Group	Stride length (m) 32mm mean (SD, range)	p Pre	3	12
Pre	0.90 (0.20, 0.53-1.15)			
3	1.01 (0.13, 0.88-1.21)	1.000		
12	1.17 (0.09, 1.09-1.29)	0.070	0.695	
Control	1.21 (0.13, 1.07-1.38)	0.029*	0.320	1.000

(c)

Group	Stride length (m) p Pre RSF	36	3 months RSF	36	12 months RSF	36	Control RSF	36
36mm	1.000		1.000		1.000		1.000	
32mm	0.119	0.051	0.133	0.101	0.217	0.255	0.274	0.202

(d)

Tables 6.3(a-d) present hip ROM in the sagittal plane. All of the groups demonstrated reduced range of hip flexion/extension prior to surgery compared to their controls ($p<0.001$, $p=0.027$ and $p=0.006$ for RSF, 36mm and 32mm, respectively). No group showed any improvements at 3 months post-operatively compared to pre-operative data ($p=1.000$ for all groups), but the 36mm group was similar to controls at 3 months post-operatively ($p<0.001$, $p=0.156$ and $p=0.044$ for the RSF, 36mm and 32mm, respectively). There were no differences between the 12 month post-operative data and controls ($p=0.133$, $p=1.000$ and $p=1.000$ for RSF, 36mm and 32mm, respectively). Additionally, the 32mm group exhibited an increased hip flexion/extension ROM at 12 month post-operatively compared to their pre-operative range ($p=0.013$).

Table 6.3(a-d) Hip flexion/extension range of motion data comparing within group data pre-operatively and at 3 and 12 months post-operatively and compared with the control data for (a) RSF group, (b) 36mm group, (c) 32mm group and (d) comparing between the groups at three time points and between the three control groups.

(a)

	Hip flexion/extension ROM (deg) RSF			
		P		
Group	mean (SD, range)	Pre	3	12
Pre	27.48 (6.43, 20.23-37.44)			
3	29.06 (6.55, 19.94-42.69)	1.000		
12	36.31 (3.92, 32.68-42.23)	0.091	0.228	
Control	44.79 (5.58, 36.94-51.54)	0.00004*	0.0001*	0.133

(b)

	Hip flexion/extension ROM (deg) 36mm			
		p		
Group	mean (SD, range)	Pre	3	12
Pre	28.73 (12.20, 6.79-41.85)			
3	33.15 (6.79, 24.33-41.16)	1.000		
12	43.42 (4.23, 38.76-47.02)	0.111	0.478	
Control	44.54 (2.53, 40.12-46.23)	0.027*	0.156	1.000

(c)

	Hip flexion/extension ROM (deg) 32mm			
		P		
Group	mean (SD, range)	Pre	3	12
Pre	22.29 (8.89, 12.82-35.30)			
3	26.81 (7.10, 18.52-38.38)	1.000		
12	38.54 (6.20, 30.30-44.86)	0.013*	0.102	
Control	40.29 (5.11, 34.42-45.66)	0.006*	0.044*	1.000

(d)

	Hip flexion/extension ROM (deg) p							
	Pre		3 months		12 months		Control	
Group	RSF	36	RSF	36	RSF	36	RSF	36
36mm	1.000		0.783		0.228		1.000	
32mm	0.863	0.667	1.000	0.258	1.000	0.664	0.457	0.609

Tables 6.4(a-d) give details of the results for the hip flexion moment. No differences between any combinations of group or time period were found. Despite this, all three patient groups exhibited a higher value of hip flexion moment than their control groups pre-operatively and lower values at 3 and 12 months post-operation. The 32mm group showed the greatest improvement, having started from a higher absolute pre-operative hip flexion moment than the other two groups (1.77Nm/kg for 32mm compared to 1.05 and 1.17Nm/kg for RSF and 36mm, respectively), however, the large standard deviations for the pre-operative data for all groups and the 3 month post-operative data for 32mm compared to the means highlights the amount of variation in these data. In these data sets the range of patient data fully encompasses that of the respective controls.

Table 6.4(a-d) Hip flexion moment data comparing within group data pre-operatively and at 3 and 12 months post-operatively and compared with the control data for (a) RSF group, (b) 36mm group, (c) 32mm group and (d) comparing between the groups at three time points and between the three control groups.

	Hip flexion moment (Nm/kg)			
	RSF			
		P		
Group	mean (SD, range)	Pre	3	12
Pre	-1.05 (1.41, -4.35- -0.25)			
3	-0.39 (0.06, -0.49- -0.31)	0.881		
12	-0.51 (0.13, -0.66- -0.33)	1.000	1.000	
Control	-0.79 (0.26, -1.15- -0.52)	1.000	1.000	1.000

(a)

	Hip flexion moment (Nm/kg)			
	36mm			
		p		
Group	mean (SD, range)	Pre	3	12
Pre	-1.17 (1.43, -3.63- -0.18)			
3	-0.43 (0.14, -0.65- -0.28)	0.706		
12	-0.59 (0.20, -0.65- -0.27)	1.000	1.000	
Control	-0.66 (0.30, -1.15- -0.43)	1.000.	1.000	1.000

(b)

	Hip flexion moment (Nm/kg)			
	32mm			
		P		
Group	mean (SD, range)	Pre	3	12
Pre	-1.77 (1.79, -3.86- -0.28)			
3	-0.68 (0.41, -1.36- -0.28)	0.338		
12	-0.45 (0.06, -0.52- -0.38)	0.343	1.000	
Control	-0.72 (0.23, -0.99- -0.43)	0.732	1.000	1.000

(c)

	Hip flexion moment (Nm/kg)							
	p							
	Pre		3 months		12 months		Control	
Group	RSF	36	RSF	36	RSF	36	RSF	36
36mm	1.000		1.000		0.978		1.000	
32mm	1.000	1.000	0.196	0.280	1.000	0.710	1.000	1.000

(d)

Data for hip extension moments are shown in Tables 6.5(a-d). Like the hip flexion moment, there were no significant differences between any combination of groups or time periods. All groups exhibited higher non-significant pre-operative hip extension moments than their respective controls. The 32mm group exhibited a larger difference compared to their control group than the other two groups (1.01Nm/kg compared to 0.52Nm/kg and 0.75Nm/kg for RSF and 36mm, respectively). By three months, all groups had hip extension moments which were closer to their controls than they had been before surgery. Between three and twelve months there was little change in moment for any group, however, it should be noted that there was high variability in the data for all three patient groups pre-operatively and at 3 months post-operatively for the RSF group.

Table 6.5(a-d) Hip extension moment data comparing within group data pre-operatively and at 3 and 12 months post-operatively and compared with the control data for (a) RSF group, (b) 36mm group, (c) 32mm group and (d) comparing between the groups at three time points and between the three control groups.

(a)

	Hip extension moment (Nm/kg) RSF			
		P		
Group	mean (SD, range)	Pre	3	12
Pre	1.09 (1.71, 0.13-5.27)			
3	0.56 (1.10, 0.41-0.69)	1.000		
12	0.58 (0.10, 0.47-0.72)	1.000	1.000	
Control	0.57 (0.13, 0.44-0.83)	1.000	1.000	1.000

(b)

	Hip extension moment (Nm/kg) 36mm			
		p		
Group	mean (SD, range)	Pre	3	12
Pre	1.35 (1.56, 0.27-3.85)			
3	0.56 (0.24, 0.24-0.87)	0.688		
12	0.64 (0.15, 0.54-0.81)	1.000	1.000	
Control	0.60 (0.16, 0.46-0.83)	0.988	1.000	1.000

(c)

	Hip extension moment (Nm/kg) 32mm			
		P		
Group	mean (SD, range)	Pre	3	12
Pre	1.70 (2.35, 0.09-5.15)			
3	0.47 (0.08, 0.38-0.59)	0.528		
12	0.59 (0.11, 0.47-0.69)	1.000	1.000	
Control	0.69 (0.17, 0.50-0.84)	1.000	1.000	1.000

(d)

	Hip extension moment (Nm/kg) p							
	Pre		3 months		12 months		Control	
Group	RSF	36	RSF	36	RSF	36	RSF	36
36mm	1.000		1.000		1.000		1.000	
32mm	1.000	1.000	0.830	0.848	1.000	1.000	0.771	1.000

No differences in hip abduction moment were found either between the groups or within the groups at the three time periods (Tables 6.6(a-d)). Pre-operatively, all groups exhibited a greater hip abduction moment than their control. At 3 months post-operatively improvements had been made by all groups. The RSF group made no further improvements between 3 and 12 months post-operation unlike the other two groups.

Table 6.6(a-d) Hip abduction moment data comparing within group data pre-operatively and at 3 and 12 months post-operatively and compared with the control data for (a) RSF group, (b) 36mm group, (c) 32mm group and (d) comparing between the groups at three time points and between the three control groups.

	Hip abduction moment (Nm/kg) RSF			
	mean (SD, range)	P		
Group		Pre	3	12
Pre	0.82 (1.17, 0.03-3.66)			
3	0.58 (0.26, 0.38-1.02)	1.000		
12	0.58 (0.19, 0.35-0.82)	1.000	1.000	
Control	0.46 (0.30, 0.10-0.80)	1.000	1.000	1.000

(a)

	Hip abduction moment (Nm/kg) 36mm			
	mean (SD, range)	p		
Group		Pre	3	12
Pre	1.01 (0.89, 0.06-2.55)			
3	0.37 (0.28, 0.08-0.84)	0.260		
12	0.65 (0.29, 0.40-0.97)	1.000	1.000	
Control	0.76 (0.20, 0.55-1.03)	1.000	1.000	1.000

(b)

	Hip abduction moment (Nm/kg) 32mm			
	mean (SD, range)	P		
Group		Pre	3	12
Pre	1.84 (1.54, 0.08-4.21)			
3	0.69 (0.30, 0.05-0.99)	0.140		
12	0.46 (0.30, 0.10-0.80)	0.151	1.000	
Control	0.61 (0.35, 0.26-1.10)	0.256	1.000	1.000

(c)

	Hip abduction moment (Nm/kg) p							
	Pre		3 months		12 months		Control	
Group	RSF	36	RSF	36	RSF	36	RSF	36
36mm	1.000		1.000		1.000		1.000	
32mm	0.390	0.738	0.658	0.870	1.000	1.000	1.000	1.000

(d)

Pre-operatively, the 36mm group exhibited a slightly higher hip abduction moment than RSF and, like the RSF group, showed a reduction at three months post-operatively. The 32mm group had a much higher, non-significant hip abduction moment than both of the other two groups and like them showed a reduced value at three months post-operatively. A further reduction was found at twelve months. All three groups recovered their hip abduction moment to values close to their respective controls.

6.4 Discussion

There were differences within the three patient groups at different time points and compared to their control groups for the spatiotemporal and kinematic parameters reported. There were no differences within the groups or compared to their control groups for any of the kinetic parameters. Neither were there any differences between the three groups at any of three time points for any parameter. A further investigation

of the three control groups showed that there were no significant differences between the groups for any of the parameters reported. These results suggest that all three patient groups were equally disabled by OA immediately prior to hip reconstruction surgery, although they allude to the 32mm group patients being less physically able. They also suggest that hip reconstruction is successful in restoring walking ability, but again, the 32mm group patients appeared not to recover as much as the patients in the other two groups. The results do not indicate, however, any significant benefits from larger heads.

The RSF and 36mm groups had similar walking speeds pre-operatively which were faster than the 32mm group. Analysis of the demographic data for the three groups in this study could give a reason for this difference. Age seems not to be the main factor since the 36mm group and the 32mm group had a similar mean age (63.3 & 62.0 years for the 36mm and the 32mm groups respectively), while the RSF group were slightly younger (51.7 years). The 32mm group, however, consisted of female participants only, while the 36mm group consisted of only male participants. The RSF group was predominantly male (7M, 3F). Gait differences have been suggested due to anthropometric differences between the males and females [122, 123].

Few similar studies perform or report pre-operative data, however, the values for walking speed reported in this study are similar to those which have been reported [35, 193, 194]. One of these studies reported a pre-operative walking speed of 0.96m/s for one of their patient groups undergoing THR [193], which was similar to those of the RSF and 36mm groups in the current study, however, their other patient group had a faster walking speed (1.09m/s). Another study reported a pre-operative walking speed of 0.75m/s for one group and 0.79m/s for their other group [194]. A

study which compared RSF to THR reported 0.83m/s and 0.93m/s for RSF and THR respectively [35]. One other study reported higher pre-operative walking speeds than those reported here (1.03 & 1.19m/s for their THR and RSF patients respectively) [18], although it should be noted that their participants were much younger than in the other two studies [193, 194] or in the current study.

In one study which reported results at 3 months post-operation [18], the groups had younger mean ages (46.6 and 46.9 years) than those in the current study and, perhaps as a consequence, had a faster walking speeds (1.16m/s and 1.24m/s) than reported in the current study at three months. Whereas another study with a mean age for their resurfacing group which was similar to that of the RSF group in the current study (49.7years), reported a similar walking speed to the RSF group in the current study (1.00m/s) [35]. Their THR group (with a 36mm diameter femoral head), however, exhibited a faster walking speed (1.10m/s). Another two studies reported speeds for 12 weeks post-operation [34, 194]. One of these [194] reported walking speeds of 0.94m/s and 0.87m/s for their two groups, which are similar to the 32mm group in the current study, however, both of the groups in the study by Mayr et al. [194] had slower walking speeds than the RSF and 36mm groups. This could be as a consequence of the RSF and 36mm groups having a younger mean age and the two groups in the Mayr et al. [194] study having a more equal gender split. The other study which reported at 12 weeks post-operation stated walking speeds of 1.25 and 1.32m/s for their THR and RSF groups respectively [34]. These values are rather high and are more akin to younger control group data from similar studies [10, 18, 193, 194]. They are also difficult to put into context since pre-operative results were not reported; nor were the results compared to a control group. None of the three studies

which reported results at around 3 months made any reference to the head size used and none of the groups consisted of hip resurfacing patients [18, 34, 194]. Failure to give details of the femoral head size is a common omission in gait analysis studies of hip reconstruction patients and can limit the comparisons that can be made between studies.

Lavigne et al. [18] reported results at 12 months post-operatively observing higher walking speeds than reported in the current study. They are also much higher than walking speed reported by other studies with longer post-operative times [14, 52, 59]. Bennett et al. [52] carried out gait analysis on 134 THR patients with a 28mm femoral head 10 years post-operatively. With such a large number of patients, they were able to carry out an age related analysis. The group which gave the fastest walking speed (1.07m/s) were also the youngest (mean age 61.35 years). This value is much lower than those reported by Lavigne et al. [18], although there is a large difference in the mean ages between the two studies. It is similar, however, to the 12 months post-operative walking speed for the 32mm group in the current study, which had a similar mean age and a small femoral head. The youngest group in Bennett et al. [52] had a similar mean age to the 36mm group in the current study, although the 36mm group had a much faster walking speed. This could be evidence that the larger head does improve gait performance. Loizeau et al. [59] carried out gait analysis around 4 years post-operatively using an older patient group (mean age 67.3 years) than any of the groups in the current study. They reported the lowest walking speed (0.707m/s) of any study reporting post-operative data, including the current study, which seems disproportionate to the mean age. The oldest group in Bennett et al. [52] had a mean age of 84.06 years and had a slightly faster walking speed than the patients in Loizeau et al. [59]. Mont et al. [14] performed gait analysis on two patients groups (RSF and

small femoral head THR) between 6 and 15 months post-operatively. They found a significant difference in walking speed between the RSF and THR groups (1.26m/s and 0.96m/s for the RSF and THR, respectively). The RSF group in the current study were similar to the RSF group in Mont et al. [14] in terms of age (51.7 and 51 years, respectively) and gender split (30% and 33% female, respectively). The results from the current study agree with Mont et al. [14] on the walking speed of RSF patients, however, there is no such agreement with the small femoral head THR patients. In Mont et al. [14], the THR group were younger than the 32mm group in the current study (58 and 62 years, respectively), however, also exhibited a much reduced walking speed compared to the 32mm group in the current study.

No significant differences were observed between groups for stride length at any time point, however, there is a suggestion that the 32mm group were more debilitated pre-operatively and did not recover to the same degree as the other two groups. The 32mm group achieved a stride length close to that of their controls; however, the controls exhibited a shorter stride length than the 36mm controls, which had a similar mean age. The difference in pre-operative stride length between all three groups and their respective controls indicates that OA had a significant effect on stride length. The lack of differences for any of the groups between 12 months post-operative stride length and their control groups indicates that hip reconstruction is successful in restoring stride length to normal levels. Both RSF and 36mm groups exhibited similar, longer, stride lengths compared to the 32mm group at all time points, adding weight to the suggestion that the larger head sizes are more successful in restoring closer to normal gait.

A comparison of the pre-operative stride length data from this study with previous studies is less comparable [193, 194], although it should be noted that these were the studies with atypical control data. The data from Mayr et al. [194] bears some similarity to the data from the current study, but the stride lengths reported by Klausmeier et al. [193] are much shorter than either the current study or the study by Mayr et al. [194]. Klausmeier et al. [193] did report the mean heights of their groups (1.68m, 1.70 and 1.75m for control and patient groups respectively), which were in line with those reported in other studies [10, 34, 54, 59] and in the current study (1.71m, 1.72m and 1.62m for RSF, 36mm and 32mm, respectively). The reduced stride length reported by Klausmeier et al. [193] cannot, therefore, be attributed to a shorter participant group. The study by Shrader et al. [35] reported a pre-operative stride length of 1.07m for their resurfacing group which supports the data in the current study, although, their 36mm group exhibited a shorter pre-operative stride length (1.04m) compared to the 36mm group in the current study.

At 3 months post-operatively, the 32mm group in the current study exhibited an improvement similar to that reported in Mayr et al. [194] at 12 weeks post-operatively. While the stride lengths of the RSF and 36mm groups exhibited similar values to those for the RSF and 36mm groups in Shrader et al. [35]. Another study reported stride length at 12 weeks post-operatively for a resurfacing and a THR group [34], however, it is difficult to make comparisons with this study since they report stride lengths at 6 and 12 weeks post-operatively which seem excessively large. The values reported in the study even at 6 weeks (1.27m and 1.19m for RSF and THR groups, respectively) are equivalent to, or greater than, some control data presented [35, 59, 193].

All three groups in the current study had a significantly reduced hip flexion/extension ROM pre-operatively, which gives further support to the debilitating nature of OA; while the success of hip reconstruction surgery is supported by the fact that there were no differences between the patient groups and their controls at 12 months post-operatively. Interestingly, the RSF group did not exhibit as much apparent recovery as the other two groups and fell some way short in sagittal plane ROM compared to their controls. Considering that resurfacing is aimed at the younger more active patient and that the geometry of the anatomical hip joint is predominantly maintained, it would be expected that performance in sagittal hip ROM would have been better restored. This is further highlighted by the data which shows that RSF were the only group exhibiting reduced sagittal ROM at three months compared to their controls. All groups exhibited reduced hip sagittal ROM pre-operatively and no differences 12 months post-operatively, although the 32mm group were the only group where a difference was found between the pre-operative and the 12 months post-operative data. All three groups improved their ROM in the sagittal plane post-operatively to the level of their control groups, although only the 32mm group made a significant improvement at 12 months post-operatively compared to their pre-operative situation. It should be noted, however, that the 32mm group had a lower pre-operative hip flexion/extension ROM than the other two groups and, therefore, had a greater scope for improvement. Despite these observations, the data showed no differences for this parameter between the groups at any of the three time points. Like the spatiotemporal parameters, however, the 32mm group did appear to be more debilitated by the condition than the other two groups as demonstrated by having a relatively reduced hip sagittal ROM. At around 44° ROM, the RSF and the 36mm groups in the current study agree with previously published control data [52, 54, 193]. Other similar studies

have reported higher control group data [58, 193] with no apparent reason being revealed in the methods or participants.

Studies which have reported pre-operative data have reported similar ranges of hip flexion/extension to the patient groups in the current study [193, 194]. Both of these studies had two patient groups and in both cases one patient group had a larger hip ROM in the sagittal plane than the other, with one group being similar to the 32mm group and the other being similar to the RSF and 36mm group. There is no apparent reason for these pre-operative differences, since the two patient groups in each study were of a similar age and gender mix. Whereas in the current study, age and gender mix could explain the difference between the 32mm group and the RSF and 36mm groups. Results at 3 months post-operatively in the current study agree with others which reported data at 12 weeks post-operatively [34, 194]. In Mayr et al. [194], the two patient groups had hip sagittal plane ROM values of 30.49° and 31.47° which were similar to that of the RSF group in the current study, while Petersen et al. [34] reported hip sagittal ROM for their two patient groups which were similar to that for the 36mm group (33.6° for both their patient groups). The 32mm group in the current study had a lower value for this parameter at 3 months compared to any other reported data at a similar follow-up time. Mayr et al. [194] did not did not state the femoral head size used, however, Petersen et al. [34] had RSF and THR groups and found no differences between the groups, although they did not comment on the size of the femoral head used in the THR group. In the current study, the RSF group had a slightly larger ROM than the slightly older all female 32mm group, however, the RSF group had a lower sagittal plane ROM than the 36mm group despite having a younger

mean age, although the 36mm group were all male and this could have been the cause of the difference.

There is some agreement in the long term post-operative results for hip flexion/extension ROM. The range of values reported by Bennett et al. [52] do not reach that of their controls and are lower than both the 32mm and 36mm groups in the current study, however, the RSF group in the current study have a ROM within the range reported by Bennett et al. [52]. The results reported by Beaulieu et al. [58] and Madsen et al. [54] for their posterolateral group are in line with those reported in the current study for the RSF and 32mm groups. Previously published data show wide ranging values for this parameter, however, there are many differences between studies which make direct comparisons difficult. No study was found where data were reported at 12 months post-operatively, with a similar patient group and which reported data in a format suitable for extraction. Like other studies, the current study demonstrates the benefits of hip reconstruction surgery, however, the study shows that the patients recovered hip flexion/extension ROM to the same level as the control groups, which is not shown in other studies [8, 9, 25, 52, 54, 58] which reported data at a minimum of 6 months post-operatively.

It is difficult to draw conclusions from the data relating to hip flexion/extension moments due to large standard deviations present in the pre-operative data. There were no differences in the data within or between the groups, or compared to the control groups. This is consistent with previously reported data [8, 34, 60], however, the data do suggest that improvements in both flexion and extension moment occurred as a result of the surgery.

Hip flexion moment data collected at 3 months post-operatively for the 32mm group agrees with the value reported by Petersen et al. [34] for their THR group (0.68Nm/kg), however, their resurfacing group exhibited a much larger value (0.75Nm/kg) than that of the RSF group in the current study. Klausmeier et al. [193], however, reported data at 16 weeks post-operatively and obtained much lower values for their two groups (0.40Nm/kg and 0.49Nm/kg) which are similar values to those for the RSF and 36mm at 3 months in the current study. Klausmeier et al. [193] and Petersen et al. [34] were in agreement over the peak hip extension moment with both studies reporting values of around 0.85Nm/kg. The values reported in the current study are considerably lower than these. Like the current study, Petersen et al. [34] found no differences for hip extension moment between RSF and THR groups, although another study did report such a difference [14], with the resurfacing group performing better. It should be noted that their RSF group did have a higher value for hip flexion moment (1.048Nm/kg) than the current study or other studies [34, 193]. Most similar studies have reported no significant differences for peak hip flexion or extension moments between patient groups and controls [8, 34, 60] even at just 16 weeks post-operatively [193]. One study reported no difference in peak hip flexion moment for a patient group with the THR implant stem in a valgus orientation and an increased peak for a group with the stem in a varus orientation [25]. Another study reported a significantly higher mean hip flexion moment during the power absorption phase of gait for their THR group compared to their resurfacing group and their control group; however they did not present results for the peaks values [10].

Pre-operative data for hip abduction moment in the current study also revealed large variability which had an influence on the comparisons within and between groups. Only two studies were uncovered which reported pre-operative data for hip abduction

moments [8, 35]. From the data presented by Foucher et al. [8], it was not possible to determine a mean value for the peak abduction moment; however, the data did exhibit a large degree of variation similar to the current study. The data presented by Shrader et al. [35] for their RSF group (0.79Nm/kg) was a little lower than that for the RSF group in the current study, however, the 36mm THR group in the Shrader et al. [35] study exhibited a much lower hip abduction moment (0.71Nm/kg) compared to the 36mm group in the current study.

The control data presented in the current study for all three groups is lower than those reported in previously published studies (approximate range 0.80Nm/kg to 1.3Nm/kg) [9, 35, 58, 60, 193]. The same holds true for the 3 months post-operative data [35]. In Shrader et al. [35], their RSF and 36mm groups exhibited much higher values for hip abduction moment (0.73Nm/kg and 0.69Nm/kg respectively) than the RSF and 36mm groups here. Comparison with 12 week post-operative data reported by Petersen et al. [34] for their RSF group (0.73Nm/kg) shows that the RSF group in the current study fell well below the value for hip abduction moment. Neither of the two THR groups in the current study exhibited peak hip abduction moments to the same level as the THR (unspecified femoral head size) group (0.77Nm/kg) in the Petersen et al. [34] study. Three months post-operative data for RSF and 36mm groups in the current study were low, even when compared to 6 weeks post-operative data (0.65Nm/kg to 0.79Nm/kg) [34, 193]. No apparent recovery was made between 3 and 12 months by the RSF group in the current study, while the 32mm group exhibited a reduction in hip abduction moment over the same period. The 36mm group improved over the period, but they did not reach control levels.

Reduced hip abduction moment following hip reconstruction surgery compared to the healthy population has often been suggested due to the approach used [54, 74, 95, 120] or the post-operative hip geometry [14, 35, 195, 196]. For this reason, it is a parameter which is often reported. Significantly reduced hip abduction moments post-operatively compared to control groups have been reported [58, 60], however, neither of these studies reported the femoral head size, although one did specify that the lateral approach was used in all cases [58]. Significant differences have been reported in comparisons between THR and RSF groups [14, 35] with the RSF group having closer to normal hip abduction moments. A study by Madsen et al. [54] compared an anterolateral group with a posterolateral group, although they did not quote results for hip abduction moment and no other study was discovered which would allow the claim that the posterior approach is superior in terms of hip abduction to be verified. The current study found no significant differences in hip abduction moments between patient groups or between patient groups and the controls, however, other studies have reported the same outcome [8, 9]. The study by Foucher et al. [8] is flawed in one respect since the patient group consisted of an almost even split of posterior and lateral approach patients which could have been responsible for there being no significant difference between the patient and control groups. Götze et al. [9] demonstrated a reduced hip abduction moment in their patient groups compared to controls, however, they did not report whether this was significant.

6.5 Summary

This study of level walking demonstrated that hip reconstruction is successful in enabling OA sufferers to regain gait function close to that of the healthy population of similar age. The results show that pre-operative OA sufferers have deficiencies in

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walking speed, stride length and hip flexion/extension ROM compared to controls and that these deficiencies no longer exist at 12 months post-operatively. It is also evident from the results that rehabilitation continues after 3 months post-operatively.

Despite these results the study failed to find any significant differences between the groups which could be attributed to head size or RSF over THR. The underlying suggestion, however, is that the 32mm group were more debilitated pre-operatively compared to the RSF and 36mm group and that they also did not recover to the same degree as the other two groups. Much of the data presented here is in agreement with other published data, although the kinetic data did tend to be more variable compared to the spatiotemporal and kinematic data and as such did not show any patterns related to the groups or the progression over time. This study has attempted to limit the number of confounding factors which could influence the data, however, the gender split of the individual groups was not ideal, but could not be prevented due ethical issues relating to the implants used. The timescale of the study and the exclusion criteria required that patients from the clinics of a second surgeon be recruited, however, both surgeons used the same approach and all patients underwent the same post-operative rehabilitation. Like most prospective studies the group sizes were smaller than was hoped for, although few participants were lost at follow-up.

7 Hip Reconstruction – Stair Descent

7.1 Introduction

Previous studies have reported the difficult and hazardous nature of stair use [97, 98]. It is also reported that the elderly population have more difficulties with stair use than the healthy young population [103]. Given that the elderly account for the majority of hip reconstruction patients, it is to be expected that they would have difficulty negotiating stairs. As evidence, the main orthopaedic questionnaires include at least one question regarding the stair negotiation abilities of the respondent. In the current study (Chapter 4), the OHS highlighted that pre-operatively only 30% (9/30) of the recruited participants whose data were available could manage to climb a flight of stairs easily or with little difficulty. Data from the WOMAC questionnaire gave a similar view with 80% (24/30) of respondents stating that they had 'moderate' to 'extreme' difficulty ascending stairs and 77% (23/30) having the same degree of difficulty descending stairs.

At each of the testing time points, participants were asked to complete a questionnaire regarding their expectations of the surgery. In one section of this questionnaire, participants were asked to indicate which items from a list of activities they hoped to be able to perform, or perform with less difficulty, than at present as a result of the surgery. 83% (25/30) of participants indicated ascending and descending stairs more easily as one of their expectations prior to surgery.

Stair use is a more demanding task than level walking [98] and although not as important as level walking, is still a commonly performed task [107]. Given the lack

of consensus between gait analysis studies of the hip reconstruction population [23], it is surprising that more studies do not use more demanding tasks, such as stair negotiation, to highlight small difference in biomechanics which may be present in OA patients who have had different hip reconstruction interventions. Since it is reported that stair descent is more demanding than stair ascent, it was decided to investigate stair descent only [98, 99].This study aimed to determine if RSF or large head THR are better able to allow normal stair descent biomechanics to be achieved following hip reconstruction surgery.

7.2 Method

Chapter 3 gives full details of the participants, general method and the data processing used during the study. The stair descent task was performed as a precursor to the level walking task. This was to ensure that the stair descent element was performed in a natural fashion since descent is seldom carried out as an action on its own. Initial instructions were given to participants followed by trial runs prior to collection of data. Participants were asked to avoid using the handrails, although it was expected that this could be hazardous to a number of the participants and health and safety considerations were the main concern over collecting usable data.

Participants were instructed to perform the task in a natural manner, using the SoS technique and without using the handrails if at all possible and to make a natural transition from stair descent to level walking before continuing along the walkway to the end. The SoS technique requires that stairs are negotiated by placing each foot on the next step rather than placing both feet on the same step (the SbS technique). Prior to commencing the task, participants were positioned on the top platform of the

staircase, with the toes at the edge above the steps. On a signal which included which limb to lead with, they were asked to commence the stair descent task. The right limb was specified as the lead off limb for the first three descents. During the descent, with the right foot leading, the left foot would make contact with the force plate at the bottom step; if the participant used the SoS method. After these three descents, the lead off foot was switched to the left foot to collect force plate data for the right foot, however, it became clear that some of the participants had problems in negotiating the stairs. Difficulties encountered included using the handrails, using the SbS technique or using some other unsafe or non-standard technique. In some instances, these were isolated incidents, whereas in others there were persistent and as a result of the participant being unable to perform the task as requested. In these situations, an outcome of 'unable to perform' was recorded. In some instances the participant may have used only light use of the handrails, however even this has been shown to influence stair use biomechanics during stair descent [98, 197].

The data collected were processed as follows. Within the Nexus software, video footage of the trials was reviewed to identify suitable trials. First, those trials where the participant used the handrails, did not use the SoS technique or used some other non-standard negotiation technique were rejected and the information noted. If possible after this cull, three descent trials each were selected where the right foot and the left foot made contact with the step force plate. If it was not possible to obtain three trials for either of the conditions, that condition was noted as 'unable to perform'. Those trials which were to be included in the final analysis were reconstructed and labelled. The trials were cropped to contain only the stair descent section of interest. Foot strike and foot-off events were identified and marked. The

first event occurred as a foot made contact with the second step from the bottom. The next event was marked when the opposite foot made contact with the bottom step. Next was the foot-off event from the second step, followed by its contact event on the floor at the foot of the staircase. The opposite foot-off event occurred next followed by its foot strike event on the floor ahead of the first foot, after which level walking took place. After the gait cycle events had been marked, processing progressed as described in Chapter 3.

Previous studies in which stair negotiation data were reported for hip reconstruction patients were reviewed to determine which spatiotemporal, kinematic and kinetic parameters had been reported previously. Cadence is the only spatiotemporal parameter which has been reported by more than one study and in both cases significant differences were reported [118, 124]. Another study reported significant differences in the walking speed and step width during stair use [35]. The author felt that walking speed was not a suitable measure for stair negotiation. Walking speed is a measure of the distance covered in a unit of time, which in stair negotiation would be influenced by vertical as well as forward distance covered. This would make walking speed less universal for comparison due to different stair designs used. Since stair negotiation involves discrete steps, cadence would seem a more suitable measure than walking speed for comparison between studies. It was also noted that the staircase used in the current study was not as wide as those found in everyday life. With the additional restriction of the handrail, it was noticeable during the data collection sessions that they were a little restrictive for all but the slightest of participants. Step width would be a measure of stability, however, it was felt that the

width of the staircase itself would be a limiting factor on the step width and this parameter was omitted from the analysis.

The work of Lamontagne et al. [105, 124] is the most comprehensive study of stair negotiation in the THR population, having investigated a large number of parameters. In the current study, it was decided to investigate kinematic and kinetic parameters which Lamontagne et al. [105, 124] found significant differences in between THR patients and controls or between different THR patient groups. Since this study was predominantly an investigation into the effects of femoral head size on stair use between three patient groups and a control group, it was decided to limit the investigation to the hip joint, although pelvic tilt was included due to its influence in maintaining balance. The parameters investigated were therefore; cadence, pelvic tilt ROM, peak hip extension angles, hip flexion moment, peak hip internal rotation moment and peak hip power generated. Data for these eight parameters were extracted. Data for each parameter were averaged across all of the participants in the group. It were these averaged data which were compared. Data were analysed using one way ANOVA's with post-hoc Bonferroni corrections applied. A 95% confidence interval was used throughout.

7.3 Results

After the initial work, it was apparent that a large number of the participants were unable to perform the task at each of the time points. It was decided that ability or inability to descend stairs was an outcome in itself. These data show that only three of the 26 participants (11.5%) in the study were capable of performing stair descent in the prescribed manner pre-operatively. At 3 months post-operatively, this number had

increased to ten (38.5%), while at 12 months post-operatively, 11 out of the 13 participants (84.6%) included at this time point were capable of descending stairs. Table 7.1 shows the breakdown of these figures for each group at each time point.

Table 7.1 Sub-group details of participants involved in stair ascent and descent task showing number able to perform the task, mean age (SD), gender split (number of males) and operated limb (number of right limb operated).

Time point	Task	RSF	36mm	32mm	N
Pre-op	Descent	1, 48.5 (14.85), 0,1	2, 53.0, 1,2	0	3
3 months post-op	Descent	6, 49.8, (12.67), 5, 4	3, 60.7 (2.08), 3, 2	1, 58.0, 0,1	10
12 months post-op	Descent	5, 55.0 (14.88), 5, 2	3, 62.0 (9.17), 3, 3	3, 64.7 (8.96), 0, 3	11

Most of those who were unable to perform the task as required used various coping strategies to enable them to descend stairs. Strategies included using handrails, the SbS method or the 'good up/bad down' method. In several cases a combination of these strategies were used between trials and within the same trial. For this analysis only the most predominant strategy was recorded. Others tried to perform the task in the required manner, but in doing so were unsafe. One participant was unable to perform the task using any means at three months post-operatively. The 'good up/bad down' is a technique taught to OA sufferers to cope with stair negotiation. During stair ascent they would be instructed to begin the ascent by leading with the good limb, while descent should be led with the bad limb. This technique was part of the physiotherapy treatment administered by physiotherapist at the QEH. Table 7.2 presents data for the three groups and time point specifying how participants performed stair descent.

Table 7.2 Details of stair ascent and descent abilities and negotiation methods of the participants at each of the three time points.

	Able to perform			Handrail use			Step-by-step			Unsafe			Unable		
	Pre	3	12	Pre	3	12	Pre	3	12	Pre	3	12	Pre	3	12
RSF	1	6	5	4	1	0	5	3	0	0	0	0	0	0	0
36 mm	2	3	3	1	2	0	3	1	0	1	0	0	0	1	0
32 mm	0	1	3	4	5	1	5	3	1	0	0	0	0	0	0

Pre-operatively, none of the 32mm group was able to descend the staircase in the manner required. The RSF group fared much better with 10.0% of the group members being able to descend the staircase, however, the 36mm group exhibited the least amount of disability with 28.6% capable of descending the staircase. The most common cause of inability to negotiate stairs for the RSF group was use of the SbS method (50.0%) with handrail use being the next most common method (40.0%). Slightly reduced percentages were noted for the 36mm group with 42.9% descending the staircase using the SbS technique and 14.3% being able to descend the staircase using handrails. One participant (14.3%) seemed over eager to perform the task without using the handrails resulting in a technique while descending the staircase that was unstable and appeared unsafe. This was pointed out to the participant, and since they would otherwise have to use the handrails, no further stair negotiation tasks were performed. There was a more even split between handrail use and SbS technique in the 32mm group with 55.6% using the SbS technique to descend the staircase and 44.4% requiring the use of the handrails for descent.

Improvements with varying degrees of success were noted across all three groups three months after surgery. Only one member of the 32mm group (11.1%) was able to descend stairs at this time point, however, the other two groups demonstrated a much

better outcome. Of those in the 36mm group, 42.9% were able descend the staircase, but the RSF group had the best outcome with 60.0% of participants being able to descend stairs. Of the remaining 40% of the RSF members, the SbS method was used by 30.0%, while 10.0% used the handrails alone. At 3 months post-operatively, twice as many of the members of the 36mm group (28.6%) were capable of descending the staircase using only the handrails compared to those who had to use the SbS method (14.3%). There was also one group member (14.3%) who could not physically perform the task by any means. The majority of those in the 32mm group who were unable to negotiate the staircase as required were able to perform descent with just the aid of the handrails (55.6%). During stair descent, 33.3% of the group members could only perform the task by using the SbS. The remaining member of the 32mm group employed the 'good up/bad down' approach to stair ascent.

One year after surgery, the RSF group showed the greatest degree of recovery with all of the one year post-operative sub-group (5 members) being able to descend the staircase in the required manner. All of the one year post-operative 36mm sub-group (3 members) were able to descend the staircase in the required manner. There were two members of the 32mm sub-group (40%) who were still unable to descend stairs in the required manner 1 year post-operatively. These participants were evenly split between requiring use of the handrails and use of the SbS method (20.0% for each method).

Due to the low numbers of participants capable of performing stair negotiation, it was decided to treat the participants as a single group to enable a comparison to be performed with a matched control group and also to compare the data to previously

reported data. Table 7.3 presents pre-operative data for the three patients capable of descending the staircase and controls. Differences were noted between the patients and the controls for cadence (p=0.023) and peak hip power (p=0.018). Patients descended the stair more slowly (75.1 steps/min) compared to controls (108.8 steps/min). Patients generated much reduced power at the hip (0.510 w/kg) compared to controls (1.505 w/kg).

Table 7.3 Stair descent movement analysis data showing mean, (sd) for the combined patient group and the control group and p values pre-operatively.

Parameter	Patient group	Control group	p	Parameter	Patient group	Control Group	p
Cadence (steps/min)	75.1 (22.1)	108.8 (13.6)	0.023*	Peak hip flexion moment (Nm/kg)	0.784 (0.259)	0.577 (0.217)	0.243
Pelvic tilt ROM (deg)	6.1 (3.4)	3.9 (1.3)	0.194	Peak hip internal rotation moment (Nm/kg)	0.082 (0.050)	0.048 (0.028)	0.223
Peak hip extension angle (deg)	8.3 (6.1)	11.4 (7.6)	0.564	Peak hip power generated (W/kg)	0.510 (0.267)	1.505 (0.518)	0.018*

Table 7.4 presents data for the ten participants who were capable of descending stairs 3 months post-operatively compared to controls. Differences were found between the patients and controls in two parameters. Patients exhibited a greater range of pelvic tilt (5.7°) compared to controls (3.9°) (p=0.048). As was the case pre-operatively, patients generated reduced hip power (0.770 W/kg) compared to controls (1.505 W/kg)(p=0.012).

Table 7.4 Stair descent movement analysis data showing mean, (sd) for the combined patient group and the control group and p values 3 months post-operatively.

Parameter	Patient group	Control group	p	Parameter	Patient group	Control Group	p
Cadence (steps/min)	91.1 (17.9)	108.8 (13.6)	0.067	Peak hip flexion moment (Nm/kg)	0.672 (0.186)	0.577 (0.217)	0.395
Pelvic tilt ROM (deg)	5.7 (1.6)	3.9 (1.3)	0.048*	Peak hip internal rotation moment (Nm/kg)	0.083 (0.035)	0.048 (0.028)	0.073
Peak hip extension angle (deg)	11.5 (6.7)	11.4 (7.6)	0.967	Peak hip power generated (W/kg)	0.770 (0.420)	1.505 (0.518)	0.012*

Table 7.5 presents 12 months post-operative biomechanical data for the 11 participants who were capable of descending the staircase compared to controls. Patients negotiated the stairs more slowly than controls (88.9 steps/min and 108.8 steps/min, respectively. P=0.042). Patients also generated less power at the hip (0.591 W/kg) compared to controls (1.505 W/kg)(p<0.001).

Table 7.5 Stair descent movement analysis data showing mean, (sd) for the combined patient group and the control group and p values 12 months post-operatively.

Parameter	Patient group	Control group	p	Parameter	Patient group	Control Group	p
Cadence (steps/min)	88.9 (18.9)	108.8 (13.6)	0.042*	Peak hip flexion moment (Nm/kg)	0.451 (0.128)	0.577 (0.217)	0.165
Pelvic tilt ROM (deg)	7.3 (4.9)	3.9 (1.3)	0.122	Peak hip internal rotation moment (Nm/kg)	0.051 (0.022)	0.048 (0.028)	0.824
Peak hip extension angle (deg)	15.1 (4.9)	11.3 (7.6)	0.249	Peak hip power generated (W/kg)	0.591 (0.301)	1.505 (0.518)	0.0005*

Table 7.6 presents biomechanical data for the patient group over the three time points. Only one parameter (peak hip flexion moment) showed any differences across the time points. Results of the post-hoc analysis on this parameter are also presented in Table 7.6. Post-hoc analysis on peak hip flexion moment reveals that differences were

present between the pre-operative and 12 months post-operative value and also between the 3 months post-operative and the 12 months post-operative value.

Table 7.6 Across time points analysis of biomechanical data for the patient group.

	Cadence	Pelvic tilt ROM	Peak hip extension angle	Peak hip flexion moment	Peak hip internal rotation moment	Peak hip power generated
p	0.456	0.661	0.179	0.009*	0.106	0.441

Peak hip flexion moment	Pre-op vs 3 months post-op	Pre-op vs 12 months post-op	3 months post-op vs 12 months post-op
p	1.000	0.025*	0.042*

7.4 Discussion

The results presented indicate that stair descent is a difficult task for hip reconstruction patients and that differences remain 12 months after surgery. The task is difficult, although most hip reconstruction patients were able to negotiate stairs using various coping strategies.

Stair Descent Abilities

The first conclusion which can be drawn from the results is that stair negotiation is problematic for the OA and hip reconstructed population, due to the effects of OA and subsequent surgery, however, the majority of sufferers were capable of negotiating stairs using some form of support or compensatory strategy. Immediately prior to surgery, only 11.5% of participants were capable of negotiating stairs without using the handrails or a compensatory strategy, although all participants were capable of descending the stairs by any means. While these figures are poor from the point of view of determining the gait kinematics during stair negotiation of the late OA population, they are encouraging for OA patients since it suggests that despite the disability, they are still capable of leading a normal life to some extent.

Looking at the pre-operative data, it is not possible to draw any definitive conclusions regarding between group abilities. It was revealed in Chapter 4 that both the RSF and 36mm groups reported a significantly higher level of general activity prior to the onset of OA, although, immediately post-operatively there was no significant difference in the general levels of activity between the three groups. This would suggest that all groups were equally debilitated by the disease at the pre-operative testing session. The results show, however, that none of the 32mm group were capable of descending the staircase using the required manner while 10% of the RSF group and 26.6% of the 36mm group were able to descend the stairs in this way. A similar, although more convincing, situation was revealed three months post-operatively. Only 11.1% of the 32mm group were capable of descending the staircase in the prescribed manner while 42.9% of the 36mm group and 60% of the RSF group were capable of descending the staircase as required. This suggests that the RSF group and, to a lesser extent, the 36mm group had achieved greater recovery at this time point compared to the 32mm group. Investigation of the data from the expectation questionnaires, however, again showed no significant difference in levels of general activity between the three groups. By 12 months post-operatively, the majority of participants included at this time point were capable of descending the stairs using the SoS method, without the aid of the handrails or other compensatory techniques. Only 2 members of the 32mm group still required the handrails for support or used the SbS techniques (40%) which represented 15.4% of the complete group.

There is the suggestion that the RSF group were less debilitated than the other two groups at three months post-operatively. There are two possible explanations for the

apparent better performance. First, the 36mm and the 32mm groups had similar mean ages (63.3 & 62.0 years for respectively) which were somewhat higher than that for the RSF group (51.7 years). It is known that stair negotiation is problematic to the older population [103] and it could be possible that part of the difficulty in stair negotiation is a result of age. Second, it could be as a result of the RSF group having greater levels of general and sport/leisure activities prior to onset of OA. There were no significant differences between the groups in the questionnaire data immediately pre-operatively, although there was a significant difference within the RSF group between the pre-operative data and that prior to onset for both general and sport/leisure activity levels. This could suggest either that the RSF group deteriorated more over the timescale of the disease than the other two groups, which would seem unlikely, or that since the disease prevented them from continuing their active lifestyle, they felt the same degree of disability as the other two groups. In actuality, it is probably a combination of age effects and previous levels of activity which are the cause of the apparent better performance of the RSF group.

No meaningful comparison between the groups was possible 12 months post-operatively due to the small number of participants included, however, it should be noted that 84.6% of those tested were capable of descending the stairs in the required manner. If these numbers carried through to the full group, then it would be evidence of the ability of hip reconstruction to return lower limb function. Since the number of participants within each group capable of descending the stairs is close to maximum, they would appear unlikely to reveal any differences between the groups.

It has been reported that stair use is a task which becomes more demanding with age to the degree that the task can become impossible for some and require changes in

strategy for others [198, 199]. Late stage OA has also been demonstrated to have a debilitating effect on stair climbing [119]. Foucher et al. [119] recruited 28 OA sufferers scheduled for THR who were tested around two weeks before surgery and again 1 year after surgery. They did not give a figure, but stated that before surgery, "most subjects" were unable to ascend the two step staircase. While another study which stated in the methods that stair ascent and descent data were collected pre-operatively did not report the results nor give an explanation for the omission [35]. Given this author's experience in the current study where 89% of the participants were unable to descend the staircase prior to surgery, it would not be implausible to assume that some or all of the participants in the study by Shrader et al. [35] were incapable of performing these tasks.

It was not just pre-operatively, however, that inability to perform the tasks was encountered. In one study it was reported that out of 28 patients in a stair climbing study, only 15 (53.6%) were capable of ascending the stairs 1 year after surgery [119]. The current study showed no such degree of difficulty at 1 year post-operatively for stair descent, which is reported to be a more difficult task [98, 99], with 85% of participants being able to perform this task. No other stair use biomechanics studies have been found which have made statements regarding participants' ability to negotiate stairs. One study investigated stair ascent and descent 3 months post-operatively [35], but made no comment concerning whether all participants could perform the stair negotiation tasks. In the current study only 38.5% of the participants were able to descend the staircase as required at 3 months post-operatively. It is possible that all of the participants (a 7 member resurfacing group and a 7 member THR group) in the Shrader et al. [35] study were able to ascend and descend stairs at 3 months post-operatively, however, given the results from the current study and

those from Foucher et al. [119] that does not seem likely. It is more likely that, like in the study by Foucher et al. [119] and the current study, this is a sub-group of only the patients who were capable of performing the task within a larger group of recruited patients. Since this is not stated it could give an apparently false view that hip reconstruction patients have little difficulty with stair negotiation at 3 months post-operatively. This problem is amplified by there being no other studies which report whether all of the recruited participants were included in the study or if only those able to perform the study were included.

By one year post-operation, the majority of the rehabilitation which will take place will have been achieved [60, 200] and therefore data at this time point should give an accurate representation of the long term abilities following hip reconstruction surgery. The results of stair negotiation ability do point to hip reconstruction patients being able to descend stairs without the aid of support or a coping strategy at one year post-operatively, although they do not show whether they have the same biomechanics.

Stair Descent Biomechanics

The analysis showed that the patients descended the staircase more slowly and generated lower power at the hip prior to, and 12 months after, surgery compared to the controls. In addition to reduced power generated at the hip 3 months post-operatively, patients also exhibited an increased pelvic tilt ROM.

There is little data regarding stair descent biomechanics for the pre-operative hip reconstruction or late stage OA populations, however, previous work has revealed biomechanical deficiencies in the late stage OA sufferers during level walking and stair descent [8, 14, 35, 201, 202] compared to the healthy population. One of these

studies reported no difference in cadence during level walking between OA sufferers and healthy controls [201]. Stair descent, however, is a more demanding and hazardous task requiring more muscle strength to enable its successful completion [97]. Patients in the current study are likely to have hip muscle degeneration [76] which may force them into a more cautious approach to descending stairs. Another study found that elderly adults with a fear of falling descended stairs with a reduced cadence than elderly adults with no fear of falling. The patients in the current study reported limited function (Chapter 4) and this could cause them to be more mindful of these limitations. Both this and the possible muscle weakness could be responsible for the lower cadence exhibited by the patients compared to controls. No studies have reported pre-operative hip power during stair descent in the pre-operative hip reconstruction population, however, given the demands made on musculature which is likely to be weakened [76, 99] it could be expected that pre-operative hip reconstruction patients generate lower hip power than controls during stair descent.

Post-operatively, three parameters were found to be significantly different for the patients compared to controls, with all except pelvic tilt ROM showing a reduction in the value. Pelvic tilt ROM and peak hip power generated were significant 3 months post-operatively compared to controls, while cadence and peak hip power generated were significant 12 months post-operatively compared to controls.

Cadence results of patient groups compared to control groups during stair descent were also reported by other studies and found to be significantly reduced for the patients compared to controls [118, 124]. One study normalised the data for participant height [118] and the values quoted in the other study were lower than the

current study for patients and controls [124]. This study reported cadence rates at about one year post-operatively [124] while patients in the study by Stansfield et al. [118] were tested around 18 months post-operatively. It would be expected that by the time these studies were performed, as much rehabilitation as would be expected would have taken place. The results from these studies and the current study suggest that post-operative hip reconstruction patients may not reach the same stair descent cadence as the healthy population.

Few studies were found which reported data for stair descent for the healthy population. The majority of these did not report cadence, but other temporal parameters, such as stride cycle duration [203, 204] or descent time [199, 205]. One study [197] which reported stair descent cadence rates had a study group which was much older than those in the current study, or the other two studies reporting cadence [118, 124]. The study by Reeves et al. [197] had a study group with a mean age of 74.9 years and they quoted a cadence rate for stair descent of 94 step/min. This value is similar to that reported by Lamontagne et al. [124] although their control group had a mean age of 63.5 years. The variation seen across the studies discussed has highlighted the need to compare patient group data to a healthy control group when investigating stair negotiation. Due to differences in staircase design and testing protocol (riser, inclination, number of steps, handrail use, gait cycle definition and step from which kinetic data were collected), few studies have carried out testing in the same manner. By collecting data for a control group, patient data can be compared to it without the reliance on other studies.

The patient group in the current study used a significantly greater range of pelvic tilt 3 months post-operatively than the control group did during stair descent. This would

suggest that the patient group flexed their upper body forward in the direction of travel. This would move their CoM forward and possible beyond the centre of pressure (CoP) while the swinging limb is descending to the lower step. This would appear to be a less stable, more hazardous strategy than remaining more upright. This was also demonstrated in the work of Reeves et al. [197] who reported that elderly adults had a greater offset in the sagittal plane between the CoM and the CoP (with the CoM being placed more forward) during stair descent unaided compared to when handrails were used. One would assume that the use of handrails would give a feeling of security not present when descending the stairs unaided which would suggest that they do not feel the need to lean forward to provide that security. With the hip reconstruction population, there may be feeling of insecurity with the implant or the musculature following surgery which would require them to adopt some strategy to provide some degree of security. Since the forward lean is more pronounced in the patient group in the current study compared to the control group, it could be that the forward lean provides this feeling of security. This would seem to be the reverse of what would be expected as the forward lean would produce a greater imbalance and would require greater control and strength to maintain balance. A forward lean, however, would provide greater visibility of the target step during stair descent and this could provide a better sense of security than an upright stance with reduced visibility of the target. Another possible cause of the increased pelvic tilt could be to limit the burden on the hip joint. By flexing the upper body forward during swing through, the swinging leg could be brought into contact with the next step while using less hip extension on the supporting limb, however, at 3 month post-operation, there was no difference in hip extension between the patients and controls.

During stair descent the patient group in the current study generated significantly less power at the hip joint than the control group. A study by Lamontagne et al. [105] also reported significantly reduced power generated at the hip during stair descent compared to controls. The patient groups in that study and the current study had similar values of hip power generation, although there was a large difference between the control groups in the two studies. In another study investigating staircase inclination [203], it was noted that peak power generated at the hip increased with the inclination of the staircase. The staircase in the current study had a steeper incline than that used in the study by Lamontagne et al. [105] and, therefore, it is possible that a higher peak hip power generated could be generated by controls in the current study. In the inclination study, however, the values reported for the three inclinations investigated were lower than those reported in the current study and that by Lamontagne et al. [105] for equivalent inclinations. The lower power generated at the hip could be a sign of muscle weakness [124]. This could be as a result of the muscle wastage during the pre-operative period, the effects of the surgery or due to adaptations and suggests that even 12 months post-operatively, hip reconstruction patients still have deficiencies which prevent them from descending stairs in the same manner as the healthy population.

This study aimed to investigate the biomechanical differences between three groups of OA sufferers during stair descent prior to surgery and at 3 and 12 month post-operatively, however, only a small number of patients were capable of performing the task in the required manner pre-operatively and at 3 months post-operatively. The reasons for the inability to negotiate stairs were predominantly the use of handrails or using the SbS method, although, it is encouraging that 3 months post-operatively, the

majority of the RSF group could perform these demanding tasks. During rehabilitation, patients may still have on-going symptoms of OA and be suffering from the effects of surgery [35, 54, 94, 95, 105, 119, 120, 124]. By 12 months post-operatively, most of the patients were capable of negotiating stairs. These findings are evidence of the debilitating nature of OA and the success of hip reconstruction surgery in enabling patients with OA to perform difficult functional tasks.

A level walking task followed on from stair descent as it was hoped that it would give a situation more like that experienced in everyday life. In retrospect, it may not have been a fitting method of data collection. It appears that other studies of stair negotiation have performed stair negotiation as an individual task. During the transition from stair descent to level walking differences in the distance from the staircase the landing foot was placed could alter the biomechanics. There could also be differences in the joint angles depending on the distance from the staircase level walking commenced following descent. If participants were instructed to descend the staircase and come to a halt at the bottom there may have been less likelihood of variations in the data. During stair descent as an individual task, the gait cycle would end with both feet on the floor next to each other, the hip and the knee in a neutral position, while the ankle would be in plantarflexion. When the landing foot is placed further from the staircase, however, it is likely that there would be less hip flexion and it is possible that the ankle could be in greater dorsiflexion and these variations would vary with the distance from the staircase footfall occurred. For these reasons, the study could have been improved if stair descent was performed independently of the level walking.

Another change which would be made if the study was to be performed again would be related to the instrumented step. In the current study, the first step from the floor was instrumented. If the aim of a study is to compare the outcome of different interventions, then a more difficult task may be required [35]. Andriacchi et al. [98] determined that hip flexion/extension moments when descending from the second step to the floor were half of those when descending from the third step to the second step. This would suggest that the protocol used in the current study was less demanding. Had the staircase had an instrumented second step there may have been more parameters which produced significant differences, as was the case in two previous studies [105, 124]. Additionally, most studies of stair negotiation have used an instrumented second step [38, 99, 118, 204] or have had multiple instrumented steps [105, 124, 197, 203]. This meant that the data from the current study could not be directly compared to most of the other reported data.

The study did highlight a number of points which should be borne in mind when designing studies of OA patients' ability to negotiate stairs. First, there is no standardised protocol for stair negotiation gait analysis. Different studies have used different numbers of stairs in the staircase. They have also used different steps for collection of kinetic data. Unlike level walking, stair negotiation is less standardised even when participants use the same technique (e.g. SoS) as there is no standardised stair design used in stair negotiation gait. As previously discussed, the narrow width of the staircase used in the current study could have had an influence on some of the gait parameters measured, however, the most important design detail would be the riser and to a lesser extent the tread of the steps; and thus, the inclination. A previous study investigated the influence of staircase inclination on gait parameter in the

young, healthy population [203]. It was reported that the inclination of the staircase has significant influence on most of the gait parameters.

There is also the question as to whether this type of analysis is necessary. Many healthy older people typically use handrails when negotiating stairs [197]. By asking patients to perform the task without using handrails may well be a situation which the participants would tend not to do on an everyday basis.

Handrail use was slightly more common in the 32mm group which was all female and much older than the RSF group. The all male 36mm group had a similar mean age to the 32mm group, although they were less dependant on the handrails. Given that so few of the patients were capable of negotiating the staircase pre-operatively and 3 months post-operatively and that older persons tend to use handrails during stair negotiation [197], it would be useful to have instrumented handrails so that the it would be possible to determine to what degree the arms were use to offload the lower limbs. This would have allowed more of the patients to be included in the analysis at pre-operatively and at three months post-operatively.

If greater numbers could have been included, it would have allowed comparisons to be made between the groups. The data showed that more of the patients in the RSF group were capable negotiating stairs 3 months post-operatively than in the other two groups. Had it been possible to analyse between group data at these two time points it may have supported the idea shown in the data of the apparent superior performance of the RSF group 3 months post-operatively. It should be remembered, however, that there was an unavoidable bias in the data due to the use of certain implants for certain groups of patients. In addition to these sources of bias, it is suggested that RSF

patients may expect better results and this allows them to recover more quickly [35]. It should also be recognised that resurfacing is aimed at the younger more active OA patient and this would give the RSF patients an advantage over the other two groups, however, this bias is difficult to avoid in an ethical study due to the dangers involved in assigning an implant randomly. For example, hip resurfacing is more commonly prescribed to males due to the adverse effects which have been attributed to metal-on-metal wear particles for female patients [48, 206].

In studies where the outcomes of hip reconstruction surgery are being investigated, this author believes that whether or not a participant is able to perform stair negotiation is an outcome measure in itself given the difficulty it gives pre-operatively. This study has shown that stair negotiation is extremely problematic for the OA population and that hip reconstruction surgery is beneficial in restoring those abilities, however, they highlight that recovery does take time and that even 12 months after surgery difficulties with stair negotiation persist. In the current study, 26 patients were tested at 3 months post-surgery. Of these, only seven could perform stair descent using the SoS technique without the aid of the handrails. Shrader et al. [35] tested their patients at the same time post-surgery, although it seems that all of their patients were capable of performing the task as required. In another study [119] testing was performed pre-operatively and one year post-operatively. Like the current study, the majority of their patients were unable to perform the task pre-operatively. They also reported that around half of their patients were unable to perform the task one year post-operatively. It is likely that other studies found similar difficulties, although the numbers who were excluded from the study due to the inability to

perform the task are not given. This could give an inaccurate representation of the functional outcome of hip reconstruction surgery.

Testing was performed one year post-operatively, although there could still be mechanisms at play which could affect the post-operative lower limb biomechanics. There could still be residual pain [124], compensatory mechanisms [105, 124], muscle weakness or reduced proprioception [35, 105, 119, 124], effects of the surgical procedure [54, 94, 95, 120, 124] or post-operative hip joint geometry [14, 35, 195, 196]. The effects of age, however, should not be discounted. It was not evident that it was the older participants who were unable to negotiate stairs or exhibited poorer biomechanics, although it could be argued that the patients groups were inherently biased since participation was voluntary and those volunteering could have been those with better general health and greater motivation.

7.5 Summary

The study highlighted the success of hip reconstruction in restoring stair negotiation abilities, even 3 months after surgery. It also determined that there are on-going issues one year post-operatively which cause the patients to exhibit abnormal biomechanics during stair descent. The stair descent gait deficiencies which were present pre-operatively (reduced cadence and peak hip power generated) were still present 12 months post-operatively however, it appears that these were not as limiting as they were pre-operatively since a greater percentage of patients were capable of performing the task in the prescribed manner 12 months post-operatively compared to pre-operatively.

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There were some limitations with the study. The small number of participants who were capable of performing the task as prescribed prevented statistical analysis between the groups to determine if larger femoral heads or resurfacing had an influence on the post-operative hip biomechanics during stair descent. Use of the first step of the staircase in the analysis may not have been sufficiently demanding to highlight differences between the patient and control groups. It was thought that having stair negotiation and level walking combined as a single task would provide a more natural task, although with hindsight this appears not to have been the best course of action. The study raises the issue that there is no standard protocol for biomechanical analysis of stair negotiation. As a result it is difficult to compare results across studies. It is also believed that future studies of stair negotiation in the hip reconstruction population should give full details of the number of participants recruited and the numbers who were incapable of performing the tasks unaided. This would give a better picture of the success of the intervention being investigated.

8 Sit to Stand

8.1 Introduction

Rising from a seated to a standing position and vice versa are complex postural transitions [129, 130]. The act of standing up requires the centre of mass (CoM) to be moved from a stable position to a more unstable one [127]. Performance of the STS movement, in addition to walking, is one of the most important ADLs [40, 128, 132-134] since it often precedes the initiation of walking [128, 130, 132, 134] and is performed many times per day [132, 134]. It has been reported that healthy individuals perform 60 STS movements per day on average [39]. Within the health care community, the ability to perform the STS movement is viewed as an indicator for independent living and mobility in the elderly and disabled populations and is regarded as a risk factor for falls [40, 128-130].

The STS task is physically demanding since it involves raising the body against gravity [130] and it requires larger movements and greater forces [41, 207] than level walking. This requires sufficient strength in the hip and knee muscles to execute the required movements to make this happen [40, 136]. It has been reported that the STS movement proves to be difficult for the elderly [128, 135] and as we age our ability to perform the task reduces [129]. These difficulties have been attributed to muscle atrophy and weakness [128, 135]. Despite the difficulties with STS , the stand-to-sit task does not seem to pose the same level of difficulty as the STS movement as weak or disabled elderly persons who are unable to perform the STS task are capable of performing stand-to-sit movements [130]. It has also been reported that those with physical impairments find the STS task difficult [136, 137]. Since muscle atrophy and

weakness are also features which would be found in the hip OA and reconstruction populations [76, 83, 84] it is not surprising that they also experience difficulties with the STS task [45, 139, 141].

It has been suggested that level walking is not demanding enough to identify some differences between normal kinetic and kinematic data and those of post-hip reconstruction surgery patients [18, 35-37] or when comparing different hip reconstruction interventions (e.g. approach used or implant femoral head size) and that more demanding tasks be used in for such research [60, 207]. Another factor which should make STS noteworthy with researchers in the hip reconstruction field is that previous studies have demonstrated that hip replacement patients continue to off-load the operated limb for some time after surgery leaving the non-operated limb to take up the shortfall in loading [45, 139]. The significance of this is that there is evidence to suggest that over-loaded non-operated limb joints are at greater risk of developing OA [45, 139, 143].

Despite all of these motives for including STS in the biomechanical analysis of the post-operative hip population, few studies have investigated the STS task with modern motion analysis equipment. Two such studies investigated the joint loading symmetry which gives a measure of the contribution to the task provided by the operated limb compared to the non-operated limb [45, 139]. One of these studies compared a THR group to a control group with the aim of investigating limb loading asymmetry as a measure of post-operative deficit [139]. The other study had a THR group and a revision group and their aim was to investigate differences between the two groups [45]. This study also had limb loading symmetry as one of the outcome

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measures as well as angular velocity of the hip and knee joints. No other studies have been found which investigate STS biomechanically in the THR population. There have been a small number of studies which have investigated hip fracture patients [140, 145] and there have been several which have had total knee replacement patients as the study group [136, 142, 143].

If overloading of the non-operated limb is identified and action taken to avoid it, the individual could be spared the misfortune of developing OA in this side. This would be a benefit to the NHS in the United Kingdom as well as the patient in the long term. It may also be the case that intervention variables (e.g. surgical procedure or reconstruction components) could influence the degree of overloading post-operatively.

This study aimed to investigate lower limb loading symmetry to determine if larger diameter femoral heads or RSF reduce the incidence of loading asymmetry with three hip reconstruction groups performing a STS task. The outcome measures used were peak vGRF and impulse. The peak vGRF will show the maximum vGRF applied by each of the limbs during the initial lift-off section of the STS movement while the impulse will give a measure of the overall force applied during the complete STS movement. The hypothesis is that the healthy population will exhibit symmetry between the limbs in both the peak vGRF and impulse. This would be exhibited by ratio values close to one. It is also hypothesised that due to the pain and muscle weakness as a result of OA of the hip, the patient groups will have ratios of less than one, meaning that more of the work during the STS movement would be performed by the non-operated limb. Further, it is expected that by 12 months post-surgery,

being pain free and rehabilitated, the patient groups will exhibit similar ratios to the control group. The study aimed to determine if there are significant differences in these ratios between the three groups.

8.2 Method

STS data were collected as one element of a battery of tasks in a motion analysis laboratory. Details of the equipment and general method are reported in Chapter 3. The STS task was performed with the participants seated on a stool which was positioned next to two force plates which were positioned side by side. Participants were instructed to sit with their arms crossed over the front of their body and their hands on the opposite shoulders. The task was to be performed in this manner. The author guided the participant to position their feet such that each foot was placed on a separate force plate and the shank was in a vertical position. Participants were instructed to rise from the sitting position to a steady standing position when given the command "stand up". After a pause, the participants would receive the command "sit down" which was their cue to return to the sitting position. Prior to data collection, the participant was asked to practice the task. Data were collected during the complete STS and stand-to-sit task and data from three performances of the task were collected.

In total, data from 26 hip reconstruction participants were collected immediately prior to surgery and at three months post-surgery. Data were collected at 12 months post-surgery for a sub-set of these participants (n=13). Data were also collected for healthy controls. Full details of the participants and groups are given in Chapter 3.

Each of the three trials for a participant was reconstructed and the STS phase of the data was extracted to a separate trial. For the purposes of this study, the start of the STS task was defined as the instant when vertical ground reaction force (vGRF) reached its minimum value in the counter movement of the STS task [132] . This was selected over other STS initiation points as it would include all of the propulsion phase without the reduction in the vGRF in the initial stage of the counter movement. The end point of the STS task was taken to be when quiet standing was achieved. This was defined as the point just prior to when the hip extension angle on the operated side (or preferred side for control participants) reached the value measured during a static standing trial less two standard deviations [128, 132]. The dynamic plug-in gait model was applied to each of the trials. Each trial was imported into Vicon Polygon where the vGRF data were normalised to the duration of the STS task and to the body mass of the participant then exported in a spread sheet format. From this file the right and left vGRF data were extracted.

No kinematic parameters of the STS task were investigated due to there being more variability within and between individuals than in level walking [132] and parameters which gave a measure of the contribution made by each limb in performing the STS task were investigated instead. Loading symmetry ratios were determined for each of the three trials for the participants. This was defined as the maximal peak vGRF in the operated limb divided by the maximal peak vGRF in the non-operated limb [45, 136]. For the control participants, the value for the non-preferred limb was divided by the value for the preferred limb. The maximal peak vGRF values used in the analysis were determined by investigating the derivative of the vGRF data from its maximal value until it reaches zero and the maximal value of vGRF during this section was

extracted as the peak vGRF [136]. The values for the operated and the non-operated limbs (or the non-preferred and the preferred, respectively) were input into the formulae:

(1) Ratio = $\dfrac{\text{Peak vGRF of operated limb}}{\text{Peak vGRF of non-operated limb}}$ or

(2) Ratio = $\dfrac{\text{Peak vGRF of non-preferred limb}}{\text{Peak vGRF of preferred limb}}$

When ratio values had been determined for all three trials for a particular participant, they were averaged to give a mean value for each participant. These values were used in future analyses.

Additionally, the vGRF data were processed to produce a value for impulse during the STS movement. For each of the three data sets for a participant, the area under the curve was estimated using the trapezoidal rule. This area was defined as the impulse, although in reality it was a unit-less value since the data had been normalised to the duration of the STS movement. In a similar fashion to the vGRF data, the impulse values for each of the three performances for a particular participant were determined separately before being combined to give a mean value. The mean values for the operated and non-operated limb (or non-preferred and preferred limb for the control participants) were used to determine ratios using the formulae:

(3) Ratio = $\dfrac{\text{Impulse of operated limb}}{\text{Impulse of non-operated limb}}$ or

(4) Ratio = $\dfrac{\text{Impulse of non-preferred limb}}{\text{Impulse of preferred limb}}$

With the ratio values for peak vGRF and impulse, a value of one represents symmetry between the operated and non-operated limb (or non-preferred and preferred limb). A value less than one shows the degree to which the operated limb is being off-loaded. When all the data had been processed it was transferred into IBM SPSS 20 (IMB Corp., Armonk, NY) for statistical analysis. Analyses were performed within groups between each time point and each time point and the control group, across group comparisons at each time point and to compare the three control groups using one-way ANOVA with post-hoc Bonferroni correction. The level of significance was set to $p < 0.05$.

8.3 Results

Tables 8.1 (a-c) show the means, standard deviations and ranges of the peak vGRF ratio for the RSF, the 36mm and the 32mm groups together with those of the three respective control groups. They also present the comparisons of the within groups analysis across the time points and the data at each time point compared to the control data. Table 8.1 (a) shows that there were no differences in the peak vGRF ratio for the RSF group between any of the three time points. Neither were there any significant differences when the data were compared to the control group. Table 8.1 (b) shows that the 36mm group had no differences when comparing the peak vGRF across the three time points. Neither were there any differences when the three time points were compared to the control data. Table 8.1 (c) shows that differences exist in the 32mm group between the three time points for the peak vGRF ratio. There were significant differences between pre-surgery and three months (p=0.022) and also 12 months (p=0.021). There was also a significant difference between the pre-surgery peak

vGRF ratio and the control data (p<0.001). At three months post-surgery, there was a

difference between the patient group and the control group (p=0.013).

Table 8.1 (a-c) Means, standard deviations and ranges for the peak vGRF ratio for (a) the RSF group, (b) the 36mm group and (c) the 32mm group collected at pre-surgery and at three and 12 months post-surgery. The table also includes the same data for the three respective control groups collected on a single occasion and the levels of significance for the within group comparisons across the time periods and with each patients group's respective control group. * denotes significant at p=0.05.

RSF				
			p	
Time	mean (sd) (range)	Pre	3	12
Pre	.804 (.390) (.180-1.493)			
3	.779 (.216) (.515-1.127)	1.000		
12	1.104 (.296) (.891-1.622)	.393	.227	
Cont	.973 (.178) (.569-1.176)	1.000	.758	1.000

(a)

36mm				
			p	
Time	Mean (sd) (range)	Pre	3	12
Pre	.760 (.379) (.298-1.352)			
3	.705 (.133) (.490-.842)	1.000		
12	.974 (.073) (.896-1.042)	1.000	.852	
Cont	.988 (.231) (.569-1.273)	.660	1.000	1.000

(b)

32mm				
			p	
Time	mean (sd) (range)	Pre	3	12
Pre	.470 (.226) (.118-.716)			
3	.741 (.165) (.491-1.012)	.022*		
12	.780 (.097) (.685-.907)	.021*	1.000	
Cont	1.021 (.143) (.780-1.174)	0.000003*	.013*	.102

(c)

Table 8.2 shows the between group statistical analysis of peak vGRF ratio at pre-surgery, and three and 12 months post-surgery. A comparison was performed comparing the peak vGRF ratio of the three control groups with each of the others, but this analysis produced no significant results. When comparing the three groups with each other at the three time points, no significant differences were noted.

Table 8.2 Between group comparison of peak vertical GRF ratio at pre-surgery and three and 12 months post-surgery. * denotes significant at p=0.05.

Time	p					
	Pre		3		12	
Group	RSF	36mm	RSF	36mm	RSF	36mm
36mm	1.000		1.000		1.000	
32mm	.208	.333	1.000	1.000	.085	.643

Tables 8.3 (a-c) give the means, standard deviations and ranges of the impulse ratio for the RSF, the 36mm and the 32mm patient groups, in addition to those of the three respective control groups. This table also includes the results of the statistical analysis within groups across the three data collection time points and compares the data at each time point with the control data. Table 8.3 (a) shows that there were no differences in the impulse ratios for the RSF group between the three time points. Neither were there any differences between the impulse ratios at any of the time point and the control data. There was one significant result from the 36mm impulse ratio data (Table 8.3 (b)). The value for impulse ratio at three months post-surgery was lower than that for the control group (p=0.050). A similar value for the impulse ratio was noted at the three months post-surgery time point, but this did not reach significance (p= 0.051). There were differences in the impulse ratio between time points for the 32mm group (Table 8.3 (c)). The impulse ratio for the pre-surgery time point was lower than those at both three months (p=0.010) and 12 months (p=0.013) post-surgery. The impulse ratio pre-surgery was also lower than the control participant's impulse ratio (p<0.0001).

Table 8.3 (a-c) Means, standard deviations and ranges for the impulse ratio for (a) the RSF group, (b) the 36mm group and (c) the 32mm group collected at pre-surgery and at three and 12 months post-surgery. The table also includes the same data for the three respective control groups collected on a single occasion and the levels of significance for the within group comparisons across the time periods and with each patients group's respective control group. * denotes significant at p=0.05.

	RSF			
		p		
Time	mean (sd) (range)	Pre	3	12
Pre	.833 (.346) (.354-1.481)			
3	.807 (.204) (.504-1.186)	1.000		
12	1.077 (.205) (.921-1.422)	.471	.253	
Cont	.955 (.139) (.667-1.128)	1.000	1.000	1.000

(a)

	36mm			
		p		
Time	Mean (sd) (range)	Pre	3	12
Pre	.726 (.205) (.291-.889)			
3	.725 (.179) (.422-.970)	1.000		
12	1.001 (.107) (.900-1.114)	.337	.334	
Cont	1.032 (.225) (.667-1.434)	.051	.050*	1.000

(b)

	32mm			
		p		
Time	mean (sd) (range)	Pre	3	12
Pre	.442 (.295) (.010-.787)			
3	.786 (.171) (.500-.981)	.010*		
12	.824 (.118) (.674-.946)	.013*	1.000	
Cont	1.001 (.128) (.789-1.145)	0.000017*	168	.632

(c)

Table 8.4 shows the results of the between groups analysis of the impulse ratio. The impulse data for the three control groups were analysed, and a significant difference was found between the RSF group and the 32mm group. The impulse value for the 32mm group pre-surgery was significantly lower than that for the RSF group.

Table 8.4 Between group comparison of impulse ratio at pre-surgery and three and 12 months post-surgery. * denotes significant at p=0.05.

	p					
Time	Pre		3		12	
Group	RSF	36mm	RSF	36mm	RSF	36mm
36mm	1.000		1.000		1.000	
32mm	.050*	.217	1.000	1.000	.089	.468

8.4 Discussion

The results presented here show that healthy individuals rise to a standing position from a sitting position using both limbs in equal measure. Peak vGRF ratios for the control groups ranged from 0.973 to 1.021 indicating that during the rising stage, the non-preferred and preferred limbs produced similar maximum forces to perform the task. These results are in agreement with those of previous studies whose control groups exhibited symmetry between the left and right limbs during the STS movement [136, 139, 142, 145]. The impulse results from this study (impulse values between 0.955 and 1.032 for the control groups) and a previous study [145] show that healthy, elderly persons also produce similar impulse values on each side. There is evidence that elderly people have difficulty with the STS task [41, 128, 129, 134, 135], although they appear to be capable of performing the task in a controlled manner.

The vGRF results presented for the patient groups show that all three groups return to symmetrical loading by 12 months post-operatively, however, the 32mm group had a lower value of symmetry compared to their control group pre-operatively and at 3 months post-operatively. The pre-operative value was also lower than the values at 3 and 12 months post-operatively. A similar picture was painted for the impulse values for the 32mm group. These show a difference between the pre-operative impulse symmetry and the control group. The pre-operative impulse was also lower than the values for 3 and 12 months post-operatively. The 36mm group had a lower impulse than their control group at 3 months post-operatively. These results show that the 32mm group over-load the non-operated limb before surgery and that both the 32mm and the 36mm groups over-load the non-operated limb 3 months after surgery.

No studies were found which reported impulse or impulse symmetry for the hip reconstruction population and only two studies which reported vGRF with this patient group [45, 139]. Both of these studies reported that loading asymmetry persisted post-operatively. One study tested the patients an average of 19 months post-operatively [139] while the other tested their patients an average of 12 months post-operatively [45]. These studies imply that even more than 18 months post-operatively, hip replacement patients continue to over-load the operated limb. The current study does not concur with these studies, showing instead that by 12 months post-operatively symmetry is restored. It should be borne in mind that only a sub-group of the participants were included in 12 month post-operative results reported, although both the RSF and 36mm groups displayed no vGRF asymmetry compared to the control groups at 3 months post-operatively. The same is not the case with the impulse symmetry results. The 36mm group had lower value at 3 months compared to their controls. Between group analysis highlights a difference in the impulse symmetry between the RSF and the 32mm groups pre-operatively. This suggests that the 32mm group were more disabled or had less muscle strength than the RSF group prior to surgery.

The peak vGRF symmetry is a useful outcome measure, although it is a measure taken at one instant in time. It is possible that an incorrect representation of the situation could arise. It is possible that the operated limb could give an instantaneous peak vGRF equal to the non-operated limb, but make no further contribution to the STS movement. In this scenario a ratio close to one would result suggesting that there was no deficit on the operated side, while it actually had a limited contribution to the

task. Compared to this, the impulse symmetry is a measure of the contribution made by both limbs. Even if the operated limb produced a similar peak vGRF to the non-operated limb, if there was little more contribution, then the impulse ratio would highlight this as a deficiency when the peak vGRF ratio would not. Given that no additional data are needed to determine the impulse compared to the peak vGRF, this author would suggest that the impulse ratio be reported in studies where different interventions are being compared in the joint reconstruction population.

There is evidence from the results presented that the 36mm and the 32mm groups favour the non-operated limb during STS. Due to muscle weakness or atrophy [54, 76, 84], these participants have adopted a strategy of applying less load to the operated limb with the non-operated limb making up the shortfall. This strategy is more prevalent in the 32mm group. They exhibited asymmetry in the peak vGRF pre-operatively and at three months post-operatively and in the impulse ratio pre-operatively. This would suggest that from some time prior to surgery until some time between 3 and 12 months post-operatively, they had been overloading their non-affected limb. There is the suggestion that the 36mm group had been overloading their non-operated side from the date of surgery to close to 12 months post-operatively. Over these time scales it is possible that permanent damage may have been caused to hip and knee joint cartilage of the non-operated side. In the long term this could result in the necessity for future joint replacements [45, 139, 143]. In addition to being a source of pain and disability, it is also a burden on the health care providers in terms of cost.

It has been reported that loading asymmetry is not a result of pain [45] and thus it is more likely to be muscle deficiency which is responsible for the asymmetry found. It has been previously reported that OA of the hip is linked to atrophy of the gluteus maximus [76], which is the main extensor of the hip [1, p.352]. Given that the hip extensors are the main muscles contributing to rising during the STS task [40, 45] it can be seen why this would be a problematic task pre-operatively in the 32mm group, and following surgery until muscle strength has been regained. With the 36mm group, it would appear that they did not suffer from the same degree of muscle weakness as the 32mm group pre-operatively given that no asymmetry was found in either the vGRF or the impulse. Following surgery; however, they may have had a period of inactivity during recovery which induced a small change in muscle strength on the operated side which resulted in the difference found in the impulse compared to the control group.

One of the other factors which accounts for continued limb asymmetry during STS is that people can be unaware that the affected limb is being off-loaded [45]. This would mean that some hip reconstruction patients may be unaware that the problem exists and therefore would not take action to correct the asymmetry. The hip OA population may have developed coping strategies over a long period of time prior to surgery, however, this is not the case with all of the participants in the current study. The RSF group showed no asymmetry in either vGRF or impulse. This could be as a result of them being younger, more active and more motived to resume an active lifestyle (as reported in Chapter 4). Many of these participants were keen to resume some activity and may have performed some strength and conditioning training on their own account. By contrast, the 36mm and 32mm groups were both older than the RSF

group and the 32mm group were generally less active than the other two groups. Since the impulse ratio for the 36mm group at three months compared to their control group was only just significant, it may be that no significant difference would be found with a larger sample size. Given that these strategies can become habitual and difficult to correct if no action is taken [141], there may be a need to identify hip reconstruction patients who overload the non-operated side and are thus at risk of causing damage to this side. Such patients should be given physiotherapy retraining to correct loading asymmetry.

This study was performed with the participants prohibited from using armrests and in a constrained position. This is an unnatural situation, although it was used to ensure that there would be some compatibility between the data. Previous research has highlighted the effects of armrest use on the vGRF during the STS task [134]. Studies demonstrated that as much as 16% of the force used to raise the body during STS can be supplied by upper extremities when armrest use is allowed [132, 145]. Another study has shown that the maximum hip extension moment can be reduced by 50% when using armrests compared to the no-armrest condition [208]. These studies confirm that if armrests had been used in the current study, inaccurate data regarding the contribution of each limb could result.

Other studies have demonstrated the influence of foot placement on STS performance [134]. One study found that the extension moment required to perform STS was reduced when the feet were placed more posteriorly compared to having the ankle joints below the knee joints [41], although, they found no difference for the vGRF data for these two foot positions. Another study tested two conditions with total knee

replacement patients, one constrained and the other when the participant was allowed to select their starting position [143]. They found that participants selected a starting foot position which resulted in lower hip extension moments. Another result worth noting was that the operated foot was placed more posteriorly in the self selected condition compared to the constrained condition. This effect, which they called stagger, was studied by another study with a healthy participant group [147]. They, like others, found that greater hip extension moment resulted when the ankle joints were positioned below the knee joints compared to being positioned more anteriorly (a 49% increase). They also found that the hip extension moment on the non-preferred limb increased when placing the preferred limb more posteriorly than the non-preferred limb when compared to both feet in a posterior position. Another finding was that the loading symmetry was reduced with the preferred limb in a more posterior position as well as in the reverse position compared to other foot positions. Previous findings show that if participants were not constrained during STS in the current study, they would likely adopt a starting position which allowed them to perform the task easier and more comfortably. This in turn would alter the side-to-side loading and inaccurate data would result.

Seat height has been shown to have an effect on the performance of the STS task [134]. Due to this, many studies use a seat which is adjusted to the leg length of the participant. This ensures that each participant begins the STS task with the lower limbs in the same amount of flexion. It is known that as the seat height reduces, the difficulty in rising from the seat increases [42]. One study reported that with increasing seat height, the vGRF reduced [41], however, this study investigated seat height rather than seat height relative to leg length. For example, the low seat in the

study may have been the optimum height for a shorter participant which would have posed little problem, whereas a taller participant would have difficulty with the same height of seat.

Despite this, seat height may have had an influence on the results from this study since a fixed height seat was used. The seat was high enough, however, not to be too low for any of the taller participants. In addition, the height of the seat used in this study was only slightly higher than the highest seat height used by the study by Kawagoe et al. [41] which produced the lower values of vGRF.

8.5 Summary

In summary, this study has shown that the 32mm group had a more asymmetric loading pattern than their control group prior to operation and compared to their control group and the RSF group three months post-operatively. The 36mm group also had a more asymmetric loading pattern than their control group at three months post-operatively. These differences were likely due to muscle weakness in the hip extensors which has lead to a compensatory mechanism being adopted. Fortunately, all groups in this study managed to correct this mechanism by one year post-operatively, however, the 36mm and 32mm groups may have been using the mechanism long enough to cause long term damage to the cartilage in the joints of the non-operated limb.

9   Conclusions

This study presented function and biomechanical data for level walking, stair descent and sit-to-stand for three patients groups and controls. It also presented level walking data for healthy adults stratified by age. The aims of the study were to determine whether hip resurfacing is more capable of allowing patients to achieve normal biomechanics than total hip replacement, whether large head total hip replacement is more capable of allowing patients to achieve normal biomechanics than small head total hip replacement and whether gait deteriorates progressively in the healthy population with age.

The results for the age related gait study failed to find any differences between the age groups which would suggest that gait deteriorated progressively with increasing age. There may, however, have been trends for decreasing hip abduction/adduction ROM and knee flexion/extension ROM with increasing age.

When investigating the orthopaedic questionnaires, the results show that patients with OA of the hip that have been scheduled for hip reconstruction suffer from physical disability as shown by poor scores in three orthopaedic questionnaires. These data show that despite age and gender differences in the three groups, they were all equally debilitated prior to surgery. Data collected 3 and 12 months post-operatively demonstrate that RSF and THR are successful in reducing that disability, however, these questionnaires did not highlight any benefits of RSF or large head THR over small head THR at either of the two post-operative time points.

Results from the expectations questionnaire show that the RSF and 36mm groups had a more active lifestyle in both general and sport/leisure activities compared to the 32mm group prior to the onset of disability due to OA. This was also the case for sport/leisure activity immediately before surgery. The RSF group appeared to be more demanding of the surgery as they reported a desire to return to more strenuous activities following rehabilitation than the 36mm and 32mm group.

The level walking study results show that hip reconstruction is a successful intervention as the patients regained gait function close to that of healthy controls. Pre-operative differences were noted in walking speed, stride length and hip flexion/extension ROM compared to controls. By 12 months post-operatively, these deficiencies no longer remain, however, it is also evident that patients are not rehabilitated 3 months post-operatively as deficiencies are still present in walking speed, stride length and hip flexion/extension ROM. The study failed, however, to find any differences between the groups. There was the suggestion that the 32mm group were more debilitated than the other two groups pre-operatively, nor did they recover to the same level as the other groups.

The results of the stair descent study confirmed the difficulty that the OA population experience in descending stairs, however, they also show the success of hip reconstruction since even 3 months after surgery a larger percentage of the patients were capable of negotiating stairs in the prescribed manner. It would seem, however, that even 12 months post-operatively, patients still exhibit deficiencies compared to controls since the deficiencies present pre-operatively (reduced cadence and peak hip power generated) were still present 12 months post-operatively. Due to the small

number of patients in the study who were capable of descending stairs in the required manner, it was not possible to perform any between group analyses.

The sit-to-stand study demonstrated that the 32mm group had greater asymmetric loading between the limbs compared to controls pre-operatively and 3 months post-operatively in both peak vGRF and impulse. Before surgery they also had more impulse asymmetry than the RSF group. There were no other differences between the groups.

In summary, this study has shown that OA is a debilitating condition which can be successfully treated with hip reconstruction surgery to allow patients to return to a normal level of function. Significant improvements were found in all three orthopaedic scores at 12 months postoperatively compared to pre-surgery. The expectations questionnaire highlighted that the 32mm group were less generally active than the other two groups prior to onset of OA and that they were also less active in sport and leisure activities three months post-operatively. In level walking there was no evidence that gait deteriorated progressively with age. Prior to surgery, the patient groups exhibited differences in walking speed, stride length and hip flexion/extension ROM compared to controls. These differences were no longer present 12 months post-operatively. Neither were there any differences between the groups. The sit-to-stand study demonstrated that the 32mm group had greater asymmetric loading between the limbs compared to controls pre-operatively and 3 months post-operatively in both peak vGRF and impulse. Before surgery they also had more impulse asymmetry than the RSF group. There were no other differences between the groups. These do not, support, however, the belief that RSF or larger head THR are

more capable of allowing the participants to achieve biomechanics equivalent to the healthy population, although the results do suggest that even 12 months post-operatively deficiencies exist between patients and controls.

The study appears to be the first to report loading impulse symmetry data for the hip reconstruction population and has shown that over-loading of the non-affected limb occurs pre-operatively and for some time post-operatively with some patients. This could have a long-term detrimental effect on the cartilage of the sound limb. Gait analysis may not have sufficient resolution to highlight small differences caused by different implants, particularly during level walking and it may be more beneficial to study more demanding tasks when comparing between implants. There is, however, a need for the biomechanics community to develop recommended protocols for data collection during stair use and sit-to-stand.

These studies did have some limitations:

- Healthy participants were volunteers – this may not reflect the general population
- Patients groups were small, although consistent with published gait studies in similar populations
- Small number of stair trials which could be included in the analysis due to disability in the patient group
- Stair descent followed by level walking – biomechanical differences could occur due to foot placement on floor
- Seat height not adjusted to leg length – could introduce biomechanical differences between participants

The studies have highlighted potential areas of future work:

- Use of stair descent to highlight possible differences between implants

  - with instrumented handrails to increase the number of useable trials

  - second step instrumented

- Use of sit-to-stand to investigate overloading of non-affected limb before and after physiotherapy retraining to determine if asymmetry can be corrected

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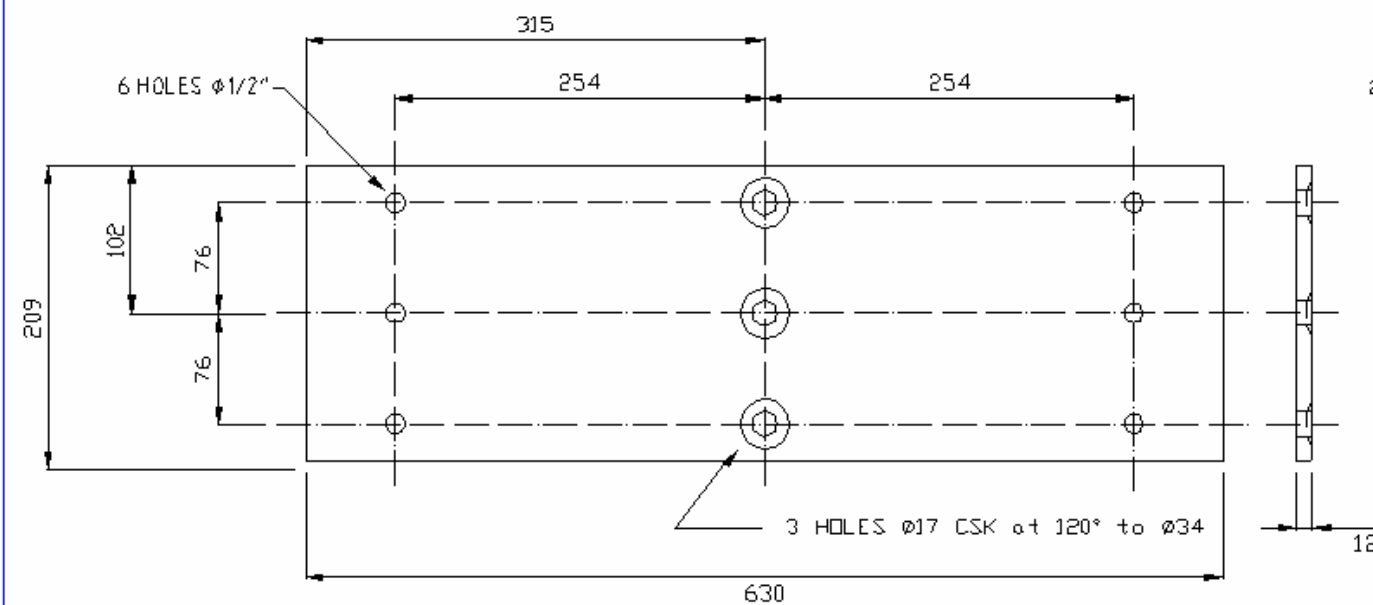
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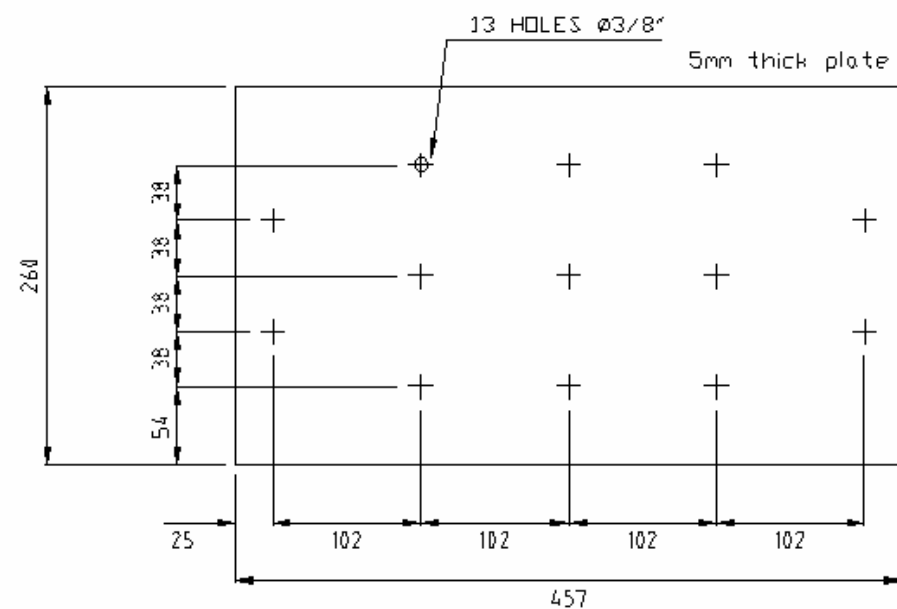
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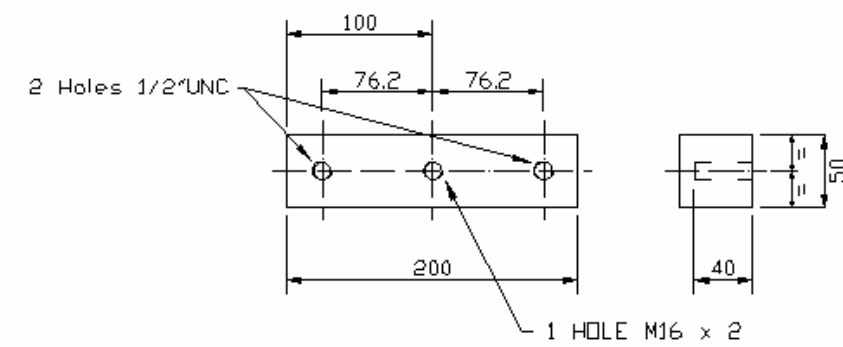
APPENDICES

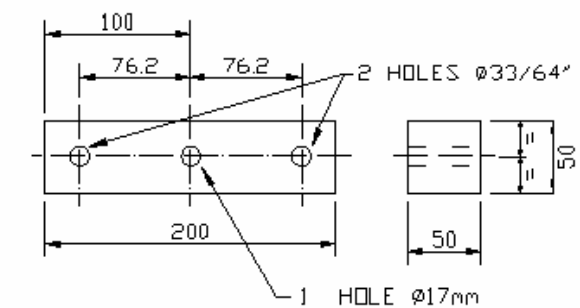*Appendix 1 Step pedestal components*

Item 1

6 HOLES Ø1/2"

315

254 254

209
102
76
76

630

12

3 HOLES Ø17 CSK at 120° to Ø34

Item 3

2 Holes 1/2"UNC

100
76.2 76.2

200

50

40

1 HOLE M16 x 2

Item 4

100
76.2 76.2

2 HOLES Ø33/64"

200

50

50

1 HOLE Ø17mm

Item 2

13 HOLES Ø3/8"

5mm thick plate

260
38
38
38
38
54

25 102 102 102 102

457

Item 5

76.2

76.2

100

25

50

3.75

3 HOLES Ø17
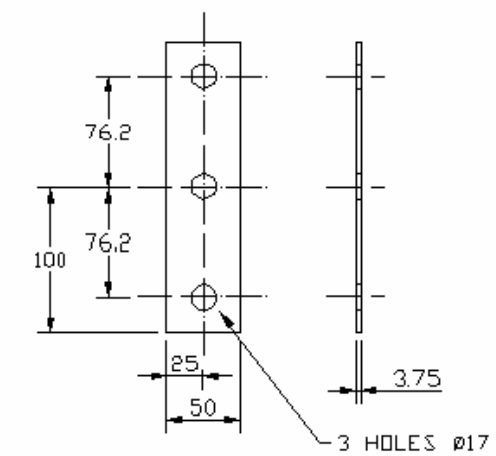
5	Shim	1 OFF
4	Upper foot block	3 OFF
3	Lower foot block	3 OFF
2	Top plate	1 OFF
1	Base plate	1 OFF
Item	Description	QTY

Appendix 2 Strap plates

8 HOLES Ø12mm CSK Ø24mm

21

232

1760

232

21

21

204

245

Quantity: 4 OFF	All dimensions in mm			Matl. — 6mm mild steel plate	
Designed by A. M. EWEN	Checked by	Approved by - date	Filename	Date 5/11/2008	Do not scale
A. M. EWEN		Strap plate			
		Appendix 2		Edition	Sheet 1/1

Appendix 3 Informed Consent form for patient participants

Gateshead Health **NHS**

NHS Foundation Trust

Participant Consent Form

Participant Identification Number for Trial:

Title of Project: Biomechanical analysis after total hip replacement and hip resurfacing.

Principle Investigator: Alistair M Ewen

If you are interested in taking part in the above study, please complete this form and return it to the Principle Investigator.

		Tick box & initial
1	I confirm that I have read and understand the information sheet dated 26/9/08 (version 1.1) for the above study and have had the opportunity to ask questions.	☐
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason or without my legal rights being affected.	☐
3	I consent to having video images recorded during parts of the study as per the information sheet dated 26/9/08 (version 1.1) for data analysis purposes. Answering "No" to this question may exclude you from taking part in the trial.	Y ☐ N ☐
4	I give my consent for the Principle Investigator to use images recorded during the study in scientific publications and conference presentations, where their use would be an aid to better understanding of the results. Answering "No" to this question will not exclude you from taking part in the trial. Your consent will be sought on each occasion images are used. However, if you would prefer not to be asked repeatedly, then to give blanket consent tick here.	Y ☐ N ☐ ☐
5	I understand that relevant sections of my medical notes and data collected during the study may be looked at by individuals from the University of North-Northumbria, from regulatory authorities or from the Gateshead Health NHS Foundation Trust, where it is relevant to my taking part in this research. I give Permission for these individuals to have access to my records.	☐
6	I agree to take part in the above study.	☐
7	I consent to having my GP informed of my participation in this study.	☐

Now, please turn over to sign

10/7/09 Version 1.1a

Participant Consent Form

Participant's Name (Block Letters) _____

Signature _____ Date _____

Witnessed By (Block Letters) _____

Signature _____ Date _____

Appendix 4 Informed Consent form for control participants

northumbria
UNIVERSITY

INFORMED CONSENT FORM

Project Title: Collection of normal movement data for comparison in clinical trials

Principal Investigator: Alistair Ewen

Participant Number:

please tick
where applicable

I have read and understood the Participant Information Sheet.	☐
I have had an opportunity to ask questions and discuss this study and I have received satisfactory answers.	☐
I understand I am free to withdraw from the study at any time, without having to give a reason for withdrawing, and without prejudice.	☐
I agree to take part in this study.	☐
I would like to receive feedback on the overall results of the study at the email address given below. I understand that I will not receive individual feedback on my own performance.	☐
Email address…………………………………………………………………	

Signature of participant... Date.....……………..

(NAME IN BLOCK LETTERS)...………………….

Signature of researcher... Date.....……………..

(NAME IN BLOCK LETTERS)...………………….

Appendix 5 Video Consent form for patient participants

Gateshead Health **NHS**

NHS Foundation Trust

CONSENT FORM FOR USE OF IMAGES

Participant's Name (Block Capitals) _____

SECTION A

The Principle Investigator of the research project you were involved in between _____ and _____ entitled "Biomechanical analysis after total hip replacement and hip resurfacing" wishes to use still and/or video images of you captured during this project in the conference presentation/journal publication detailed below.

CONFERENCE/JOURNAL TITLE:-

I give consent for my still and/or video images to be used by the Principle Investigator in the conference/journal detailed.

Sign   Date

If you would prefer not to be contacted on each occasion, please complete Section B.

SECTION B

I give my consent for the Principle Investigator of the project entitled "Biomechanical analysis after total hip replacement and hip resurfacing" to use my still and/or video images captured during the project in future conference presentation and in journal papers without seeking my consent on each occasion.

Sign   Data

Appendix 6 Video Consent form for control participants

VIDEO RECORDINGS CONSENT FORM

Project title: Collection of normal movement data for comparison in clinical trials

Principal Investigator: Alistair Ewen

Participant Number: _____

I hereby confirm that I give consent for photographic and/or videotape recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.

I understand that the material may form part of my confidential records and has value in scientific assessment. The material may also be used for teaching purposes or for dissemination of findings and as such may be presented to students/professional staff for the purpose of education/staff training/professional development or to delegates at scientific conferences.

I understand that my name or other personal information will never be associated with the recording(s).

Signature of participant.. Date.....……………..

Signature of researcher.. Date.....……………..

I hereby give consent for the photographic recording made of me on......................
to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent.

Signature of participant.. Date.....……………..

Signature of researcher.. Date.....……………..

Appendix 7 Participant Information Sheet (patients)

Participant Information Sheet

1   Study Title

Biomechanical analysis after total hip replacement and hip resurfacing.

2   Invitation to take part.

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3   What is the purpose of the study?

This study is being carried out to investigate the benefits of the different types of implants used in hip replacement surgery. This study will investigate patient recovery to determine if there are significant differences between the implants in terms of ease and speed of recovery and regaining normal function.

4   Why have I been approached?

You are being asked to take part in this study because you will be undergoing hip replacement surgery and meet the other conditions for participants. 59 other people will also be asked to take part in the study.

5   Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You are still free to withdraw at any time and without giving a reason. A decision to withdraw, or not to take part, will not affect your level of care.

6   What will happen to me if I take part?

If you take part in the research study, you will need to attend pre- and post-treatment assessments at the Gait Lab of the Northumbria University at Newcastle. These sessions will last around 60 minutes. The first of these will be scheduled prior to your hip replacement surgery; the remaining two will be scheduled for 3 months and 12 months after your surgery. Reasonable travelling expenses will be arranged for you for each assessment session at the university (up to £10).

220

During these sessions, movement data will be collected while you are walking, stair ascending/descending, sitting into and rising from a chair and single leg stance. To collect this data, a number of small markers will be attached to your skin using surgical tape. When you move, cameras connected to a computer follow these markers and the computer will convert these markers into a stick figure on the computer screen. To accurately follow the movement of the body, you will have to wear shorts and a t-shirt or other close fitting clothing. Video cameras may also be used. This is standard practice and is used to help to build the stick figure. Also, if you give consent, your video footage may be used in presentations to scientific conferences and in published documents. You will be given the chance to view the edited footage and give consent each time your images are used.

In total, your involvement in the project will last around 13 months.

7   What do I have to do?
You will need to attend the assessment sessions and perform the tasks stated above.

8   What is the procedure that is being tested?
The surgery you will undergo will use recognised procedures and implants. The study aims to investigate each of the implants performs in terms of allowing the patient to regain leg function. The only difference with taking part in this study is that your movement will be studied in addition to the treatment you would normally receive.

9   What are the alternatives for treatment?
If you choose not to take part in the research, you will undergo hip replacement surgery. The treatment prescribed will be on a par with the treatment given to those taking part, but your movement will not be studied.

10   What are the side effects of any treatments received when taking part?
There are no known side effects of the filming and the side effects of your medical care will be fully explained by your medical care team.

11   What are the possible disadvantages and risks of taking part?
Since the only difference between taking part and not is that those who take part will have a filming session, there are no disadvantages of taking part.

12   What are the possible benefits of taking part?
There are no personal benefits of taking part. All hip replacement patients, whether they take part or not, will be given the same level of care using recognised procedures and implants as determined by your consultant. Any benefits will be to future hip replacement patients if this study highlights benefits of one implant over another.

13   What if new information becomes available?
Sometimes during the course of research project, new information becomes available about the treatment that is being studied. If this happens, the research leader will tell you about it and discuss with you whether or not you want to continue in the study. If you decide to withdraw, your medical care will continue

as normal. If you decide to continue in the study you will be asked to sign an updated consent form.

14   What happens when the research study stops?
When the time allocated to the study ends, you will be continued to be followed up by your consultant as normal, however, no more movement and loading data will be collected.

15   What if something goes wrong?
All participants are covered by the University's public liability policy. This policy covers injury or property damage as a result of negligence for which the University is liable. If you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, you can contact the University Secretary at Ellison Building, Ellison Place, Northumbria University, Newcastle upon Tyne, NE1 8ST. Tel: (0191) 227 4010.
Any complaints regarding your medical care should be addressed through the regular NHS complaints procedure.
http://www.dh.gov.uk/en/Managingyourorganisation/Legalandcontractual/Complaintspolicy/NHScomplaintsprocedure/DH_376

16   Will my taking part in this study be kept confidential?
Information which is collected about you during this project will be kept strictly confidential. Any information about you which leaves the hospital will have your name and address removed so that you cannot be recognized.
The data collected at the university will use just your patient ID number as identification.
No video footage will be used for purposes other than computer model construction without your full consent. Any stills from the footage used will have your identity concealed.

17   What will happen to the results of the research study?
The results will be presented in scientific journals and at scientific conferences. They will also be presented in a thesis submitted to the Northumbria University for the purposes of achieving a Doctor of Philosophy qualification for the Principle Investigator.
Preliminary results and report should start appearing in 2009 at conferences and in scientific journals.
In all instances, no information identifying you will be published, except video footage, if you have previously given full consent for it to be used.

18   Who is organising and funding the research?
This research is being funded by Biomet UK Ltd, who are one of the main manufacturers of orthopaedic implants.

19   Who has reviewed the study?
This study has been reviewed, and accepted, by the Newcastle & North Tyneside Research Ethics Committee and by the Ethics Committee of the Northumbria University. The Gateshead Heath NHS Foundation Trust has also reviewed and approved the study. There is also a tri-monthly review by the

supervisory team members from the Queen Elizabeth Hospital, Gateshead and the Northumbria University at Newcastle.

20   Contact for further information.
If you require any further information, or would like to discuss any aspect of this study, please contact:

Alistair M. Ewen (Principle Investigator),
Bioengineering Researcher,
School of Psychology & Sports Science,
Northumberland Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST
Tel: 0191 243 7018 (office) or 0191 272 0479 (home)
Mob: 07950 359739
e-mail: alistair.ewen@northumbria.ac.uk

Thank you for reading this information sheet and considering taking part in this study.

If you decide to take part in this study, you will be given a copy of this document and a signed copy of the consent form to keep.

Appendix 8 Hip patient expectation questionnaire

Hip Expectations Questionnaire

Pre-op

General Activity

Before having problems with your hip; how would you describe your level of general activity?

Very active   Not active at all
○   ○   ○   ○   ○

How would you describe your level of general activity today?

Very active   Not active at all
○   ○   ○   ○   ○

Sporting/Leisure Activity

Before having problems with your hip; how would you describe your level of sporting/leisure activity?

Very sporty   Not sporty at all
○   ○   ○   ○   ○

How would you describe your level of sporting/leisure activity today?

Very sporty   Not sporty at all
○   ○   ○   ○   ○

Expectations

Following your operation and rehabilitation; what do you hope to be able to do that you cannot do now or can do, but only with pain or discomfort? (Tick all that apply)

Walk to the shops or a friends ☐   Sit into or rise from a chair ☐

Climb or come down stairs ☐   Get into or out of a bath ☐

Get into or out of a car ☐   Put on or take off shoes ☐

Move about the house more comfortably ☐

Get out more often ☐

Resume a sporting, outdoor or leisure activity ☐   Please specify _____
(e.g golf, hill walking, dancing)
_____

Any other comments:-

Hip Expectations Questionnaire

3 Months Post-op

General Activity

How would you describe your level of general activity today?

Very active				Not active at all
O	O	O	O	O

Comparing where you are today with your expectations for general activity; how would you rate your progress?

I have achieved all of my expectations ☐

I have achieved most of my expectations ☐

I have achieved some of my expectations ☐

I have achieved a few of my expectations ☐

I have achieved none of my expectations ☐

Sporting/Leisure Activity

How would you describe your level of sporting/leisure activity today?

Very sporty				Not sporty at all
O	O	O	O	O

Comparing where you are today with your expectations for sporting/leisure activity; how would you rate your progress?

I have achieved all of my expectations ☐

I have achieved most of my expectations ☐

I have achieved some of my expectations ☐

I have achieved a few of my expectations ☐

I have achieved none of my expectations ☐

Expectations

In the next 9 month; what do you hope to be able to do that you cannot do now or can do, but only with pain or discomfort? (Tick all that apply)

Walk to the shops or a friends	☐	Sit into or rise from a chair	☐
Climb or come down stairs	☐	Get into or out of a bath	☐
Get into or out of a car	☐	Put on or take off shoes	☐
Move about the house more comfortably	☐		
Get out more often	☐		
Resume a sporting, outdoor or leisure activity (e.g golf, hill walking, dancing)	☐	Please specify _____	

Any other comments:-

Hip Expectations Questionnaire

1 Year Post-op

General Activity

How would you describe your level of general activity today?

Very active				Not active at all
O	O	O	O	O

Comparing where you are today with your expectations for general activity; how would you rate your progress?

I have achieved all of my expectations ☐

I have achieved most of my expectations ☐

I have achieved some of my expectations ☐

I have achieved a few of my expectations ☐

I have achieved none of my expectations ☐

Sporting/Leisure Activity

How would you describe your level of sporting/leisure activity today?

Very sporty				Not sporty at all
O	O	O	O	O

Comparing where you are today with your expectations for sporting/leisure activity; how would you rate your progress?

I have achieved all of my expectations ☐

I have achieved most of my expectations ☐

I have achieved some of my expectations ☐

I have achieved a few of my expectations ☐

I have achieved none of my expectations ☐

Expectations

In the next year; what do you hope to be able to do that you cannot do now or can do, but only with pain or discomfort? (Tick all that apply)

Walk to the shops or a friends ☐   Sit into or rise from a chair ☐

Climb or come down stairs ☐   Get into or out of a bath ☐

Get into or out of a car ☐   Put on or take off shoes ☐

Move about the house more comfortably ☐

Get out more often ☐

Resume a sporting, outdoor or leisure activity ☐   Please specify _____
(e.g golf, hill walking, dancing)   _____

Any other comments:-

Appendix 9 Participant Information Sheet (controls)

PARTICIPANT INFORMATION.

TITLE OF PROJECT: Collection of normal movement data for comparison in clinical trials

Participant ID
Number:

Principal Investigator: Alistair Ewen

Investigator contact details: Email: alistair.ewen@northumbria.ac.uk

This project is funded by: Biomet UK Ltd

Number of participant points / payment: None

INFORMATION TO POTENTIAL PARTICIPANTS
1. What is the purpose of the project? This project is being carried out to establish a database of walking patterns from the general population. People with certain conditions or who have undergone certain treatments can have their walking patterns altered. These changes can be used to identify a problem, to aid in rehabilitation, to determine a course of action or to compare two or more clinical interventions. In order to do this, these patterns often have to be compared to those of the unaffected population. This project aims to collect a large set of normal data which can be used in current and future work in movement analysis within Northumbria University.

| **2. Why have I been selected to take part?**

The project requires individuals between the ages of 18 and 75 who have had no previous lower limb joint replacement surgery and who do not currently suffer from any lower limb problems or other condition which could influence lower limb movements. |

| **3. What will I have to do?**

If you agree to take part, you will be invited to the Gait Lab in Sport Central, City Campus. The motion capture session will last between 45 and 60 minutes.
At the motion capture session data will be collected while walking, stair |

ascending and descending, rising from a chair and while performing a single leg stance. To collect this, a number of small markers will be attached to your skin using toupé tape. When you move, software in the computer will convert these markers into a 3 dimensional model on the computer screen. To accurately follow the movement of the body, you will have to wear shorts and a t-shirt or other suitable close fitting clothing of your choice, or provided by the investigator. Video cameras may also be used. This is standard practice and is used to help to build the computer model. Also, if you give consent, your video footage (or stills from extracted from it) may be used in presentations to scientific conferences, in publications or for educational purposes. You will be asked if you have had any condition or treatment which may have affected your walking pattern or other lower limb functions.

4. What are the exclusion criteria (i.e. are there any reasons why I should not take part)?

Individuals with known conditions (such as lower limb joint replacement or surgery, history of lower limb pain, discomfort or treatment) which could influence their walk or other lower limb functions will be excluded as will those with a Body Mass Indices above 35.
There are no known risks associated with this form of motion capture.

5. Will my participation involve any physical discomfort?

No

6. Will my participation involve any psychological discomfort or embarrassment?

No

7. Will I have to provide any bodily samples (i.e. blood, saliva)?

No

8. How will confidentiality be assured?

You will be identified in all documentation and saved data by a participant number only and no records will be kept relating participant number with personal details.

9. Who will have access to the information that I provide?

All information and data gathered during the study will only be made available to the research staff within the Division of Sport Sciences involved in current and future research in movement analysis. Should the research be presented or published in any form, then that information will be generalised (i.e. your

personal information or data will not be identifiable).

10. How will my information be stored / used in the future?

All information and data gathered during this study will be stored in line with the Data Protection Act and will be destroyed 10 years following the conclusion of the study. During that time the data may be used by members of the research team only for purposes appropriate to the research questions, but at no point will your personal information or data be revealed. Insurance companies and employers will not be given any individual's information or test results, and nor will we allow access to the police, security services, social services, relatives or lawyers, unless forced to do so by the courts.

11. Has this investigation received appropriate ethical clearance?

Yes, the study and its protocol have received full ethical approval from the School of Psychology & Sport Sciences Ethics Committee. If you require confirmation of this please contact the Chair of this Committee, stating the title of the research project and the name of the principle investigator:

Chair of School of Psychology & Sport Science Ethics Committee,
Northumberland Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST

12. Will I receive any financial rewards / travel expenses for taking part?

No financial rewards or travel expenses will be given for participating in this study.

13. How can I withdraw from the project?

If, at any time during the study, you decide that you do not wish to take any further part then please inform one of the research team as soon as possible, and they will facilitate your withdrawal. Any personal information or data that you have provided (be it in paper or electronic form) will be destroyed/deleted as soon as possible.
After you have completed the research you can still withdraw your personal information/data by contacting one of the research team (their contact details are provided in section 14. Provide them with your participant number and the data will be destroyed/deleted.

14. If I require further information who should I contact and how?

Principle Investigator: Alistair Ewen (Postgraduate Researcher),
School of Psychology and Sport Sciences,
Northumbria University,
Northumberland Building,
Newcastle upon Tyne,
NE1 8ST
Tel: 0191 243 7018
Email: alistair.ewen@northumbria.ac.uk

Academic Supervisor: Dr Nick Caplan,
School of Psychology and Sport Sciences,
Northumbria University,
Northumberland Building,
Newcastle upon Tyne,
NE1 8ST
Tel: 0191 243 7382
Email: nick.caplan@northumbria.ac.uk

Appendix 10 Control participant screening questionnaire

northumbria
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Participant Screening Questionnaire

Participant ID _____

_____

Are your lower limbs usually free from pain?	☐
Are you able to walk without a support?	☐
Are you able to walk for 30 minutes or more without difficulty?	☐
Do you walk with a limp?	☐
Can you put on socks or shoes without difficulty?	☐
Can you use stairs without using a railing?	☐
Are you able to use public transport?	☐
Can you sit comfortably in a chair for an hour?	☐

Appendix 11 Participant Debrief Sheet

PARTICIPANT DEBRIEF

TITLE OF PROJECT: Collection of normal movement data for comparison in clinical trials

Principal Investigator: Alistair Ewen

Investigator contact details: Email: alistair.ewen@northumbria.ac.uk

Participant Identification Number: _____

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1. What was the purpose of the project?

This project was carried out to establish a database of walking patterns from the general population. It aims to collect a large set of normal data which can be used in current and future work in movement analysis within Northumbria University.

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2. How will I find out about the results?

This project will produce no specific results itself.

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3. Will I receive any individual feedback

No, however, you will receive overall feedback if you requested it.

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4. What will happen to the information I have provided?

The information you provide will be stored in a secure manner with access limited to those invovled in relevant research within the Division of Sport Sciences. Only participant numbers will be used to identify data. Your data will be used as control data (either individually or averaged with other data) in current and future reseach projects.

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5. How will the results be disseminated?

This project itself will produce no specific results.

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6. Have I been deceived in any way during the project?

No

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7. If I change my mind and wish to withdraw the information I have provided, how do I do this?

If, at any time, you decide that you do not wish your data to be used, then

please inform one of the research team as soon as possible, and they will facilitate your withdrawal. Any personal information or data that you have provided (be it in paper or electronic form) will be destroyed/deleted as soon as possible.

If you have any concerns or worries concerning the way in which this research has been conducted, or if you have requested, but did not receive feedback from the principal investigator concerning the general outcomes of the study within 2 few weeks after the study has concluded, then please contact Professor Kenny Coventry via email at kenny.coventry@northumbria.ac.uk, or via telephone on 0191 2437027.