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A prospective cohort study investigating functional recovery in patients with osteoarthritis following total hip arthroplasty using a direct anterior versus direct lateral surgical approach

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Kinesiology

A PROSPECTIVE COHORT STUDY INVESTIGATING FUNCTIONAL RECOVERY IN PATIENTS WITH OSTEOARTHRITIS FOLLOWING TOTAL HIP ARTHROPLASTY USING A DIRECT ANTERIOR VERSUS DIRECT LATERAL SURGICAL APPROACH

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Abstract

We used a quasi-randomized cohort study to investigate whether there are differences in early functional recovery between patients who undergo total hip arthroplasty using a direct anterior (DA) or direct lateral (DL) surgical approach. We found significant differences in favour of the DA group for many functional outcomes including: gait velocity, stride length, operative limb single-limb support, single-limb support symmetry and time to complete the Timed Up and Go. Our primary outcome, gait velocity, was significantly greater in the DA group at discharge, two weeks and six weeks postoperative with adjusted mean differences of 0.12m/s, 0.15m/s and 0.17m/s respectively. There was no difference between the groups at any time point for quality of life or pain. The DA approach to THA offers better early functional outcomes than the DL group.

Keywords

Total hip arthroplasty, direct anterior, direct lateral, Hardinge, Heuter, gait, GAITRite, osteoarthritis.

Co-Authorship Statement

This prospective cohort study was designed in collaboration with Drs. Bryant, Hunter and Lanting. I was solely responsible for conducting the study including: patient identification, patient recruitment, data collection, and data analysis. I wrote the original draft of the manuscript and Drs. Bryant and Hunter made comments and suggestions towards its improvement into this thesis document. Drs. Lanting and Howard were also sent this thesis for their comments and suggestions towards the final submission.

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Chapter 1

1 Introduction

Total hip arthroplasty (THA) is a common procedure performed to treat patients living with severe osteoarthritis of the hip. THA has a proven track record of pain relief and functional improvement[1–5]. There are several surgical techniques available to surgeons performing THA. Currently, the type of surgical approach chosen is dependent on surgeon preference and expertise, with little clear evidence available to support one approach over another[6,7].

The direct lateral (DL) and direct anterior (DA) surgical approaches are both acceptable methods for performing a THA, each using a minimally invasive technique[8,9] with comparable exposure of the hip joint. The DA is a relatively newer surgical approach and is less often used in usual practice even though it is suspected to offer superior outcomes to the DL approach as it does not involve releasing any muscles from their attachments around the hip[1,3,7,10,11]. On the other hand, the DL approach involves the release of a third of the gluteus medius and minimus[2,3,8,12–15], which can lead to a slower recovery[1,10,16].

Gait analysis can be used to look for differences in the recovery of functional mobility in patients following THA. Previous studies comparing the DA to DL have found few differences between surgical approaches later than 3-months post-surgery[3,5,10,16,17]. We suspect that important differences may exist earlier than 3 months after surgery because this is when the effects of the more invasive DL approach may be most apparent. Early differences are important because they can translate to a shorter length of stay in hospital and faster rehabilitation and achievement of major milestones in the recovery of independent functional mobility, which can decrease costs to the hospital and Ministry of Health.

Chapter 2

2 Literature Review

This literature review will have four main areas of focus: anatomy, osteoarthritis, total hip arthroplasty, and gait. The anatomy section will focus on the hip abductor muscles, a group that is affected during the specific surgical techniques of interest in this study for total hip arthroplasty. We will specifically discuss osteoarthritis of the hip including its impact in Canada, diagnosis, available treatments and the direct anterior and direct lateral surgical approaches. Next, we will describe the history, technique, and studies that have reported recovery following each approach with a focus on those studies that have directly compared the direct anterior to the direct lateral approach. Finally, we will describe the gait cycle, gait analysis and how gait is affected by osteoarthritis and total hip arthroplasty and summarize studies that have investigated recovery of gait parameters following each surgical technique.

2.1 Anatomy of the Hip

The hip is an enarthrosis, or ball-and-socket joint, involving the rounded head of the femur and the cup-like acetabulum on the pelvis. The articulating surfaces of the acetabulum and femur, each covered with a layer of hyaline cartilage, as well as the joint capsule comprise the hip joint. The hip is a synovial joint and is capable of a wide range of motion (ROM) including flexion, extension, internal and external rotation, abduction, adduction and circumduction.

The acetabulum is formed by all three components of the pelvis: the ilium, ischium and pubis[18]. It is cup-shaped, relatively shallow and sits laterally to articulate with the femoral head. A fibrocartilaginous labrum is attached to the rim, or margin of the acetabulum, thus deepening the socket and providing a more secure cup to prevent dislocation[19]. The cartilage within the acetabulum is C-shaped, with the centre free for the acetabular fossa[18,20].

Hyaline cartilage completely covers the head of the femur where it articulates with the acetabulum except for a depression, the fovea, just inferior to the centre where the ligamentum teres attaches[18,21]. The femoral head cartilage is thicker near the centre and thinner around the circumference[21].

The hip joint capsule is one of the strongest structures in the body and helps to stabilize the hip joint[22]. The joint capsule connects the rim of the acetabulum to the neck of the femur and contains both circular and longitudinal fibres. The zona orbicularis is the name given to the circular fibres of the capsule, which acts as a collar around the neck of the femur[18,21,22].

The longitudinal fibres of the articular capsule form three distinct ligaments: the iliofemoral, the pubofemoral, and the ischiofemoral ligaments. The iliofemoral ligament, also the Y ligament of Bigelow, is “the most powerful ligament” in the body[18,20,21] and stretches across the front of the hip joint (Figure 1)[19,21]. It acts to restrict extension and reinforces the superior and anterior aspects of the capsule[19,20,22]. The iliofemoral ligament originates at the inferior portion of the anterior inferior iliac spine and then splits to insert onto the intertrochanteric line on the proximal femur[18,19,21,22].

The role of the pubofemoral ligament is to restrict external rotation when the joint is in extension (Figure 1)[20]. It reinforces the inferior aspect of the capsule originating on the pelvis at the superior pubic ramus and inserts onto the neck of the femur[22].

Finally, the ischiofemoral ligament reinforces the posterior aspect of the capsule and restricts internal rotation and adduction[20]. It originates on the posterior rim of the acetabulum and inserts onto the intertrochanteric crest[22].

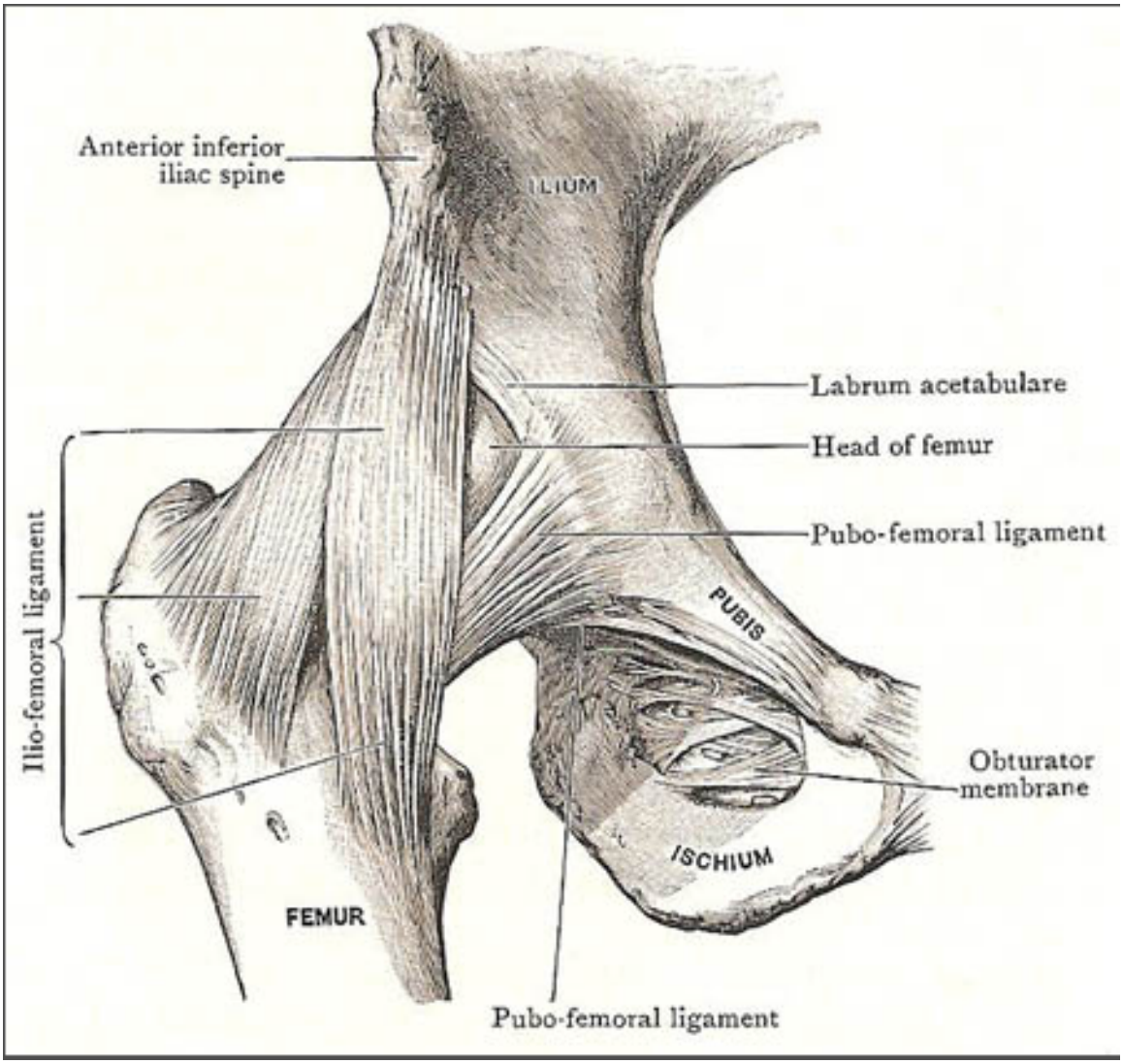

Figure 1: The anterior ligaments and interior anatomy of the hip capsule

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Another ligament associated with the hip joint is the ligament of the head of the femur, ligamentum teres, which is a synovial fold[22]. Ligamentum teres connects the transverse ligament to the femoral head at the fovea[20]. The ligamentum teres has an artery that runs through it, which provides the blood supply to the head of the femur[18].

The transverse acetabular ligament forms the inferior margin of the acetabulum and is connected with the ligamentum teres and the articular capsule[20]. The role of the transverse acetabular ligament is to prevent inferior movement of the femoral head,

which it does by deepening the inferior aspect of the acetabulum and completing the C shape of the acetabular cartilage into an O[20].

The lateral femoral cutaneous nerve is part of the lumbar plexus and is formed by the second and third lumbar nerves[20,21]. It innervates the skin of the anterolateral thigh[20,23]. The lateral femoral cutaneous nerve begins at the lateral portion of the middle of the psoas muscle and travels across the iliacus muscle towards the anterior superior iliac spine[21]. The lateral femoral cutaneous nerve then passes over the Sartorius muscle where it then divides into an anterior and posterior branch. The anterior branch continues distally into the fascia latae within an aponeurotic canal and rises superficially approximately ten centimetres below the inguinal ligament where it then divides into many branches along the anterior and lateral part of the thigh. The subdivisions of the anterior branch of the lateral femoral cutaneous nerve reach as far as the knee. The posterior branch of the lateral femoral cutaneous nerve descends into the fascia latae where it then divides into branches, which reach to the posterior and lateral surfaces of the thigh[21].

There are many muscles that help to dynamically reinforce the stability of the hip joint and assist with joint mobility. Generally these muscles are grouped according to their role in hip function: flexors, extensors, external rotators, abductors, and adductors.

The short external rotators of the hip include the piriformis, superior and inferior gemelli, obturator internus and quadratus femoris. The piriformis originates from the anterior surface of the sacrum and inserts into the superior border of the greater trochanter[18,20–22]. Sacral spinal nerves S1 and S2 innervate the piriformis muscle[22].

The obturator internus originates from the inner surface of the obturator foramen, pubis and ischium and inserts into the medial surface of the greater trochanter[22]. The obturator nerve innervates this muscle[22].

The superior gemellus originates from the outer surface of the ischial spine and the inferior gemellus originates from the upper portion of the ischial tuberosity. Both muscles insert into the medial surface of the greater trochanter[21,22].

The conjoint tendon is the collective term used to refer to the combined tendons of the obturator internus and superior and inferior gemelli[24]. Together the tendons of these muscles join before inserting into the medial aspect of the greater trochanter[24].

Quadratus femoris originates from the upper portion of the ischial tuberosity and inserts into the linea quadrata, a line crossing the posterior intertrochanteric line[21]. A synovial bursa lies between the quadratus femoris and the lesser trochanter[21].

The hip abductors play a significant role in pelvic control during gait and function to not only abduct the thigh, but also help with internal rotation[25]. They act to resist contralateral pelvic drop when standing on one leg, an essential activity that occurs during gait[26]. This group of muscles includes the gluteus medius, gluteus minimus and tensor fascia latae[25], which are innervated by the superior gluteal nerve[18].

The gluteus medius originates from the iliac crest between the anterior and posterior gluteal lines and forms a broad tendon to insert onto the oblique line of the greater trochanter[18,21,23]. A synovial bursa lies between the gluteus medius tendon and the greater trochanter anterior to its insertion[21]. The gluteus medius is covered posteriorly by the gluteus maximus and anteriorly by the tensor fascia latae[18,21].

The gluteus minimus is the smallest and deepest of the three gluteal muscles. It originates from the outer surface of the ilium between the anterior and inferior gluteal lines and inserts onto the anterior surface of the greater trochanter[18,21,23]. Between the tendon and greater trochanter lies another synovial bursa[21]. The gluteus minimus works in conjunction with the gluteus medius to abduct and internally rotate the thigh[18].

The tensor fascia latae (TFL) originates from the anterior portion of the iliac crest and anterior superior iliac spine, and inserts into the ilio-tibial band[18,21,23]. It not only works to abduct and internally rotate the thigh, but also helps with flexion[18].

Two other muscles involved in hip flexion include the sartorius and rectus femoris, both of which are innervated by the femoral nerve[23]. Sartorius is the longest muscle in the body[21,22]. It originates from the anterior superior iliac spine and then crosses obliquely

over the anterior portion of the thigh and inserts into the proximal medial tibia below the knee[18,21–23]. Sartorius also helps with external rotation of the thigh at the hip joint[18,23].

Rectus femoris is one of four muscles that together form the quadriceps and is located in the anterior region of the thigh. It originates from the anterior inferior iliac spine and the superior rim of the acetabulum and inserts into the patella and tibial tubercle[18,21–23]. Rectus femoris not only acts to flex the hip, but also plays a role in knee extension[22,23].

2.2 Osteoarthritis

Osteoarthritis (OA) is a degenerative joint disease that most commonly affects the weight bearing joints of the lower extremities, specifically the knee and hip. The prominent pathological feature of OA is deterioration of the articular cartilage, ultimately leading to pain and stiffness of the affected joint, which can significantly impact quality of life[27,28]. Symptomatic OA is suspected to be caused by a combination of mechanical stresses and biochemical changes resulting in disrupted cartilage repair mechanisms that ultimately lead to cartilage degeneration[29]. OA is the most common form of arthritis[28] and is a major cause of long-term disability in seniors, adults over the age of 65[27,28], as well as a major economic burden[27].

2.2.1 Disease Burden in Canada

Osteoarthritis affects almost 10% of the Canadian population, more than three million adults[30,28]. It is the most responsible diagnosis for 79% of visits to primary care physicians and 20% of visits to surgical specialists, of which 97% were orthopaedic surgeons[28]. In 2012-2013, there were more than 35 600 total hip joint replacements performed in Canada, 76.5% of which were for OA[27]. This is a five-year increase of 16.5% and a one-year increase of more than 5.3%, which represents an enormous economic burden. The burden of OA alone has not been reported in Canada, but it was estimated that all arthritic diseases combined, of which OA is the most common, cost 6.4 billion dollars in 2000 in both direct and indirect health care costs[28].

2.2.2 Osteoarthritis of the Hip

OA of the hip is a disorder of the entire joint affecting not only the articular cartilage, but also the bone and joint capsule[31]. It is characterized by thickening of the subchondral bone, formation of osteophytes at the joint margins, and asymmetric joint space narrowing[32].

Symptoms develop gradually over time and include pain and stiffness of the joint. Pain is usually localized to the anterior groin[23,32], related to activity and can be relieved by rest. In advanced stages of the disease, pain can persist despite rest and be present at night[32]. Stiffness is generally restricted to the morning, lasting around thirty minutes[32]. As a result of pain and stiffness, the joint may be used less often through reduction of weight-bearing activities, which can lead to weakening of the muscles surrounding the hip, also referred to as disuse atrophy[26]. One important functional consequence of weakness of the hip muscles is the development of abnormal gait patterns[33].

2.2.3 Risk Factors

OA is separated into two categories, primary and secondary. Primary OA is idiopathic and has no specific cause of onset, while secondary OA is caused by some joint abnormality leading to destruction of the articular cartilage[32,34–37].

Several risk factors thought to contribute to primary OA include increased age, family history, high body mass index (BMI), physical inactivity, and participation in certain sports and occupations[32]. Age-related changes that affect the joint include decreased muscle strength, loosening of ligaments, and thinning of cartilage, which can lead to OA[28]. The prevalence of hip OA increases along with age. There appears to be a genetic predisposition to the development of OA, where those with a family history of OA have an increased risk of developing the disease[32]. The risk of OA also increases as weight increases with obese people twice as likely to develop hip OA and require a hip replacement due to increased forces placed on the joint[28]. Inactivity has been shown to exacerbate muscle wasting and lead to joint stiffness, which together can cause joint instability and contribute to OA[28]. Sports, such as running, can also lead to early wear on

the joint[32]. Occupations requiring heavy lifting and prolonged periods of standing are also shown to have an increased risk of OA, such as those in agricultural fields[32].

Risk factors associated with the development of secondary OA include systemic disease, developmental deformities and joint injury[32]. Systemic diseases can include Paget's disease or gout. Perthes disease is also commonly associated with the development of hip OA, as well as osteonecrosis[32,34]. Slipped capital femoral epiphysis and injuries such as acetabular fracture or those resulting in cartilage damage can also lead to OA.

There has been a lot of debate as to whether the two categories of OA truly exist, with many arguing that all OA is secondary[34–36]. Supporters of this theory claim that there is usually some underlying abnormality that has not been identified[35].

2.2.4 Diagnosis

Diagnosis of hip OA is determined with patient history, physical examination and radiographs. The key to diagnosis is to first eliminate other possible causes of hip pain.

An accurate and thorough medical history is the first step in any diagnosis. Pain in the lateral or anterior thigh or groin is common and usually occurs with prolonged ambulation, but can be relieved with rest. Morning stiffness or pain is also indicative of hip OA, especially when it only lasts for up to thirty minutes. It is important to rule out other possible causes of hip pain such as referred pain from the knee and lumbar spine. Anterior or inguinal pain and tenderness is indicative of true involvement of the hip joint[32].

Key components in a physical examination include an evaluation of gait and hip ROM. Abnormal gait patterns, such as a coxalgic, antalgic and Trendelenburg gait, are common among patients with hip OA due to hip abductor weakness. Decreased ROM accompanied by pain with internal or external rotation are also usually found[32,38].

There are three key characteristics on radiographs: joint space narrowing, osteophytes and subchondral sclerosis (Figure 2). The amount of joint space is a representation of the amount of cartilage in the joint, as cartilage does not appear on x-rays. Joint space

narrowing is evidence of cartilage loss due to OA. Osteophytes are bony outgrowths that develop from remodelling processes as a result of cartilage degeneration and occur most commonly at the joint margins[39]. Subchondral sclerosis is an area of thickened subchondral bone or increased bone density. Sites of sclerosis occur most commonly at the joint margins and are visible on radiographs as thick white lines[32].

The Kellgren-Lawrence scale is frequently used to describe the severity of OA. It relies on radiographic imaging to grade OA severity on a scale from zero, indicating no OA, to four, severe OA (Figure 2 and Table 1). The presence of specific features, such as osteophytes and joint space narrowing, are used to determine the grade[37,40].

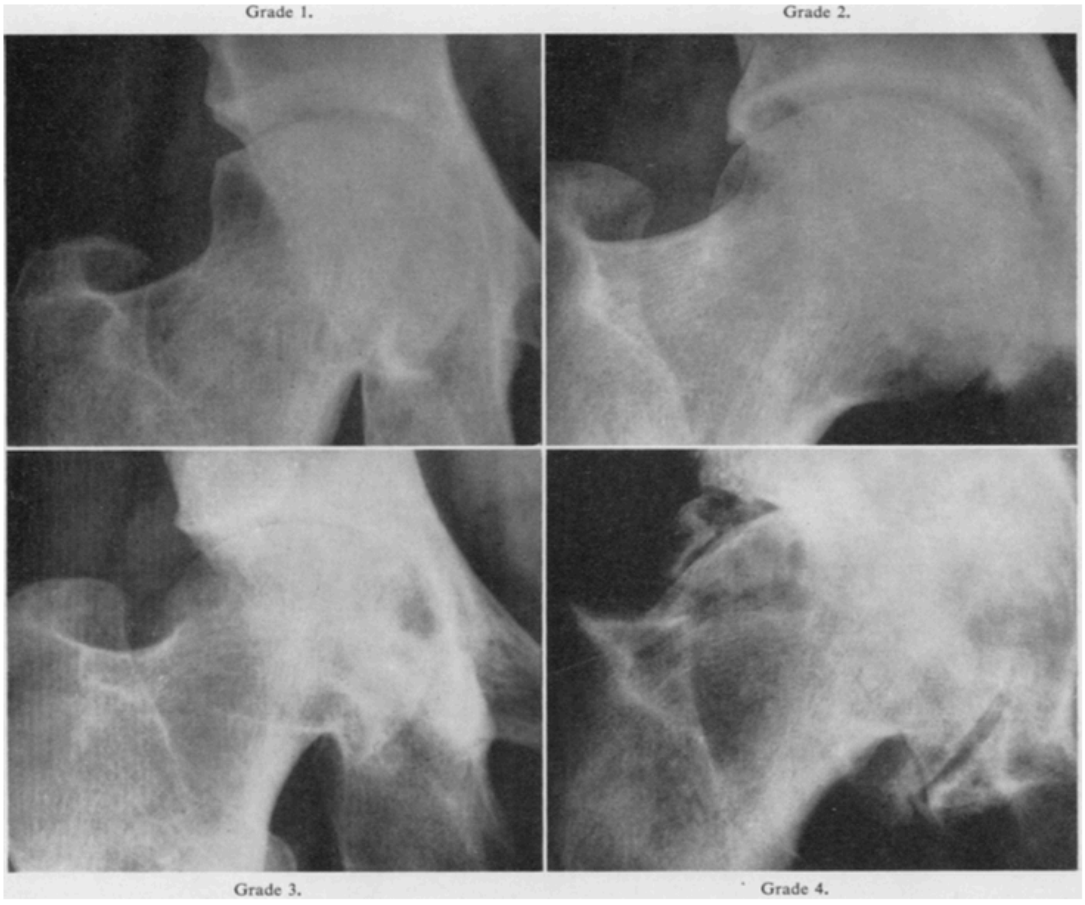

Figure 2: Radiographic evidence of osteoarthritis of the hip graded on the Kellgren-Lawrence scale

Reproduced from Radiological Assessment of Osteo-Arthrosis, J.H. Kellgren and J.S. Lawrence, Vol. 16(4), pp. 494-502, 1957 with permission from BMJ Publishing Group Ltd[40].

Table 1: Kellgren-Lawrence scale for evaluating radiographic evidence of osteoarthritis

Grade	Description
0	No radiographic evidence of OA
1	Doubtful joint space narrowing, possible osteophytes
2	Possible joint space narrowing, definite osteophytes
3	Definite joint space narrowing, moderate osteophytes, some sclerosis, possible deformity of femoral head or acetabulum
4	Marked joint space narrowing, large osteophytes, severe sclerosis, definite deformity of femoral head and acetabulum

Injection of anaesthetic into the intra-articular space can be used to aid in diagnosis by helping to determine whether the hip is the true source of pain. If the hip is the source of pain then the injection should provide some, if not complete, pain relief. This can also be predictive of the results after total hip arthroplasty[41]. Injection is generally used when the diagnosis is unsure, or when there is confusion between spinal or hip pathology as the source of pain[41].

Clinical examination alone has been shown to be quite sensitive and specific for diagnosing hip OA, but when radiographic examination is included both are significantly improved[29]. Altman *et al*. were able to achieve 91% sensitivity and 89% specificity for separating patients with hip OA from controls[29] when using both clinical and radiographic examinations.

2.2.5 Treatment

There are no cures for the damage that results with OA, but there are a number of options for treating the symptoms and slowing the progression of the disease. Conservative management is available at the onset of symptoms and may provide relief for many people, but severe OA generally requires operative treatment. All treatment options have the same goals: to control pain and improve function.

2.3 Total Hip Arthroplasty

Sir John Charnley developed the first consistently successful total hip arthroplasty (THA) procedure in the 1960's[42]. THA is the indicated treatment for individuals who suffer from

deterioration of the hip joint leading to pain, limited ROM and deformity. Indications for THA include, but are not limited to: OA, rheumatoid arthritis, avascular necrosis, bone tumours, and hip fracture.

Total hip arthroplasty has been reported as one of the most successful orthopaedic surgical procedures[13,43–45]. Pain relief as a result of THA for OA has been reported in over 90% of patients[46]. Most of the benefits seen after surgery occur within the first six months post-operatively and the most significant improvements occur during the first three months[46]. By three months post-operative, the majority of patients have achieved pain-free function in everyday activities[46] and by one year patients are reported as achieving similar activity levels to healthy individuals[47].

Regardless of how successful any surgery may be, there are always complications that may occur. In the case of THA these include dislocation, leg length discrepancy, gait disturbances and nerve injury. Dislocations are a common complication; they occur in 0.4% to 11% of patients[13,45,46] and are associated with weakness in the hip muscles[46]. Leg length discrepancy (i.e., unequal leg lengths) as a complication has decreased with improved templating, greater implant options to balance the hip, and the use of improved measurement techniques as this allows surgeons to better assess leg length with trial components prior to placement of the final components. Common gait disturbances present as a persistent limp or positive Trendelenburg sign and are thought to be the result of a disruption of the abductor muscles of the hip[44]. Injury to the lateral femoral cutaneous nerve is a common complication with the direct anterior approach that has been reported to occur in 53-67% of patients[48,49]. Injury to this nerve can result in reduced sensation or numbness to the anterolateral portion of the thigh post-surgery, but has been reported to resolve in the majority of patients by two years[48].

2.3.1 Direct Lateral Approach

The direct lateral (DL) approach to THA was first described in 1903 by Kocher[13] and was then modified in 1954 by McFarland and Osborne[50]. This approach was based on the continuity of the gluteus medius and vastus lateralis over the greater trochanter via fascial connection. The original procedure involved the detachment of the entire gluteus medius

and vastus lateralis from their posterior border on the greater trochanter to expose the joint capsule.

Hardinge popularized a modified DL approach in 1982; and thus it is also referred to as the 'Hardinge' technique[51]. In this version only the anterior third to half of the gluteus medius and vastus lateralis are reflected. Several more modifications have since been described for the surgical technique to minimize the damage to the hip abductors[12]. There is no one accepted standard technique for the DL approach.

2.3.1.1 Surgical Technique

The surgeons at University Hospital, London Health Sciences Centre, currently utilize the following DL surgical technique for THA.

Patients are placed under spinal, or general anaesthesia and positioned in the lateral decubitus position on an operative table with appropriate bolsters. The incision is approximately eight to ten centimetres long and starts two fingerbreadths above and extends distally four fingerbreadths below the greater trochanter (Figure 3). The TFL is split in line with the incision and the abductors are visualized with the use of retractors. The gluteus medius is then split, releasing the anterior third off its insertion on the greater trochanter. The gluteus minimus is then split with the capsule as a single layer.

A T-shaped incision in the capsule is used to gain access to the interior of the joint. A pin is then placed into the iliac crest to help determine offset and leg length later. The hip is dislocated anteriorly using external rotation, adduction and extension[12]. An osteotomy is then performed to remove the femoral head.

The labrum is excised and the acetabulum is reamed for the acetabular cup with progressively larger sized heads until the final size is reached. Screws may be used as needed to secure the final cup and the liner is impacted into place.

The femoral canal is then broached with sequentially larger broaches until the desired fit and fill of the femur is reached. Reduction of the hip is achieved and a caliper is used to

check offset and leg length. The final stem is then inserted into the femoral canal, and the final head is also impacted onto the stem.

After irrigating the surgical incision, the wound is sutured closed in layers and a sterile dressing is applied.

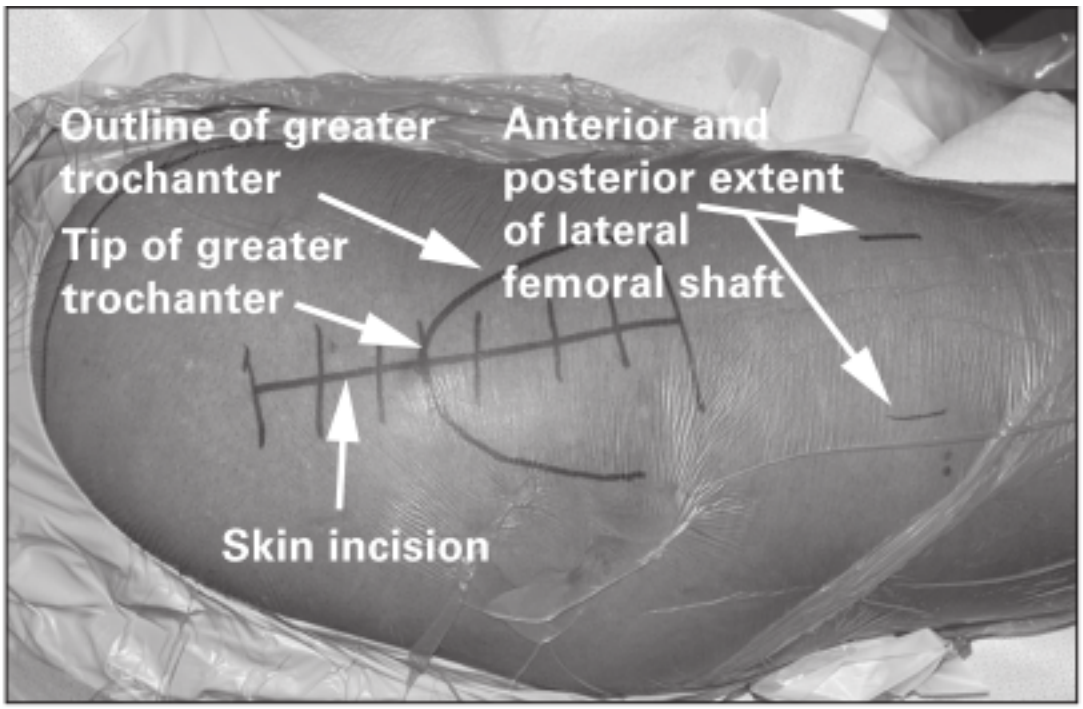

Figure 3: Location of the incision during the direct lateral surgical approach for total hip replacement.

Reproduced with permission from Petis *et al.* Surgical approach in primary total hip arthroplasty: anatomy, technique and clinical outcomes, *Canadian Journal of Surgery*, Vol. 58(2), pp. 128-139, 2015[52].

2.3.1.2 Rehabilitation and Recovery

Certain activity and movement restrictions are placed on patients after a DL THA to help reduce the risk of possible dislocation. The restrictions vary based on institution and surgeon, but are generally quite similar. At University Hospital, London Health Sciences Centre, patients are discouraged from flexing their operative hip more than 90 degrees, rotating their leg to the extremes of internal or external rotation, or twisting their body

when standing[13,53]. These restrictions are encouraged for the first six weeks of recovery to protect the abductor repair and to protect against dislocation[13].

Physiotherapy begins within one day of surgery and continues until approximately three-months post-surgery, but may be stopped earlier based on the successful achievement of functional milestones. The focus of physiotherapy during this time is on abductor strengthening[13]. It's been reported that by three months post-surgery the majority of patients can expect good to excellent abductor muscle strength[54], however there are still deficits compared to controls more than one year post-surgery[55,56].

Studies investigating the efficacy of the DL approach for THA have reported good overall results. Demos *et al.* report a dislocation rate of only 0.4% at more than three years of follow-up. They also reported an 11.6% incidence of a limp at the same time point[13].

Some studies have compared the DL approach against other surgical approaches and found few differences between them. Greidanus *et al.* compared the DL approach with the anterolateral (AL) and posterolateral (PL)[57]. The AL approach uses the intermuscular interval between gluteus medius and minimus and the TFL, and the PL approach interrupts the short external rotators and the posterior hip capsule. They found no differences for function, quality of life, satisfaction or complications at three months or one year between the groups[57]. Bernasek *et al.* compared the DL and AL approaches and found no differences in operative measures, complications or Harris Hip Score (HHS) at one year[12]. There was no evidence of limp or positive Trendelenburg tests at one year in either group[12]. Witzleb *et al.* also compared the DL and posterior approaches, but they found the DL group to have significantly increased range of motion at one week and decreased operative time compared to the posterior group[58]. Both groups however had significantly improved Western Ontario McMaster Osteoarthritis Index (WOMAC), a self-administered questionnaire used to assess function, stiffness and pain, and HHS scores over the three-month study period[58].

Overall, the DL approach is reported as an effective surgical technique for THA. Studies that have compared the DL approach to other techniques have tended to evaluate effects

at three months or later post-surgery. The only study that did report a significant difference, measured outcomes as early as one week post-surgery[58]. This could indicate very early differences between various surgical techniques that disappear farther out from surgery, as differences did not persist at the three-month time point[58]. Early advantages could be important for earlier rehabilitation and earlier return to daily activities, which may be important to the patient.

2.3.2 Direct Anterior Approach

Dr. Robert Judet originated the direct anterior (DA) approach in 1947 at Hospital Raymond Poincare in France[45]. It originally involved detachment of the anterior portion of the TFL, but has since been modified to no longer involve the detachment of any abductor muscles[45]. There are three main justifications for the use of this approach for THA: (1) the hip is an anterior joint and is therefore closer to the skin anteriorly than posteriorly; (2) the approach follows the internervous plane between the superior and inferior gluteal nerves laterally and femoral nerve medially; (3) it exposes the hip capsule without requiring the detachment of any muscles[45]. This approach is also referred to as the 'Heuter Approach' or the 'Short Smith-Pete'.

Not only does the DA approach follow an internervous plane, but also an intermuscular plane between the sartorius and TFL muscles[43]. The abductor muscle attachments on the greater trochanter are preserved, but the conjoint tendon often needs to be released to improve femoral exposure.

Although the procedure can be done on a standard operating room table without imaging, many surgeons use a specialized table and fluoroscopy; both of which increase the costs of this procedure. This is a disadvantage of using a DA approach. Originally the Judet table was used, but a number of other tables are now available. For example, the PROfx (Mizuho OSI, Union City, CA) and HANA (Mizuho OSI, Union City, CA) tables are now commonly used. While not necessarily required for the procedure, the table enhances femoral access and makes the surgery easier to perform. The tables have mobile spars that allow for manipulation of each leg separately including traction, rotation and angulation[45]. The DA approach typically is done with the patient in a supine position.

When the specialized table is used, it is possible to operate on both hips easily without redraping or repositioning of the patient.

2.3.2.1 Surgical Technique

The surgeons at University Hospital, London Health Sciences Centre, currently utilize the following DA surgical technique for THA.

Patients are placed under general anaesthesia and positioned in supine on the HANA orthopaedic operative table. The incision is made two centimetres distal and lateral to the anterior superior iliac spine and is approximately eight to twelve centimetres long (Figure 4). The incision continues distally and laterally at 20 degrees to the mid-coronal plane. After transposing the lateral femoral cutaneous nerve medially, the fascia is split in line with the skin and incised over the TFL muscle belly. The TFL is retracted laterally and Sartorius is retracted medially to expose the hip capsule[45]. Exposure of the capsule can be enhanced by excision of the overlying fat pad.

A capsulotomy is performed with the use of a T-shaped incision to expose the femoral neck[45]. The femoral neck is then cut using a reciprocating saw, and the head removed. Traction and rotation of the limb is accomplished with the use of the mobile spars of the table.

The labrum is excised and the acetabulum is reamed for the acetabular cup with progressively larger sized reamers until the final size is reached. Component positioning is confirmed with the use of fluoroscopy. Screws may be used as needed to secure the final cup and the liner is impacted into place.

Extending, adducting and externally rotating the leg facilitates femoral exposure. Release of the conjoint tendon may be required to optimize exposure. The femoral canal is then broached with sequentially larger broaches until the desired fit is reached. Reduction of the hip is achieved and fluoroscopy is used to judge offset and leg lengths as well as the broach position and alignment. The final stem is then implanted into the femoral canal, and the final head is also impacted onto the stem.

After reducing the hip and irrigating the surgical incision, the wound is sutured closed in layers and a sterile dressing is applied.

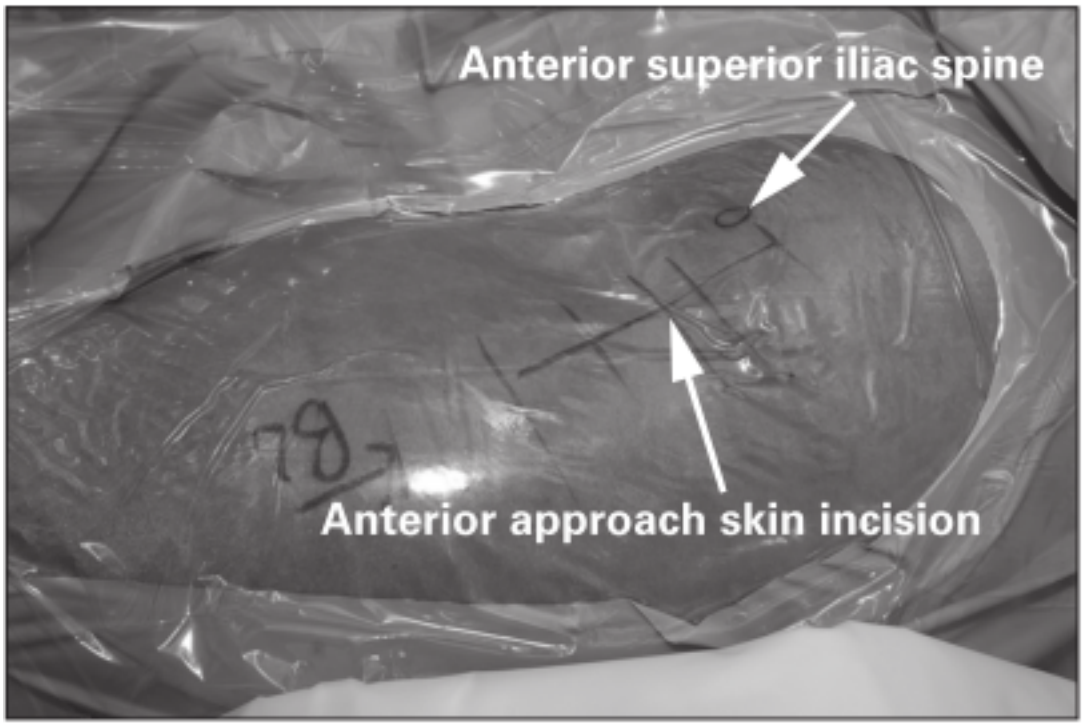

Figure 4: Location of the incision during the direct anterior surgical approach for total hip arthroplasty.

Reproduced with permission from Petis *et al.* Surgical approach in primary total hip arthroplasty: anatomy, technique and clinical outcomes, *Canadian Journal of Surgery*, Vol. 58(2), pp. 128-139, 2015[52].

2.3.2.2 Rehabilitation and Recovery

Unlike the DL THA, there are no standardized guidelines regarding rehabilitation after the DA surgical technique for THA. At University Hospital, London Health Sciences Centre, there are no restrictions placed on patients regarding leg positioning or movement post-surgery[45]. Patients are allowed to weight-bear as tolerated and start physiotherapy on the day of surgery, with pain as the only restriction to activity.

Several studies have reported the efficacy of the DA approach for THA. Matta *et al.* reported accuracy of more than 90% for placing implants within target abduction and

anteversion angles[45]. Once past the learning curve, low complication rates are also reported[45,59,60]. Dislocation rates are quite low with this approach and have been reported by Sariali *et al.* as 1.5% by one-year post-surgery[59]. This technique was shown by Hallert *et al.* to be significantly influenced by BMI for operative duration and acetabular cup deviation[61]. Oinuma *et al.* reported an average of only 5.3 days before patients were able to walk 50m with only the use of a cane[11].

Few studies have compared the DA approach against other techniques. Spaans *et al.* compared the DA with the posterolateral (PL) approach and found the DA group to have significantly longer operative duration, increased blood loss, and more complications[62]. No differences between the techniques were reported for HHS or Oxford Hip Score, a self-reported questionnaire used to assess activities of daily living, pain and function, up to one year post-surgery, but both groups showed significant improvements pre- to post-surgery for these same measures[62]. Taunton *et al.* randomized patients to the DA or a mini-posterior approach and compared them with respect to the attainment of functional milestones[63]. They found the DA group to cease gait aid use significantly earlier (on average six days) than the posterior group, but found no other significant differences between the groups for functional outcomes[63]. Finally, Barrett *et al.* randomized patients to the DA or posterolateral (PL) approach and compared functional outcomes with the Six Minute Walk Test (6MWT) and HHS[43]. They found the DA group to walk significantly farther during the 6MWT on days zero, one and two post-surgery compared to the PL group. The DA group also had more patients who could walk unlimited distance according to the HHS at six weeks and three months post-surgery. No differences were found between the groups at the six-month or one year time points[43].

Several of these studies report that the DA technique is more technically demanding than others due to the limited exposure[61]. Because it is a newer approach and more technically difficult, the learning curve has been reported as longer than standard approaches[62]. This is a weakness of many studies as most look at the first consecutive patients of a surgeon using this approach[11,59,61,62], which may suggest higher complication rates and longer operative times than experienced surgeons. More studies are needed where the surgeons are experienced and have performed upwards of 200 procedures with this technique.

2.3.3 Direct Lateral Versus Direct Anterior

There are a number of studies that have compared the lateral and anterior surgical approaches for THA. These comparisons have investigated both intra-operative and postoperative outcomes and have reported varying results. Berend *et al.* conducted a retrospective study to compare early outcomes of primary total hip arthroplasty through an anterior supine intermuscular (ASI) approach, a version of the DA approach, versus a DL approach[64]. They looked at a total of 655 hips in 605 patients with 372 in the ASI group and 258 in the DL group. They found no differences between the groups for operative duration, blood transfusions, length of hospital stay, pre-operative HHS or pre-operative Lower Extremity Activity Scale, a self-reported questionnaire used to assess activity levels. The ASI group had significantly higher estimated blood loss ($p=0.006$)[64]. There was also a significant difference in favour of the ASI group for HHS ($p<0.0001$) and Lower Extremity Activity Scale ($p=0.03$) at six weeks.

Alecci *et al.* conducted a retrospective study to compare the efficacy of the DA and standard lateral approaches for intraoperative and perioperative outcomes[1]. They looked at a total of 419 patients (198 lateral and 221 DA) and found significant differences between the groups for many of the outcomes. The DA group was found to require less intraoperative fluids ($p<0.0005$), fewer transfusions ($p=0.008$) and had a shorter length of stay ($p<0.0005$). There were also more patients discharged to home ($p<0.0005$) and higher day one haemoglobin levels in the DA group. These results favour the anterior group, but there was also found to be increased surgical time required for this approach ($p<0.05$). The authors suggested that the difference in procedure time between the two approaches could be accounted for by a learning curve, since the DA approach was a new technique for the study surgeons[1].

Amlie *et al*. compared three surgical approaches for THA for satisfaction, pain, function and health-related quality of life in a cross-sectional study[65]. They used the Norwegian Arthroplasty Register to find 1273 patients between 50 and 80 years old who underwent a primary THA. The three approaches included the DA (421 patients), PL (421 patients), and DL (431 patients). Follow-up was at an average one to three years post-surgery. The DA and PL approaches had nearly identical results. The DA group had significantly

better scores than the DL group for all subsections of the Hip Disability OA Score (HOOS): pain (p=0.005), other symptoms (p=0.006), activities of daily living (p<0.001), sport and recreation (p=0.01), and quality of life (p=0.002). There were also significant differences in favour of the DA group for the Visual Analog Scale (VAS) for satisfaction (p=0.03) and absence of pain (p=0.007). The authors calculated a relative risk for limp of 2.0 (95% CI 1.4 to 2.8) for the DL approach compared to the DA approach. They also noted that when they adjusted for limp, the differences found in the patient-reported outcome measures by approach almost disappeared, with the only difference remaining in the activities of daily living subsection (p=0.05). Significant ceiling effects were found for both the WOMAC and EQ5D, a self-reported questionnaire used to assess health outcomes[65].

Restrepo *et al.* compared functional outcomes between a DA approach (modified Smith-Pete) and a DL (modified Hardinge)[5]. They recruited a total of 100 patients with unilateral hip OA between 18 and 75 years of age with a BMI less than 30 and used computer-generated cards to randomize them to one of the two groups (50 patients in each). One surgeon performed all procedures. Outcomes were evaluated preoperatively and at six weeks, six months, one year and two years post-surgery. The DA group was significantly better than the DL group at all time points up to one year for HHS, WOMAC, and SF-36 physical and mental health component scores. No differences were found between the groups at two years post-surgery. The DA group used a cane for significantly less time post-surgery compared to the DL group (2.40 vs. 3.76 weeks, p=0). Both groups experienced significant improvements from pre- to post-surgery. There were no differences between the groups for any surgical outcomes such as estimated blood loss or operative time, or for length of hospital stay. The strengths of this study included no loss to follow-up and an experienced surgeon who was past the learning curve for the DA approach. This study demonstrates early functional differences between the two approaches with no differences past one year[5].

The above studies have shown the DA surgical approach to have equivalent, if not superior, results compared to the DL surgical approach intra-operatively and up to one year post-surgery[1,5,64,65]. The authors suggested that the longer operative duration and

increased blood loss found with the DA approach in some of these studies may have been due to the learning curve of the technique[1,64]. The DA approach has been noted as a more technically difficult technique than the DL approach as there is limited exposure of the hip joint. The learning curve for the anterior approach may play a role in results as this was a new approach for many surgeons involved in the above studies[1,5,64]

2.4 Gait

Gait is an activity unconsciously coordinated by interactions between the musculoskeletal and nervous systems[33]. Gait refers to human ambulation or locomotion in the cyclic fashion and is developed by age five[66], after which gait patterns are fully integrated and remain constant allowing for easy comparison between individuals[67]. Gait is a very efficient process that is dependent on joint mobility of the lower extremities and the timing and intensity of the muscles[26,67].

2.4.1 The Gait Cycle

Gait is often described as a cycle, beginning when the heel of one foot strikes the ground, and ending when that same foot strikes the ground again. Each gait cycle is divided into phases; one stance and one swing phase per leg, or periods; two single-limb stance phases separated by two double-limb stance phases. The stance phase is the period during which the foot is in contact with the ground while the swing phase is the time the foot is in the air for limb advancement. Approximately 60% of the gait cycle is spent in stance phase and the remaining 40% in swing phase (Figure 5)[26,33]. The stance phase of the gait cycle can be broken down into initial double-limb support, single-limb support, and second double-limb support, while the swing phase is broken into initial, mid- and terminal swing (Figure 6)[33]. Single-limb support lasts for approximately 40%[68,69] of the gait cycle in healthy individuals and double-limb support for 20% of the gait cycle[68–70]. The gait cycle can again be further broken down into smaller phases defined by Perry *et al*. as initial contact, loading response, mid-stance, terminal stance, pre-swing, initial swing, mid-swing and terminal swing[26]. Unfortunately these terms are not standardized and therefore may vary depending on the source.

Various factors can influence each stage of the gait cycle; for example faster walking speeds will tend to lengthen the single-limb stance phases and shorten double-limb stance phases[26]. Another way the gait cycle is described is in terms of the tasks that are accomplished during a cycle by each limb: weight acceptance, single limb support and swing limb advancement[26].

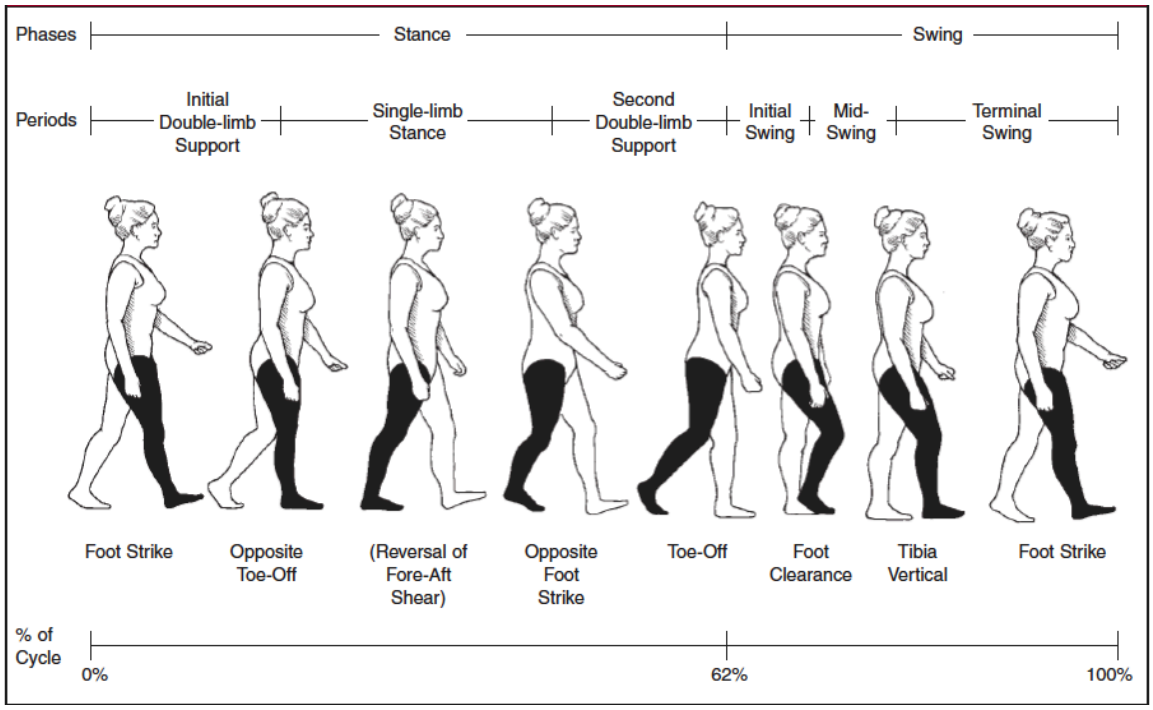

Figure 5: The normal gait cycle.

Reprinted with permission from Lippincott Williams & Wilkins originally published by Wolters Kluwer Health in *Human Walking* by Jessica Rose and James G. Gamble in 2005.

2.4.2 Gait Analysis

Gait analysis is the evaluation of a particular type of movement, such as walking or running[67]. Qualitative measures are most commonly used in clinical settings and quantitative measures use specialized equipment such as stopwatches, 3D sensors or force plates. Clinicians use observational, or qualitative analysis, all the time in their practices. Qualitative analysis involves general observation of gait for abnormalities, but minor deviations may be difficult to observe when more obvious abnormalities are also present. Observational analyses are generally performed in two stages; first a general

overview to get a sense of the person's gait as a whole, and second a more structured analysis focusing on one body segment, progressing from distal to proximal (ankle/foot, knee, hip and then trunk)[26,33]. Subtle changes or variations in a gait pattern may be difficult to detect with a qualitative analysis, so quantitative analysis may need to be undertaken to obtain precise measurements.

Quantitative gait analysis involves the use of a measurement tool, of which there are five main types: motion analysis, dynamic electromyography (EMG), force plates, stride analysis, and energy expenditure[26]. Motion analysis looks at the magnitude and timing of individual joint movements and can involve the use of electrogoniometers, cameras, or motion markers. Dynamic EMG investigates the period and intensity of muscle function. Force plates measure functional demands (e.g., force generated by the muscles) experienced during weight-bearing. Stride analysis looks at overall walking capability and finally, energy expenditure measures the efficiency of gait[26].

Instrumented walkways have become a popular tool for stride analysis. These walkways generally consist of on/off sensors imbedded within the mat that are then electronically connected to a computer. Once an individual walks onto the mat the sensors register contact time and allow for the collection of a variety of temporal and spatial gait characteristics. The most important advantage of using instrumented walkways for gait analysis is that nothing needs to be applied to the subject (e.g., special sensors or cables). These walkways, however, usually require a large amount of floor space when in use which can be a significant disadvantage. One instrumented walkway currently available is the GAITRite® Portable Walkway System (CIR Systems, Inc.), which comes in a variety of lengths and can be rolled up for easy transportation[71].

Various temporal and spatial characteristics can be measured during gait analysis including velocity (distance per time), cadence (steps per time), or stride length (distance covered during one gait cycle). The primary determinants of gait velocity are stride length and cadence. Stride length in healthy individuals varies with age, height and sex, but is approximately 1.39m[55,68,69,72]. Side-to-side variations of up to 10% are considered normal and symmetric[73]. Gait velocity in healthy individuals is approximately

1.24m/s[55,68,70,72–78] and generally remains unchanged throughout adult life. However, over the age of 60, gait velocity starts to decrease; 3% for ages 60 to 65, 9% for ages 60 to 80, and 11% after age 80[26].

Concerns have been mentioned in the literature whether the evaluation of gait in a lab setting is equivalent to a person's performance in a real world setting. Studies by Finley *et al.* and Waters *et al.* investigated gait velocity in people unaware they were being observed and found values very similar to those found in a lab setting, 1.3m/s[79,80]. Stride length values were also similar, 1.41m[79,80]. Another study conducted by Foucher *et al.* also compared gait speeds among healthy individuals in a lab setting with habitual speeds, but found discrepancies of 0.32 ± 0.21m/s (p=0.038)[74]. The authors suggested that individuals might attempt to optimize their performance when in a lab setting, whether consciously or subconsciously[74]. While gait testing may not necessarily provide real-world values for gait characteristics, reliable differences between groups can still be found provided all groups are tested with the same protocol.

Gait can also be analyzed in terms of symmetry between limbs. Most commonly, analysis is done for step length and single-limb stance, but can also be measured for ROM [44,72,73,81]. A symmetry ratio can be calculated by dividing the affected limb by the non-affected limb, with values closer to one indicating symmetric gait[82]. A 10% deviation from perfect symmetry has been suggested as indicative of asymmetry, and this value has been supported by the work of Hodt-Billington *et al.*[73]. Symmetry indices may also be used to investigate symmetry in gait parameters, but there is currently no standardized way to do this. Each study that calculates a symmetry index does so a different way, which makes comparison across studies difficult, if not impossible[44,72,73,81,82]. Patterson *et al.* have called for a standardized symmetry index to be created for the stroke patient population, where symmetry is measured quite frequently[82], and the same is needed for the hip OA and THA populations as well.

2.4.3 Involvement of the Hip

In the sagittal plane, the hip performs extension during the stance phase of the gait cycle and flexion during the swing phase. The total dynamic range of motion (ROM) of the hip

in a healthy individual is reported as ranging between 40 and 50 degrees[26,55,68,72,75,83]. ROM in the sagittal plane at the hip joint is most commonly described in terms of thigh movement relative to the vertical where thigh position in quiet standing is set as zero degrees. When measured this way, maximum extension is approximately 15 degrees[26,55,68,75,83] during terminal stance[26,75] and maximum flexion is approximately 35 degrees[26,55,68] during mid-swing[26,75]. Hip extension is used to propel the body forwards prior to toe-off of the ipsilateral limb while hip flexion is used to advance the swing limb.

Hip motion in the coronal plane is through abduction and adduction. In healthy individuals, the hip joint begins the gait cycle in a neutral position in the coronal plane (at initial contact) and achieves maximum adduction (ten degrees)[26,68,75] during loading response[26,75]. A neutral position is again reached during pre-swing and then maximum abduction (five degrees)[26,68] is achieved during toe-off[26,75]. The total dynamic ROM in the coronal plane is approximately 15 degrees[26,55,68].

There is also hip motion in the transverse plane, which, similar to sagittal plane measurements, is commonly described in terms of thigh movements. Total dynamic ROM in the transverse plane in healthy individuals is approximately ten to 15 degrees[26,68] when thigh movements are combined with those of the pelvis. Maximum internal rotation occurs during loading response and maximum external rotation occurs during initial swing, with neutral thigh position at initial contact[26].

The hip abductor muscles, gluteus medius, gluteus minimus, upper gluteus maximus and TFL, function during the initial half of the stance phase. Attempts to control drop of the contralateral pelvis during the transfer of body weight onto the ipsilateral limb results in a large abductor moment at the hip. Thus, the hip abductors are most active during initial foot contact[26].

Action of gluteus medius begins at the end of the swing phase and increases in intensity after initial contact. Gluteus medius activity ceases midway through the stance phase[26,69,70]. The action of gluteus minimus is similar to gluteus medius[26].

Upper gluteus maximus has a similar pattern of action to gluteus medius and gluteus minimus. Action begins at the end of the swing phase, increases to a peak just after foot contact and then terminates midway through the stance phase[26].

Action of the TFL differs between its anterior and posterior portions. The anterior portion begins its action during the end of the stance phase while the posterior portion begins just after foot contact. Termination of activity for both portions of the TFL is variable between subjects[26].

2.4.4 Changes in Gait Caused by Osteoarthritis

Pain avoidance strategies, both conscious and unconscious, are an initial trigger of gait impairments in people with OA of the hip[26,67]. These strategies can relieve pain caused by cartilage deterioration and deformity, but can also lead to muscle weakness. To relieve pain at rest, the hip joint has a tendency to assume a position of minimum intra-articular pressure, flexion between 30 and 65 degrees[26]. Over time this can result in a flexion contracture leading to functional restrictions, which ultimately reduces single-limb support time during gait to decrease tension on the anterior joint capsule. Reduction in single-limb support time will subsequently decrease velocity as well.

Dynamic range of motion can be dramatically altered as a consequence of hip OA, which can also lead to changes in gait. Patients with OA have been shown to have an overall decrease in the total flexion/extension excursion of the affected joint, decreased total dynamic ROM, decreased hip extension, and reduced peak hip abduction[26,83,84]. Eitzen *et al.* found differences in ROM in hip OA patients compared to healthy individuals to be present whether patients had mild or severe OA as measured by joint space narrowing[83]. Consequences of decreased hip extension are shorter step lengths of the affected limb, and increases in anterior pelvic tilt and lumbar lordosis. The pelvic tilt and lordosis are thought to compensate for the reduced hip extension[33].

Other adaptations resulting from hip OA include decreased walking speed, decreased cadence, inequality in step and stride lengths, and asymmetry in the duration of stance phase side-to-side[26,68,73,83,84]. The decreased walking speed is thought to be a result of

shorter step lengths as well as slower cadence. The average gait velocity for individuals with unilateral hip OA is 0.87m/s[26,68,73].

Assistive devices may be prescribed to those affected by OA to help improve balance and gait mechanics[85]. Some individuals with OA use assistive devices when walking due to the pain, but each systematically decreases gait velocity. Velocity is fastest with no gait aid and subsequently decreases with the use of a cane, one crutch, two crutches, and finally a walker[26].

Evaluation of gait is important as an outcome because it can be a marker for adverse events. Individuals who walk with a velocity slower than 1m/s are at an increased risk for health-related outcomes such as falls[86].

2.4.4.1 Gait Patterns

There are three distinct gait patterns that can develop as a result of hip OA: antalgic gait, coxalgic gait, and Trendelenburg gait[33]. Antalgic gait is found in patients with painful conditions of the lower extremities, including hip OA. It is characterized by decreased stance time on the affected limb to minimize the amount of time spent weight-bearing on that limb. The affected limb is only on the ground long enough to swing the other limb through. As a consequence of these adaptations, step length of the contralateral limb is shortened and gait velocity is reduced[33].

Coxalgic gait is seen in patients with painful hips or mild abductor weakness. It is characterized by a shift of the torso towards the affected limb during single-limb stance (Figure 6). This shifting of the torso attempts to reduce the forces on the joint and is also referred to as an abductor lurch, gluteus medius lurch, or the Duchennes sign[33]. Shifting the torso moves the center of gravity laterally over the stance hip joint, which reduces the moment arm and decreases the abductor force required to keep the pelvis level. In coxalgic gait, the shifting of the torso is sufficient enough to overcome the hip abductor weakness thus the pelvis remains level. Coxalgic gait can also have an antalgic component with decreased single-limb stance time on the affected limb[33].

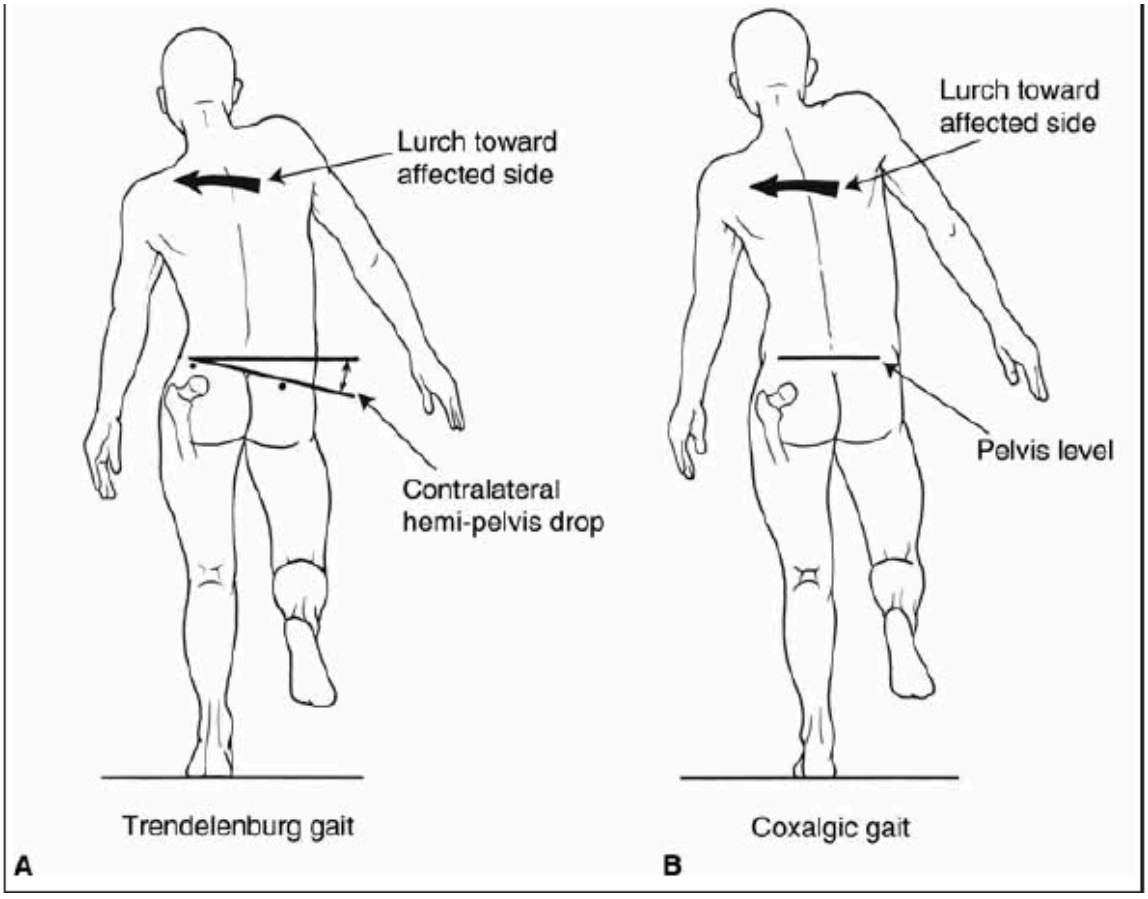

Figure 6: The Trendelenburg and Coxalgic gait patterns that can develop as a result of hip osteoarthritis.

HOPPENFELD, STANLEY, PHYSICAL EXAMINATION OF THE SPINE & EXTREMITIES, 1st Edition, © 1976. *Reproduced in print and electronically by permission of Pearson Education, Inc., Upper Saddle River, NJ.*

Trendelenburg gait looks similar to coxalgic gait, but the pelvis doesn't remain level (Figure 6)[26,33]. Trendelenburg gait is caused by significant abductor weakness where the hip abductors are unable to produce enough force to keep the pelvis level and as a result the pelvis drops on the contralateral side during single-limb stance on the affected limb. The shifting of the torso over the affected stance limb is not enough to overcome the abductor muscle weakness. As a result of the contralateral pelvic drop, more knee flexion must occur to allow the contralateral foot to clear the ground during its swing phase – the pelvic drop produces a functional leg length discrepancy where the stance leg is functionally shorter[33].

2.4.5 Changes After Total Hip Replacement

While the goal of THA is to relieve pain and improve function, returning the hip to normal function may not be possible. Gait is reported as not normal as far out as ten years after THA[55]. Deficits in muscle strength, reduced ROM and reduced gait velocity have all been reported six months or more after THA compared with controls[55,56,76]. Gait velocity after unilateral THA is approximately 1.05m/s by three months post-surgery[44,68,87] and 1.27m/s by one year[75,88]. However, significant improvements are found in many gait characteristics, including velocity, when comparing preoperative to postoperative values for THA patients. Aminian *et al.* found an 88% decrease in the asymmetry of stance time and more specifically a 250% decrease in double-limb stance time at nine months post-surgery[89].

Several studies have investigated gait characteristics between THA patients and healthy controls. Ewen *et al.* performed a systematic review and meta-analysis and found overall reduced walking velocity, stride length, hip flexion/extension ROM, and peak hip abduction moment in the THA patients[76]. Rasch *et al.* compared the operative versus non-operative limb in patients who underwent THA with a posterior surgical approach and found muscle strength deficits in almost all aspects measured at the six-month mark including hip extension, flexion, and abduction[56]. These deficits disappeared in all aspects except hip abduction at two years of follow-up[56]. Bennett *et al.* conducted three-dimensional (3D) gait analysis on THA patients at ten years post-surgery and compared different age groups with healthy controls[55]. In all age categories, the THA group had decreased velocity, step length, stride length, range of hip flexion/extension, maximum hip extension, range of knee flexion/extension, and range of hip abduction/adduction compared to controls. Similar kinematics were shown across 54 to 80 year olds, but it was speculated that differences found in the over 80 population may be due to aging and not THA[55]. Agostini *et al.* found the THA group at one-year post-surgery to have a significantly higher percentage of atypical gait cycles and an increased heel contact phase compared to controls[70]. The THA group also had a decreased flat foot phase and dynamic hip ROM compared with the control group[70]. Foucher *et al.* compared THA patients one year post-surgery to healthy controls and found differences in peak hip abduction

moment and hip internal rotation moment[47]. Overall, whether at one or ten years post-surgery, differences in gait compared to healthy controls persist in the THA patient population.

2.4.5.1 Gait Analysis Following Direct Lateral Total Hip Arthroplasty

All studies that have investigated gait after the DL THA have used 3D gait analysis with reflective markers placed on bony landmarks and cameras to collect information. Lamontagne *et al.* performed a cross-sectional study comparing DL patients to healthy controls for stair ascent and descent[67]. They found all significant differences between the groups to occur during the transition from double- to single-limb stance where the THA group had significantly decreased power, angle of hip adduction, abduction moment of force, and anterior and superior forces at contralateral foot-off during ascent. During descent they found decreased hip external rotation and internal rotation moment of force in the THA group[67].

There are three studies that have directly compared the DL and anterolateral (AL), or Watson Jones, surgical approaches using 3D gait analysis[3,16,90]. Müller *et al.* conducted a randomized study where they compared the two approaches and found no differences between the groups at three months for gait parameters (speed, cadence, step length or stance duration), range of motion or incidence of a positive Trendelenburg sign[16]. Range of motion increased pre- to post-surgery for both groups[16]. Kiss *et al.* also conducted a randomized trial comparing the DL and AL approaches and found the greatest improvements in spatiotemporal parameters to occur within the first six months post-surgery for both groups[3]. The DL group recovered to normative values for step length, double-stance duration and swing duration by one year post-surgery, but the DL group had a longer recovery time compared to the AL group. The DL group also had decreased hip ROM and peak hip extension at one year compared with the control group[3]. A randomized study by Martin *et al.* compared gait at one year and found the DL group to have increased passive hip flexion and adduction, and decreased passive hip extension compared to the AL group[90]. No differences were found between the groups for the 3D gait analysis[90].

Three other studies compared the DL, AL and posterior approaches for gait, which all used 3D gait analysis[4,17,91]. Queen *et al.* looked at the early postoperative period and found the only significant differences between the groups to be decreased abduction and adduction angle at heel strike at six weeks in the posterior group, but these differences existed preoperatively as well[4]. All three groups demonstrated increased stride and step length, gait velocity and peak hip extension from pre- to post-surgery[4]. Another cross-sectional study by Queen *et al.* found no differences in gait parameters, HHS or Timed Up and Go (TUG), a walk test used to assess functional mobility, at one year post-surgery between the DL, AL and posterior groups[91]. Holnapy *et al.* conducted a randomized study comparing the three surgical approaches for gait variability at three different gait speeds[17]. They found that the DL group had increased variability in spatiotemporal parameters in the operative limb at three and six months at all gait speeds compared to controls. When results at six months were compared to preoperative measurements, step length and support phase duration were decreased. Hip ROM was decreased in the operative limb at all time points and speeds compared to controls, but when compared pre- to six months post-surgery the results were opposite with variability increasing postsugery[17].

All of these studies had relatively small sample sizes with the largest study having only 42 patients per group. Four of the studies had one surgeon performing all procedures while another had two. Involving more surgeons would increase the ability to apply the results of the studies to other centres. Overall, these studies showed no differences in gait parameters when comparing the DL approach with the AL or posterior approaches, the only difference was found by Kiss *et al.* who reported a longer time to recovery for the DL group compared to the AL[3]. These studies also show consistent differences between DL patients and controls as far as one year post-surgery; however, consistent improvements are seen from pre- to post-surgery.

2.4.5.2 Gait Analysis Following Direct Anterior Total Hip Arthroplasty

Few studies have investigated gait after the DA approach for THA. Two studies used 3D gait analysis to compare results before and after THA with the DA approach[68,92]. Both

studies found hip range of motion (ROM) to increase from pre- to post-surgery in the sagittal plane[68,92], but Meyer *et al.* reported that hip ROM did not reach the level of controls by three months[92]. Mayr *et al.* found significant improvements from pre- to six weeks post-surgery for single-limb support and stride time and improvements at 12 weeks for cadence, stride length and velocity, but gait velocity did not reach normal levels by 12 weeks post-surgery[68].

Two studies compared the DA approach to different variations of the posterior approach for gait[69,88]. Maffiuletti *et al.* performed a cross-sectional study using the GAITRite® mat to test patients six months after THA at both self-selected and fast speeds[69]. They found no differences between the groups for any gait parameters at self-selected speed, but found both approaches to have slower speed and decreased step and stride lengths at fast speed compared to controls[69]. Rathod *et al.* used 3D gait analysis to compare the two approaches and found the DA group to have significantly increased gait velocity and hip ROM in the sagittal and transverse planes, and decreased single-limb support compared to the posterior group at one year[88]. Both groups had significantly increased sagittal hip ROM, peak hip flexion and extension torque moments, and HHS from pre- to post-surgery[88].

In summary, few studies have investigated gait after the DA approach for THA. Those studies that have looked into gait have many limitations. The largest study had only 43 patients enrolled per group and the smallest only ten, which limits the generalizability of the results to clinical practice. Only one study investigated gait early in the postoperative period (before three months). Important differences in gait characteristics such as velocity may exist in the very early postoperative period. Overall, these studies have shown improved outcomes, including ROM, from pre- to post-surgery after DA THA, but when compared to the posterior approach it's unclear if there are any advantages.

2.4.5.3 Gait Analysis Following Direct Lateral Versus Direct Anterior Total Hip Arthroplasty

Only two studies have directly compared the DA and DL surgical approaches for gait. Varin *et al.* published a study comparing a previous cohort of DL THA patients with DA

approach patients approximately ten months post-surgery[75]. A total of 60 participants, 50 to 75 years old, were recruited, 40 retrospectively (20 DL and 20 DA) and 20 healthy controls matched for age, height and weight. Compared to controls, the DA group had significantly reduced peak hip extension, hip ROM in the sagittal plane, peak hip adduction, and peak hip abduction. The DL group, compared to controls, had significantly reduced hip flexion at ipsilateral foot-off, peak hip extension, hip ROM in the sagittal plane, peak hip adduction, peak hip abduction moment, and velocity (1.14m/s vs. 1.29m/s). When comparing the DA and DL groups to each other, the DA group had significantly greater pelvic tilt ROM and velocity (1.31m/s vs. 1.14m/s), but a lower hip peak abduction moment. It's surprising to find decreased hip abductor moments in the DA group compared to the DL group, as the gluteus medius and gluteus minimus, thought to be the main hip abductors, are not disrupted in this technique. Some limitations of this study were the unequal gender ratios between the groups (10/10 vs. 14/6 for females/males), and the lack of preoperative gait analysis. Overall, this study did not indicate one surgical approach as better than the other with respect to recovery of gait function[75].

Lugade *et al.* investigated the effect of a DA approach to an AL approach (modified Hardinge) on postoperative limping[44]. They recruited 23 patients (12 DA and 11 AL) with an average age of 57 years and BMI of 31, and included ten age-matched controls. One surgeon performed all DA procedures while another performed all AL procedures. Force plates and 3D markers were used to analyze gait preoperatively and at six and 16 weeks post-surgery. Both the DA and AL groups had significantly more asymmetry compared to controls and significantly reduced gait velocity (0.94m/s vs. 1.28 m/s, $p=0.002$ and 1.07m/s vs. 1.28m/s, $p=0.051$ respectively) preoperatively. Both THA groups also had decreased single-limb support and increased step length in the operative versus non-operative limb preoperatively. The DA group had significantly improved single-limb support from preoperative to six weeks post-surgery approaching control values. There was no difference between the THA groups for gait velocity at six weeks post-surgery. Both the DA and AL groups improved in symmetry and velocity from preoperative to 16 weeks post-surgery, but the AL group still had significantly more asymmetry compared to controls at 16 weeks. Both groups also had increased pelvic drop

at mid-stance on the operative limb compared to controls at all visits. This study demonstrated the potential impact of different surgical approaches on short-term changes in gait characteristics[44].

There is a distinct lack of studies directly comparing gait parameters between the DA and DL surgical approaches. Both available studies on this topic had very small sample sizes[44,75] and one only measured gait at one time point[75]. While the study by Lugade *et al.* looked at multiple early time points, the differences they found between the groups may not actually exist due to their small sample size of less than 12 per group[44]. Clinically meaningful differences in gait velocity are reported as 0.14m/s within a group[93]. Goldsmith *et al*. states that a between group difference is approximately 20% of the within group difference, which would mean a difference between the groups of only 0.028m/s is clinically important[94]. According to this standard, the differences in gait velocity found between the groups and controls by Lugade *et al.* are both significantly different and clinically important[44]. One difficulty with conducting gait studies is when attempting to compare gait velocity because it varies greatly depending on the instructions given to patients.

2.5 Summary

Osteoarthritis of the hip causes degenerative changes to the entire hip capsule including the cartilage and bone and results in severe pain which can affect the ability to perform activities of daily living. The gold standard of treatment for hip OA is THA, where the acetabulum and femoral head are replaced with artificial components. The literature demonstrates that THA is a very successful procedure for relieving pain and improving functional mobility.

There are many different surgical approaches used to perform THA, two of which are the direct lateral and direct anterior. The DL approach begins with an incision in line with the greater trochanter and ultimately involves releasing the anterior third of the gluteus medius and minimus from their attachments around the hip in order to achieve adequate exposure of the hip capsule. The DA approach begins with an incision following the intermuscular interval between the TFL and sartorius muscles and does not involve

releasing any muscles from their attachments. The DL approach is more commonly used in regular practice in Canada, but the DA approach suggests some advantages to functional recovery because there is little muscular damage.

The gluteus medius and minimus are muscles of the hip involved in abduction and play a significant role in pelvic control during gait. During initial contact, the abductor muscles attempt to keep the pelvis level by controlling contralateral pelvic drop. Coxalgic and Trendelenburg gait patterns can develop as a result of weak or damaged hip abductors.

Little research has been done to directly compare the DL and DA surgical approaches for THA. Differences in gait characteristics such as velocity and symmetry would be expected between these approaches due to the differences in technique, with only one approach involving the release of abductor muscles from their attachments. Only two previous studies have performed gait analyses to compare these approaches. Both studies showed improvement from pre- to post-surgery for each group, but had conflicting results when directly comparing the approaches to each other. More research is required to better understand if there are early postoperative functional differences between the two approaches.

Chapter 3

3 Objectives

Our primary objective was to examine the change in gait velocity during the first three months following total hip arthroplasty using the direct anterior approach or the direct lateral approach for patients with osteoarthritis of the hip. Our secondary objectives were to compare the two surgical procedures for the following outcomes: function using the Western Ontario McMaster Osteoarthritis Index, Harris Hip Score and Timed Up and Go; quality of life using the Short Form 12; and pain using a Visual Analog Scale.

We hypothesized that the recovery of gait velocity during the first three months post-surgery would be different for patients who underwent total hip arthroplasty using the direct anterior approach versus the direct lateral approach. We also hypothesized that there would be differences between the two surgical approaches for function, quality of life and pain.

Chapter 4

4 Materials and Methods

4.1 Study Design

This was a single-centre prospective, expertise-based, quasi-randomized trial that took place in London, Ontario. The study involved patients undergoing a primary total hip arthroplasty to reduce the pain and disability associated with hip osteoarthritis through either the direct anterior (DA) or direct lateral (DL) surgical approach. Baseline assessments were performed at the patients' pre-admission clinic visit, approximately one month prior to surgery. After surgery, follow-up study assessments occurred according to the standard of care for this surgery: on the day of discharge from the hospital and at 2 weeks, 6 weeks and 3 months post-surgery. The study took place at the London Health Sciences Centre (LHSC), University Hospital between May 2014 and June 2015 and was approved by the University of Western Ontario Health Sciences Research Ethics Board (Appendix A).

4.2 Eligibility Criteria

Patients included in the study were between 18 and 75 years of age, diagnosed with osteoarthritis and undergoing a primary unilateral total hip arthroplasty. Exclusion criteria included a BMI greater than 40, total knee arthroplasty on the ipsilateral limb, co-morbidities of a lower extremity that would affect gait or an inability to ambulate at least 10 metres without the use of a gait aid preoperatively. Patients were also excluded if they were awaiting another joint replacement surgery of any lower extremity joint within 3 months of the primary surgery, or were unable to give informed consent.

4.3 Randomization

Referrals to the orthopaedic outpatient clinic were sorted onto the monthly schedule randomly and patients were then seen by whichever surgeon held clinic on that day. Thus, patients were 'quasi-randomized' to each surgeon and therefore to treatment arm.

According to expertise and preference, one orthopaedic surgeon performed all DA procedures and the other performed all DL procedures.

4.4 Treatments

Briefly, the difference between the DA and DL approach is in whether muscles are released to gain access to the hip joint. The more traditional DL approach has the patient lain in a lateral position and releases the anterior third of the gluteus medius and gluteus minimus. The DA approach has the patient positioned in supine and follows the intermuscular interval between the tensor fascia latae and sartorius muscles without releasing any muscles from their attachments. The difference in whether muscles are released may mean that patients who undergo the DA approach will have a faster recovery and less pain post-surgery. The details of each procedure follow below.

4.4.1 Direct Anterior Approach

The surgeons at University Hospital, London Health Sciences Centre, currently utilize the following DA surgical technique for THA.

Patients were placed under general anaesthesia and positioned in supine on the HANA orthopaedic operative table. The incision was made two centimetres distal and lateral to the anterior superior iliac spine and was approximately eight to twelve centimetres long. The incision continued distally and laterally at 20 degrees to the mid-coronal plane. After transposing the lateral femoral cutaneous nerve medially, the fascia was split in line with the skin and incised over the TFL muscle belly. The TFL was retracted laterally and Sartorius was retracted medially to expose the hip capsule. Exposure of the capsule could be enhanced by excision of the overlying fat pad.

A capsulotomy was performed with the use of a T-shaped incision to expose the femoral neck. The femoral neck was then cut using a reciprocating saw, and the head removed. Traction and rotation of the limb was accomplished with the use of the mobile spars of the table.

The labrum was excised and the acetabulum was reamed for the acetabular cup with progressively larger sized reamers until the final size was reached. Component positioning was confirmed with the use of fluoroscopy. Screws were used as needed to secure the final cup and the liner was impacted into place.

Extending, adducting and externally rotating the leg facilitated femoral exposure. Release of the conjoint tendon might be required to optimize exposure. The femoral canal was then broached with sequentially larger broaches until the desired fit was reached. Reduction of the hip was achieved and fluoroscopy was used to judge offset and leg lengths as well as the broach position and alignment. The final stem was then implanted into the femoral canal, and the final head was also impacted onto the stem.

After reducing the hip and irrigating the surgical incision, the wound was sutured closed in layers and a sterile dressing was applied.

4.4.2 Direct Lateral Approach

The surgeons at University Hospital, London Health Sciences Centre, currently utilize the following DL surgical technique for THA.

Patients were placed under spinal, or general anaesthesia and positioned in the lateral decubitus position on an operative table with appropriate bolsters. The incision was approximately eight to ten centimetres long and started two fingerbreadths above and extended distally four fingerbreadths below the greater trochanter. The TFL was split in line with the incision and the abductors were visualized with the use of retractors. The gluteus medius was then split, releasing the anterior third off its insertion on the greater trochanter. The gluteus minimus was then split with the capsule as a single layer.

A T-shaped incision in the capsule was used to gain access to the interior of the joint. A pin was then placed into the iliac crest to help determine offset and leg length later. The hip was dislocated anteriorly using external rotation, abduction and extension[12]. An osteotomy was then performed to remove the femoral head.

The labrum was excised and the acetabulum was reamed for the acetabular cup with progressively larger sized heads until the final size was reached. Screws may be used as needed to secure the final cup and the liner was impacted into place.

The femoral canal was then broached with sequentially larger broaches until the desired was reached. Reduction of the hip was achieved and a caliper was used to check offset and leg length. The final stem was then implanted into the femoral canal, and the final head was also impacted onto the stem.

After irrigating the surgical incision, the wound was sutured closed in layers and a sterile dressing was applied.

4.4.3 Rehabilitation

Postoperative activity restrictions for direct lateral patients include not flexing the hip more than 90 degrees, not crossing the legs at the knees or ankles, not rotating the leg inward or outward too far, or twisting the body when standing[13,53]. These restrictions were encouraged for the first six weeks of recovery to protect the abductor repair and to protect against dislocation[13]. Direct anterior patients did not have any of these restrictions. All patients were instructed to weightbear as tolerated. Direct anterior patients were allowed to cease the use of walking aids at any time, while direct lateral patients continued to use walking aids until their physiotherapist or surgeon indicated a change[53].

All patients were provided with an initial set of exercises to perform after surgery and were encouraged to follow-up with a physiotherapist within two weeks of hospital discharge. At subsequent visits with physiotherapy more exercises may be introduced. Physiotherapy is continued until approximately three months post-surgery. The lack of restrictions placed on the patients who undergo DA THA allows for the earlier introduction of exercises, involving abduction and rotation of the leg, not provided to the direct lateral patients until six weeks post-surgery[53]. In this way direct anterior patients are allowed to progress through physiotherapy at an accelerated pace.

4.5 Outcome Measures

The study coordinator registered the patients into the secure web-based data management system (EmPower Health Research, Inc, www.empowerhealthresearch.ca) that allowed patients to login and directly access their questionnaires. If patients were not comfortable using a computer, the study coordinator provided them with hard copies of the questionnaires at each appointment. We measured all patients preoperatively at the preadmission appointment (approximately one month prior to surgery), on the day of discharge from hospital, and at 2 weeks, 6 weeks and 3 months post-surgery. Patients were told to use their preferred gait aid during gait testing at all time points.

4.5.1 Primary Outcome Measure

The primary outcome, gait velocity, was measured using the GAITRite® system for spatiotemporal analysis of gait. The GAITRite® is a portable walkway system consisting of a mat that is 8.3 metres long by 0.89 metres wide[77,95]. The mat contains sensors embedded within it in a horizontal grid, which allows for the collection of temporal and spatial data by a computer connected to the mat. The GAITRite® system is able to measure several spatiotemporal gait parameters, including velocity, step length, stride length, swing time, stance time, double support time, single support time and cadence[77,95]. All of these parameters are automatically collected by the system. The main gait parameter of interest was velocity, but stride length, single support time and double support time were also collected for analysis.

At the time of testing, we asked the patients to walk at a normal, comfortable pace across the mat three times. The average of the three trials was used for data analysis to ensure enough footfalls had been recorded for validity and enough repeated measures to improve reliability. We asked patients to start walking a minimum of one metre before the mat to allow them to accelerate to their normal walking speed, and then to stop a minimum of one metre after the end of the mat to compensate for deceleration. This allowed for maintenance of a constant walking velocity across the entire length of the mat.

The GAITRite® system has been found to be both valid and reliable. Its concurrent validity is excellent for speed, cadence and stride length when compared with the

objective Clinical Stride Analyser® (CSA) and paper-pencil method (r=0.97-0.99)[77,96]. Its inter-trial reliability is excellent for gait speed, cadence, stride length, single limb support time and percentage of the gait cycle in double limb support at preferred and fast walking speeds (ICC=0.84-0.97)[77]. The GAITRite®'s test- retest reliability is also excellent among both old and young populations (ICC=0.82 and 0.94 respectively)[95].

4.5.2 Secondary Outcome Measures

Patients completed the patient-reported questionnaires in random order at, or no more than one week prior to, each study visit. The walk tests were always administered in the same order with the Timed Up and Go Test performed prior to the GAITRite®.

4.5.2.1 Western Ontario McMaster Osteoarthritis Index

The Western Ontario McMaster Osteoarthritis Index (WOMAC) is a self-administered questionnaire used to measure functional outcome. The tool evaluates three domains comprised of five questions relating to pain, two to stiffness and 17 to physical function for a total of 24 questions. Each question is rated on a five-point ordinal scale (0-4) with higher scores indicating worse function and health. Maximum scores are 20 for pain, 8 for stiffness and 68 for physical function. Scores for each subsection can be used individually, or they can be combined to create a global score to evaluate function and health. At University Hospital the scores for the WOMAC are inverted to ensure better scores for all outcome measures lie in the same direction, high scores are a better outcome.

The WOMAC has been tested and found to be valid, reliable and sensitive for detecting important health changes after surgery[97]. It has been found to have convergent validity with several similar measures when evaluating patients after hip arthroplasty including the Short Form-36, Harris Hip and both gait velocity and gait symmetry. It has also been found to be responsive in a population of THA patients with large effect sizes for all three subsections (1.7-2.58, 1.0-2.17 and 1.8-2.9 respectively). Overall, the WOMAC has high internal consistency for all components and high test-retest reliability for the physical function and pain subsections[97]. An electronic version of the WOMAC was found by

Marsh *et al.* to be valid and reliable for use among joint replacement patients when compared with the paper version[98].

4.5.2.2 Timed Up and Go Test

The Timed Up and Go (TUG) Test evaluates functional mobility. The testing protocol requires patients to start from a seated position in a standard arm chair and, when given the instruction "go", are timed as they stand, walk three metres to a marked line, return and sit back down. Shorter times have been found to indicate better mobility and longer times appear to trend towards a higher risk for falls in the frail elderly[99].

While the TUG has been most extensively used in the frail elderly population, its reliability and validity has also been demonstrated in THA patients. It has good test re-test reliability (ICC=0.75) and its minimally detectable change is reported as 2.49 seconds[100].

4.5.2.3 Harris Hip Score

The Harris Hip Score (HHS) is a clinician-reported measure, which looks at range of motion, deformity, pain and function. It is a disease-specific questionnaire for hip surgery that gives a maximum total score of 100 with higher scores indicating better results. It has been reported that a total score below 70 points represents a poor result. The HHS can be administered both before and after surgery, and can be compared between different time points.

The Harris Hip Score has been found to have high convergent validity with both the WOMAC and Short Form-36. It has excellent test re-test reliability when completed by physicians (ICC=0.94) and inter-observer reliability (ICC=0.74-1.00). The Harris Hip Score also shows high internal consistency in each domain[101].

4.5.2.4 Short Form-12

The Short Form 12 (SF-12) is a patient-reported questionnaire used to measure health-related quality of life. It consists of 12 questions; each rated on a three to five point

ordinal scale. Physical and mental health composite scores (PCS and MCS) can be calculated using the 12 questions and are scored on a population-normalized scale.

The SF-12 has been found to have good reliability in THA patients with ICC values of 0.8 and 0.84 for the physical and mental components respectively. Large effect sizes have also been found when comparing scores at one and three months post-surgery, but much smaller earlier on. Minimally detectable differences have been reported as 12.18 for the PCS and 14.14 for the MCS in this patient population[102]. Electronic versions of the SF-12 have been shown to be valid and reliable for use in joint arthroplasty patients when compared with paper versions[98].

4.5.2.5 Visual Analog Scale

The Visual Analog Scale (VAS) is a self-administered measure for pain consisting of a scale from zero to ten with zero indicating no pain and ten indicating the worst pain imaginable. We asked patients to mark their average pain over the past week across a ten centimetre long line at every study visit. On the day of discharge from the hospital we asked patients to mark their average pain since their surgery as opposed to over the past week.

Test-retest reliability has been shown to be good to excellent for the VAS (ICC=0.71-0.94). It demonstrates good construct validity to a numeric rating scale (r=0.62-0.91) and is sensitive to change with a minimum clinically important difference reported between 1.1 and 1.37cm[103].

4.5.2.6 Cost Diary and Questionnaire

We had patients keep a diary to record pain, use of medications and participation in rehabilitation. We asked them to record information daily for the first two weeks post-surgery and on a weekly basis thereafter. The cost questionnaire inquired after emergency room visits and hospitalizations; visits to various healthcare professionals; tests, procedures and surgeries; and medications.

4.5.2.7 Patient Characteristics and Surgical Details

We collected demographic information including: birthdate, operative hip, symptomatic other hip, dominant side, gender, BMI, marital and employment status, smoking habits, race, education, government funding, prescription pain medication use, previous surgeries of the hips and spine, and comorbidities. Information we collected from surgery included: date of surgery, age at surgery, surgical approach, implant used, anaesthesia used, American Society of Anesthesiologists (ASA) physical status score, surgical time, pre- and post-surgery haemoglobin, and other releases performed. We also asked patients their living status at discharge and where they were living at each follow-up.

4.6 Preventing Bias

4.6.1 Blinding

We blinded the person conducting the TUG and the gait test to patient group allocation to avoid expectation bias. To maintain the blind, we asked patients not to reveal which surgeon had performed their surgery and patients' scars were covered at all times during gait and TUG testing. The assessor used standardized instructions while conducting these assessments to reduce observer bias. A computer collected gait data from the GAITRite® system and no interpretation of this data was required. All other measures were patient-reported. Because of the location of the scar and the description of the procedure provided by the physician, we were unable to blind the patients to group allocation.

4.6.2 Intention to Treat

We analyzed all patients according to the treatment arm they were assigned to regardless of whether or not the approach was actually used during their surgery.

4.6.3 Standardization

Both treatment arms received the same pre-operative and in-hospital care, following normal, standard-of-care procedures. Post-surgery physical therapy exercises were similar between the two groups based on the usual standard-of-care for each approach.

4.7 Sample Size

We required 37 patients per group with an expected Type I error rate of 5% and 80% power to detect a moderate between-groups effect size (0.65)[104]. We expected a death rate of 0.04% within our study period[105], and minimal loss to follow-up due to our short follow-up period. Thus, our inflation rate was 2% or 80 patients in total.

4.8 Data Analysis

We used SPSS version 23.0 to perform the analyses of the data. We used descriptive statistics to present the demographic characteristics of the patients in each treatment group using means and standard deviations for continuous variables (age, BMI) and proportions for nominal variables (sex, operative hip, previous THA, dominant side).

We calculated symmetry ratios for step length and single-limb support by dividing the values for the operative limb by the values for the non-operative limb[81].

We used an ANCOVA test to determine whether there was a statistically significant difference between groups for all of our outcome measures including gait velocity, symmetry, temporal and spatial gait characteristics, TUG, SF-12, WOMAC, HHS and VAS. The independent variable was the group (anterior or lateral approach), the dependent variable was the outcome measure score and the covariate was baseline measurements. We also used the time from the administration of the last pain medications and type of anaesthesia used during surgery as covariates at the discharge time point for gait velocity, symmetry, temporal and spatial gait characteristics, TUG and VAS. To compare the approaches graphically over time we presented a plot of the scores for each outcome measure over time with each group as a separate line and included 95% confidence intervals. Baseline measurements were labelled as time zero.

We presented all continuous data (TUG, WOMAC, gait, VAS, SF-12, Harris Hip) as the adjusted mean ± the standard error and all comparisons with 95% confidence intervals around the estimate. We did not need to correct for multiple comparisons because none of our outcomes were independent; pain should affect patient performance for the TUG and

gait tests. We calculated the time from last administered pain medication prior to gait testing and used this as a covariate at the discharge time point.

Time to no pain was calculated using the VAS scores from the diaries. No pain was defined as less than five on a scale of 100.

We tested the assumptions for an ANCOVA, which are normality, homogeneity of variance, random independent samples, a linear relationship between the dependent and independent variables, homogeneity of regression slopes and the covariate is independent of treatment effects. We tested for normality by looking at the skewness and kurtosis for each outcome measure and then looking at histograms. Because of our small sample size we performed non-parametric tests to establish the robustness of our results. We used Mann-Whitney U tests as our non-parametric tests.

We looked for influential data points within our data, defined as data points more than three standard deviations from the mean, and then performed tests both with and without these points to investigate how our results changed. One influential data point was found in one of our tests, TUG at discharge.

For missing midpoint data we used the mean of the group for that time point and for missing end point data we used the last outcome carried forward.

Chapter 5

5 Results

5.1 Participant Flow

Figure 7 outlines the flow of participants through each stage of the study. From May 2014 to April 2015, 143 patients were screened for eligibility, 72 met the exclusion criteria, eight declined to participate, three were missed and seven were enrolled in another study and therefore ineligible.

Fifty-three patients gave consent to participate in this study. One participant in the DL group withdrew at the two-week follow-up visit. Two participants randomized to the DL group underwent their THA through the DA approach. These patients are analyzed in the DL group according to the intention-to-treat (ITT) principle.

Surgical characteristics including operative duration, ASA physical status and mean change in haemoglobin were well balanced between the groups (Table 2). All participants in the DA group were placed under general anaesthesia while only 20% (4/20) of the DL group had general anaesthesia; all others received spinal anaesthesia. To achieve adequate exposure more than half (12/20) of the participants in the DA group required a release of the conjoint tendon and two required releases of the posterior joint capsule.

One participant in the DL group underwent THA through the DA technique because of a communication error with the operating room nurse, who had set up the room for a DA approach. This participant also had a release of the conjoint tendon. One participant in the DL group required a release of the inferior capsule to achieve adequate exposure, and another had an abductor tear present at the time of surgery that was repaired.

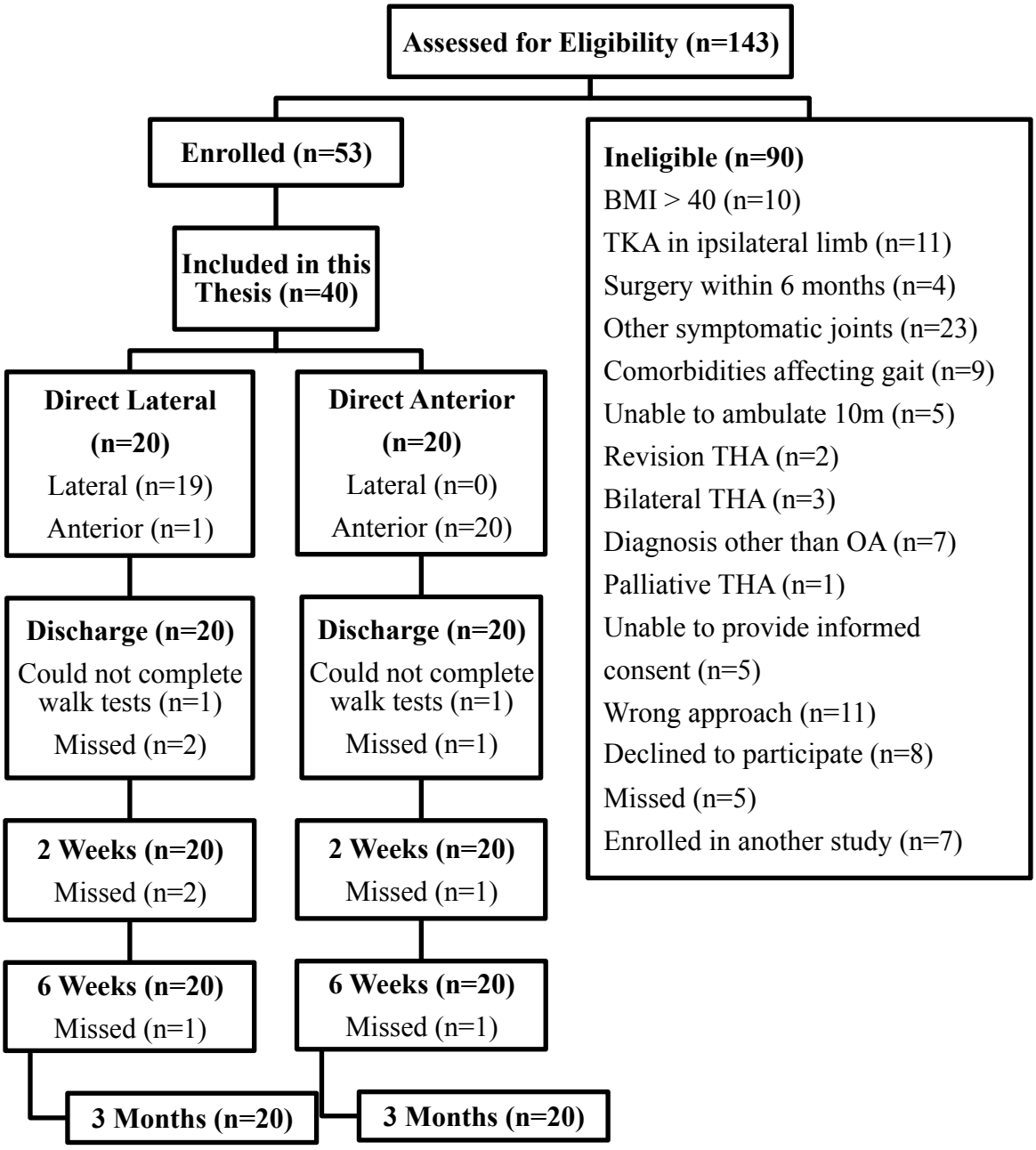

Figure 7: Participant flow through the study

*Only the first 40 patients to complete follow-up were included in this thesis including only one of the two crossover patients

Table 2: Surgical characteristics for total hip arthroplasty through the direct lateral and direct anterior surgical approaches

Characteristics	Direct Lateral (n=20)	Direct Anterior (n=20)
Surgical Approach, n (%)		
Direct Anterior	1 (5)	20 (100)
Direct Lateral	19 (95)	0
Releases, n (%)		
Conjoint Tendon	1 (5)	12 (60)
Other	1 (5)	2 (10)
Abductor Tear, n (%)	1 (5)	N/A
ASA Status, n (%)		
1	2 (10)	1 (5)
2	14 (70)	12 (60)
3	4 (20)	5 (25)
4	0	2 (10)
Anaesthesia, n (%)		
General	4 (20)	20 (100)
Spinal	16 (80)	0
Implant Used, n (%)		
Corail and Pinnacle	20 (100)	2 (10)
Corail and R3	0	18 (90)
Mean Operative Duration ± SD, hr	1.00 ± 0.14	1.18 ± 0.13
Mean Change in Haemoglobin ± SD, mmHg	25.35 ± 14.19	26.63 ± 11.60

Abbreviations. ASA = American Society of Anesthesiologists physical status, TFL = tensor fascia latae

5.2 Demographic Information

At the time of analysis, 40 participants had fully completed the study protocol to three months follow-up. Demographic characteristics were similar between the two groups (Table 3). Comorbidities were also similar between the groups.

Table 3: Baseline demographics for patients undergoing total hip arthroplasty through the direct lateral and direct anterior surgical approaches

Characteristic	Direct Lateral (n=20)	Direct Anterior (n=20)
Sex, n (%)		
Male	14 (70)	12 (60)
Mean Age ± SD, y (min-max)	59.3 ± 8.8 (34-70)	60.65 ± 8.8 (45-74)
Mean Height ± SD, in (min-max)	68.4 ± 3.5 (59-74)	66.3 ± 4.4 (54-73)
Mean Weight ± SD, lb (min-max)	199.2 ± 35.1 (120-250)	180.9 ± 29.7 (116-240)
Mean BMI ± SD, kg/m^2 (min-max)	29.9 ± 5.0 (19-40)	28.9 ± 4.2 (22-39)
Operative Hip, n (%)		
Right	7 (35)	9 (45)
Symptoms in Other Hip, n (%)	3 (15)	4 (20)
Dominant Side, n (%)		
Right	19 (95)	18 (90)
Employment Status, n (%)		
Currently working	13 (65)	11 (55)
Unemployed	1 (5)	0
Retired	6 (30)	8 (40)
Prescription Pain Medication, n (%)	11 (55)	10 (50)
Previous Hip Surgery, n (%)	5 (25)	7 (35)
Previous Spinal Surgery, n (%)	1 (5)	1 (5)

Abbreviations. SD = standard deviation, BMI = body mass index

5.3 Primary Outcome

5.3.1 Gait

There were two participants, one from each group, who refused, or were unable to complete the walk test on the GAITRite® mat at discharge from the hospital. At two weeks there were three patients who lived more than 100km away and were therefore not required to attend their two-week follow-up. At six weeks, two patients arrived outside of their scheduled appointment and were missed by the research coordinator. We used baseline measurements as a covariate in all of our analyses, and time from last pain medication and type of anaesthesia as covariates at discharge.

5.3.1.1 Gait Velocity

At discharge and two weeks there were no statistically significant differences found between the groups for gait velocity (Table 4). At six weeks there was a statistically significant difference between groups, but no significant difference at three months post-surgery. Similar results were found when non-parametric tests were performed, except there was a significant difference found at discharge ($p<0.01$). Figure 8 presents the unadjusted mean gait velocity for each group at all time points with the 95% confidence interval. Both groups worsened immediately after surgery, but continued to improve at all follow-ups and surpassed baseline values at three months.

Table 4: Gait velocity following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	1.03 ± 0.21	1.05 ± 0.21		
DC	0.20 ± 0.06	0.31 ± 0.05	0.11 (-0.08 to 0.30)	0.25
2w	0.71 ± 0.06	0.86 ± 0.06	0.15 (-0.01 to 0.31)	0.07
6w	0.95 ± 0.04	1.11 ± 0.04	0.17 (0.07 to 0.27)	<0.01
3m	1.15 ± 0.02	1.18 ± 0.02	0.03 (-0.04 to 0.09)	0.44

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

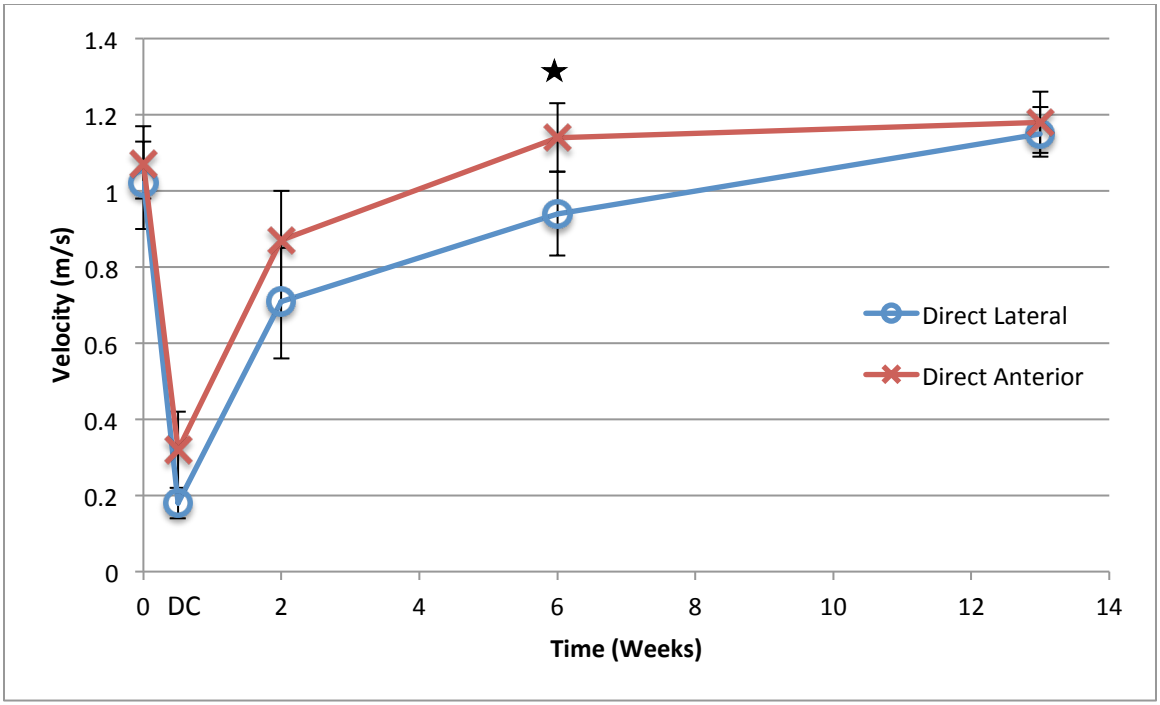

Figure 8: Gait velocity following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals), stars indicate a significant difference, DC = discharge

5.3.1.2 Other Temporal and Spatial Gait Characteristics

Stride length was not significantly different between the groups at discharge or two weeks (Table 5). The groups were significantly different at six weeks but were again similar at three months. Similar results were found with non-parametric tests except there was a significant difference at discharge ($p<0.01$) and there was no longer a significant difference at six weeks ($p=0.09$).

Double-limb support was not significantly different at discharge or two weeks, but was significantly different at six weeks (Table 5). At three months there was no difference. Non-parametric tests found similar results.

Single-limb support time for the operative limb was not significantly different at discharge, but was significantly different at two and six weeks post-surgery (Table 5). The groups were not significantly different at three months. Similar results were found

with non-parametric tests except there was a significant difference found between the groups at discharge ($p=0.01$).

Single-limb support time for the non-operative limb was not significantly different between the groups at any time point (Table 5). Similar results were found with non-parametric tests.

There were no significant differences between the groups for step length on the operative limb at discharge or two weeks, but significant differences were found at six weeks (Table 5). No differences were found at three months. Non-parametric tests found no significant difference between the groups at six weeks ($p=0.10$), but similar results were found for all other time points.

For step length on the non-operative limb, there were no significant differences between the groups at any time point (Table 5). Similar results were found with non-parametric tests except there was a significant difference at discharge ($p<0.01$).

Table 5: Temporal and spatial gait characteristics following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Gait Characteristic	Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Stride Length, m	Preop	1.19 ± 0.17	1.20 ± 0.22		
	DC	0.50 ± 0.06	0.66 ± 0.06	0.16 (-0.04 to 0.36)	0.11
	2w	0.98 ± 0.04	1.08 ± 0.04	0.10 (-0.02 to 0.23)	0.10
	6w	1.15 ± 0.03	1.26 ± 0.03	0.11 (0.02 to 0.20)	0.02
	3m	1.29 ± 0.02	1.32 ± 0.02	0.03 (-0.02 to 0.09)	0.21
Double-Limb Support, % gait cycle	Preop	29.81 ± 4.02	29.07 ± 3.18		
	DC	63.13 ± 3.99	61.08 ± 3.83	-2.05 (-15.77 to 11.67)	0.76
	2w	38.37 ± 1.82	34.10 ± 1.82	-4.27 (-9.51 to 0.96)	0.11
	6w	31.46 ± 0.63	29.42 ± 0.63	-2.04 (-3.84 to -0.24)	0.03
	3m	28.22 ± 0.42	28.38 ± 0.42	0.16 (-1.04 to 1.37)	0.79
Single-Limb Support (Operative Limb), % gait cycle	Preop	33.25 ± 3.08	34.35 ± 2.55		
	DC	16.47 ± 1.77	15.58 ± 1.70	-0.89 (-7.02 to 5.23)	0.77
	2w	27.72 ± 1.15	31.61 ± 1.15	3.89 (0.57 to 7.21)	0.02
	6w	32.54 ± 0.50	35.22 ± 0.50	2.68 (1.22 to 4.14)	<0.01
	3m	35.52 ± 0.27	36.08 ± 0.27	0.57 (-0.20 to 1.34)	0.14
Single-Limb Support (Non-operative Limb), % gait cycle	Preop	37.16 ± 1.91	36.66 ± 1.34		
	DC	23.31 ± 2.05	22.71 ± 1.97	-0.60 (-7.69 to 6.50)	0.87
	2w	33.60 ± 0.92	34.62 ± 0.92	1.01 (-1.64 to 3.67)	0.45
	6w	35.86 ± 0.32	35.73 ± 0.32	-0.14 (-1.06 to 0.79)	0.77
	3m	36.27 ± 0.34	36.09 ± 0.34	-0.17 (-1.16 to 0.82)	0.73
Step Length (Operative Limb), cm	Preop	61.65 ± 10.45	61.12 ± 9.87		
	DC	44.27 ± 2.96	43.50 ± 2.85	-0.77 (-10.99 to 9.46)	0.88
	2w	53.11 ± 1.79	58.24 ± 1.79	5.13 (0 to 10.26)	0.05
	6w	59.15 ± 1.28	64.20 ± 1.28	5.05 (1.37 to 8.73)	<0.01
	3m	64.96 ± 0.91	67.23 ± 0.91	2.27 (-0.34 to 4.88)	0.09
Step Length (Non-operative Limb), cm	Preop	59.68 ± 10.37	56.36 ± 9.04		
	DC	8.30 ± 4.53	20.25 ± 4.35	11.95 (-3.62 to 27.52)	0.13
	2w	44.67 ± 3.00	49.77 ± 3.00	5.10 (-3.50 to 13.70)	0.24
	6w	55.65 ± 2.00	61.44 ± 2.00	5.79 (0.04 to 11.53)	0.05
	3m	63.71 ± 1.04	64.47 ± 1.04	0.77 (-2.21 to 3.75)	0.61

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

5.3.1.3 Step Length Symmetry

No significant differences were found between the groups at any time point for step length symmetry ratios (Table 6). Similar results were found with non-parametric tests. Figure 9 presents the unadjusted mean symmetry ratios for step length at all follow-ups

with 95% confidence intervals. At discharge the symmetry ratios worsen, but reach baseline values at six weeks for both groups.

Table 6: Step length symmetry ratios following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	1.08 ± 0.09	1.03 ± 0.07		
DC	3.13 ± 6.20	-0.83 ± 5.95	-4.02 (-25.55 to 17.52)	0.71
2w	1.42 ± 0.19	1.30 ± 0.19	-0.12 (-0.68 to 0.45)	0.68
6w	1.12 ± 0.05	1.05 ± 0.05	-0.08 (-0.23 to 0.08)	0.34
3m	1.03 ± 0.01	1.04 ± 0.01	0.01 (-0.02 to 0.04)	0.46

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

**Negative values indicate the majority of patients had negative non-operative step lengths where the non-operative foot never passes the operative foot; positive values indicate the majority of patients had positive step lengths.*

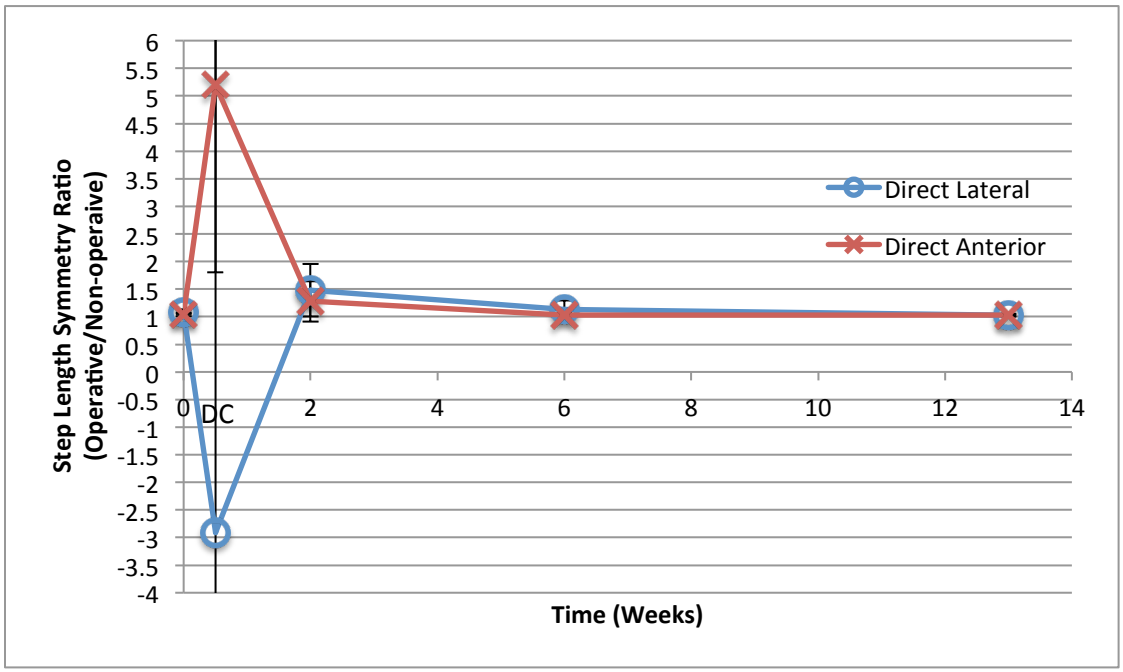

Figure 9: Step length symmetry ratios following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals), DC = discharge

**Negative values indicate the non-operative foot never passes the operative foot (less time is spent on the operative leg in single leg stance leading to a shorter step length with the non-operative foot); positive values indicate the non-operative foot passes the operative foot.*

5.3.1.4 Single-Limb Support Symmetry

No significant differences were found between the groups at discharge (Table 7). At two weeks, six weeks and three months post-surgery the single-limb support symmetry ratios were significantly different between the groups. A significant difference was found at discharge, $p<0.01$ when non-parametric tests were performed, but similar results were found at all other time points. Figure 10 presents the unadjusted mean single-limb support symmetry ratios for the operative limb at all follow-ups with 95% confidence intervals. Both groups worsened immediately after surgery, but improved at all time points afterwards. The DA group surpassed baseline values at six weeks while the DL group did not improve past baseline until three months post-surgery.

Table 7: Single-limb support symmetry ratios following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ±SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	0.90 ± 0.08	0.94 ± 0.07		
DC	0.65 ± 0.05	0.71 ± 0.05	0.06 (-0.11 to 0.23)	0.47
2w	0.82 ± 0.03	0.92 ± 0.03	0.10 (0.02 to 0.18)	0.02
6w	0.90 ± 0.02	0.99 ± 0.02	0.09 (0.05 to 0.13)	<0.001
3m	0.97 ± 0.01	1.01 ± 0.01	0.04 (0.01 to 0.06)	0.01

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

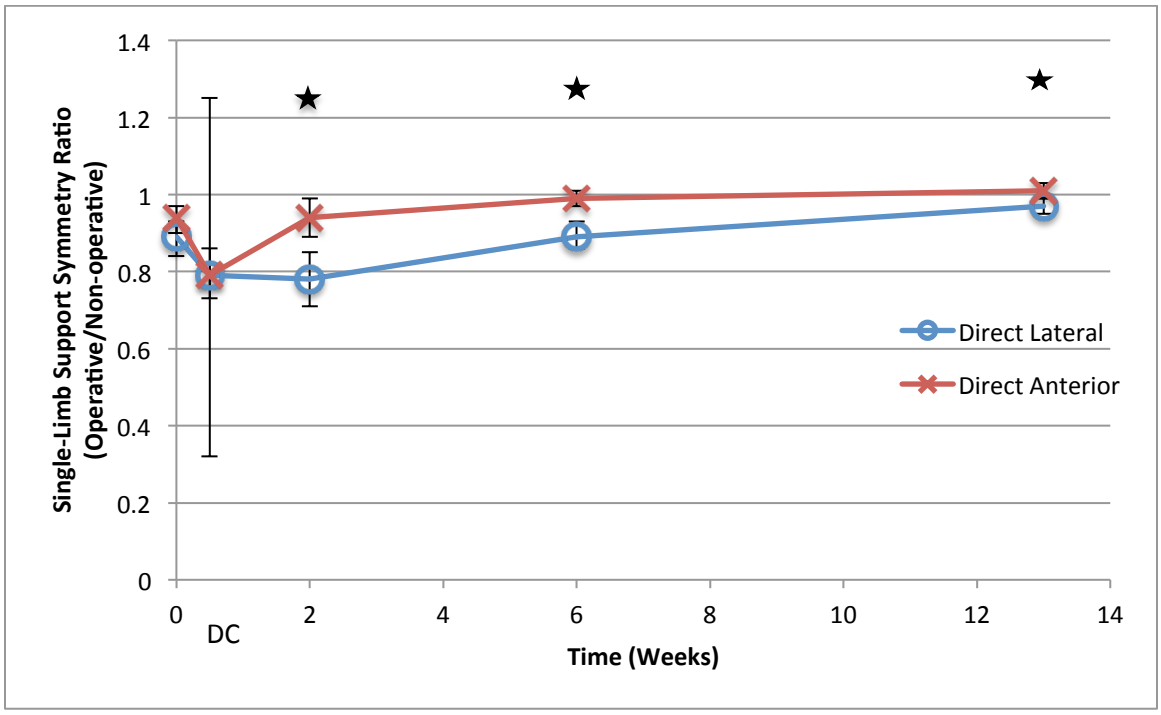

Figure 10: Single-limb support symmetry ratios following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals), stars indicate a significant difference, DC = discharge

5.4 Secondary Outcomes

We used baseline measurements as a covariate in all of our analyses. For the outcome analyses done at discharge, time from last pain medication and type of anaesthesia were also included as covariates.

5.4.1 Length of Stay

The length of stay in the hospital was significantly different between the groups. The DA group had a mean length of stay of only 1.0 ± 1.4 days while the DL group had a mean length of stay of 2.2 ± 0.4 days for a mean difference between the groups of -1.2 days (-1.9 to -0.5), $p<0.01$.

5.4.2 Western Ontario McMaster Osteoarthritis Index

No significant differences were found between the groups at six weeks or three months for the pain, stiffness or function domains (Table 8). Similar results were found with non-parametric tests. Figure 11 presents the unadjusted mean total WOMAC scores for both groups at all time points with 95% confidence intervals. Both groups improved beyond baseline at six weeks and continued to improve at three months post-surgery.

Table 8: Western Ontario McMaster Osteoarthritis Index scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Domain	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	Pain	49.7 ± 14.5	47.0 ± 16.6		
	Stiffness	46.7 ± 16.1	41.9 ± 21.2		
	Function	46.8 ± 10.7	45.2 ± 16.5		
	Total	48.0 ± 11.7	45.3 ± 16.7		
6w	Pain	80.5 ± 2.8	75.2 ± 2.8	-5.3 (-13.3 to 2.7)	0.19
	Stiffness	72.9 ± 3.8	62.1 ± 3.8	-10.8 (-21.8 to 0.3)	0.06
	Function	79.3 ± 3.0	74.5 ± 3.0	-4.7 (-13.4 to 3.9)	0.27
	Total	78.4 ± 2.8	72.3 ± 2.8	-6.1 (-14.1 to 1.9)	0.13
3m	Pain	90.7 ± 2.7	85.8 ± 2.6	-4.9 (-12.5 to 2.6)	0.20
	Stiffness	76.6 ± 3.6	73.5 ± 3.6	-3.2 (-13.5 to 7.2)	0.54
	Function	88.4 ± 2.6	84.6 ± 2.6	-3.8 (-11.2 to 3.5)	0.30
	Total	86.8 ± 2.4	82.9 ± 2.4	-3.9 (-10.9 to 3.1)	0.41

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, 6w = 6 weeks, 3m = 3 months

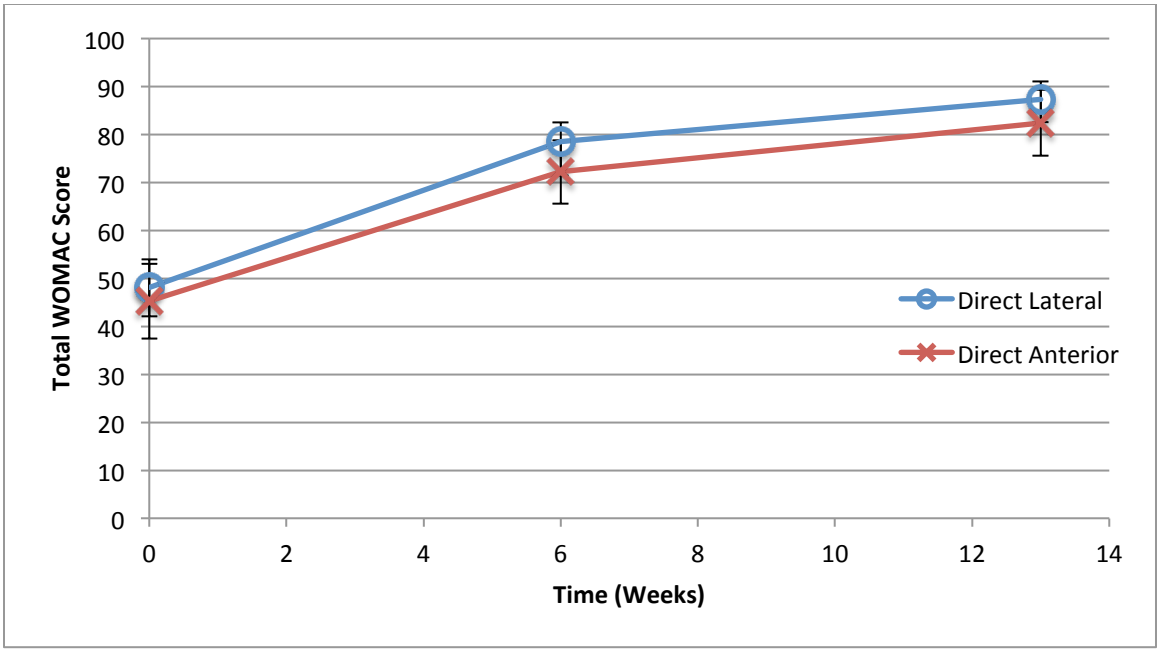

Figure 11: Total Western Ontario McMaster Osteoarthritis Index scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals)

5.4.3 Timed Up and Go Test

There were two participants, one from each group, who refused, or were unable to complete the TUG test at discharge and so were not included in this analysis. At two weeks there were three participants who lived more than 100km away and were not required to attend their two-week follow-up. At six weeks, two participants arrived outside of their scheduled appointment and were missed by the research assistant.

There was an influential data point within the dataset at discharge. We analyzed the data both with and without the influential point and found the mean to decrease by almost 10 seconds and the confidence interval around the mean to narrow when the point was removed. We have presented the analyses without the outlier because the results are more representative of the sample.

No significant difference was found between the groups for time to complete the TUG at discharge (Table 9). Significant differences were found at two weeks and six weeks post-surgery. No significant difference was found between the groups at three months post-

surgery. When using non-parametric tests, the time to complete the TUG was significantly different between the groups at discharge, p=0.03. Similar results were found with non-parametric tests at all other time points. Figure 12 presents the unadjusted mean time to complete the TUG at all follow-ups with 95% confidence intervals. Compared to preoperative times, mean times worsened at discharge for both groups and at two weeks for the DL group. Both groups reached baseline values at six weeks post-surgery.

Table 9: Time to complete the Timed Up and Go in seconds following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	10.30 ± 2.66	9.35 ± 2.46		
DC	58.23 ± 5.99	47.34 ± 5.52	-10.90 (-31.03 to 9.24)	0.28
2w	22.13 ± 2.22	13.10 ± 2.22	-9.02 (-15.45 to -2.60)	0.01
6w	11.45 ± 0.68	8.81 ± 0.68	-2.64 (-4.61 to -0.66)	0.01
3m	8.25 ± 0.34	8.16 ± 0.34	-0.09 (-1.07 to 0.90)	0.86

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

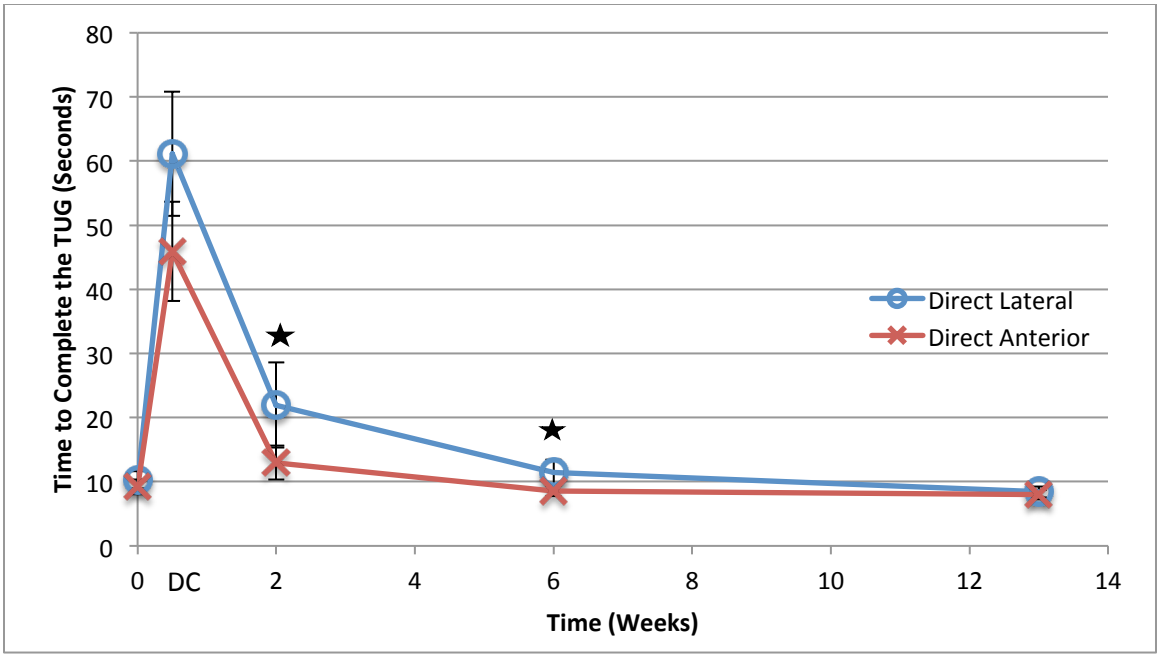

Figure 12: Time to complete the Timed Up and Go following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals), stars indicate a significant difference, DC = discharge

5.4.4 Harris Hip Score

The HHS scores were not significantly different between the groups at three months post-surgery (Table 10). Similar results were found with non-parametric tests. Compared to preoperative values, both groups improved at three months post-surgery.

Table 10: Harris Hip scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	60.2 ± 13.7	65.4 ± 7.7		
3m	94.0 ± 1.4	95.9 ± 1.4	1.8 (-2.3 to 5.9)	0.38

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, 3m = 3 months

5.4.5 Short Form-12

No significant differences were found between the DL or DA groups for the physical component score (PCS) or mental component score (MCS) of the SF-12 at two weeks, six weeks or three months (Table 11). Similar results were found with non-parametric tests. Figure 13 presents unadjusted mean PCS and MCS scores for the SF-12 at all follow-ups with 95% confidence intervals. Mean PCS scores for both groups improved beyond baseline values at six weeks post-surgery and continued to improve at three months. Mean MCS scores did not change for either group over the course of the study.

Table 11: Short Form-12 scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Subsection	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	PCS	33.0 ± 8.0	34.6 ± 8.7		
	MCS	52.7 ± 12.6	53.1 ± 13.3		
2w	PCS	31.2 ± 2.0	32.9 ± 1.9	1.7 (-3.8 to 7.2)	0.53
	MCS	55.6 ± 2.1	54.1 ± 2.1	-1.5 (-7.4 to 4.5)	0.63
6w	PCS	42.9 ± 1.9	42.6 ± 1.9	0.4 (-5.7 to 5.0)	0.90
	MCS	53.0 ± 2.1	54.7 ± 2.1	1.7 (-4.5 to 7.9)	0.58
3m	PCS	49.0 ± 1.9	46.7 ± 1.9	-2.4 (-7.9 to 3.1)	0.38
	MCS	55.0 ± 1.9	55.6 ± 1.9	0.6 (-4.9 to 6.2)	0.82

Abbreviations. SE = standard error, CI = confidence interval, PCS = physical component score, MCS = mental component score, Preop = baseline, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

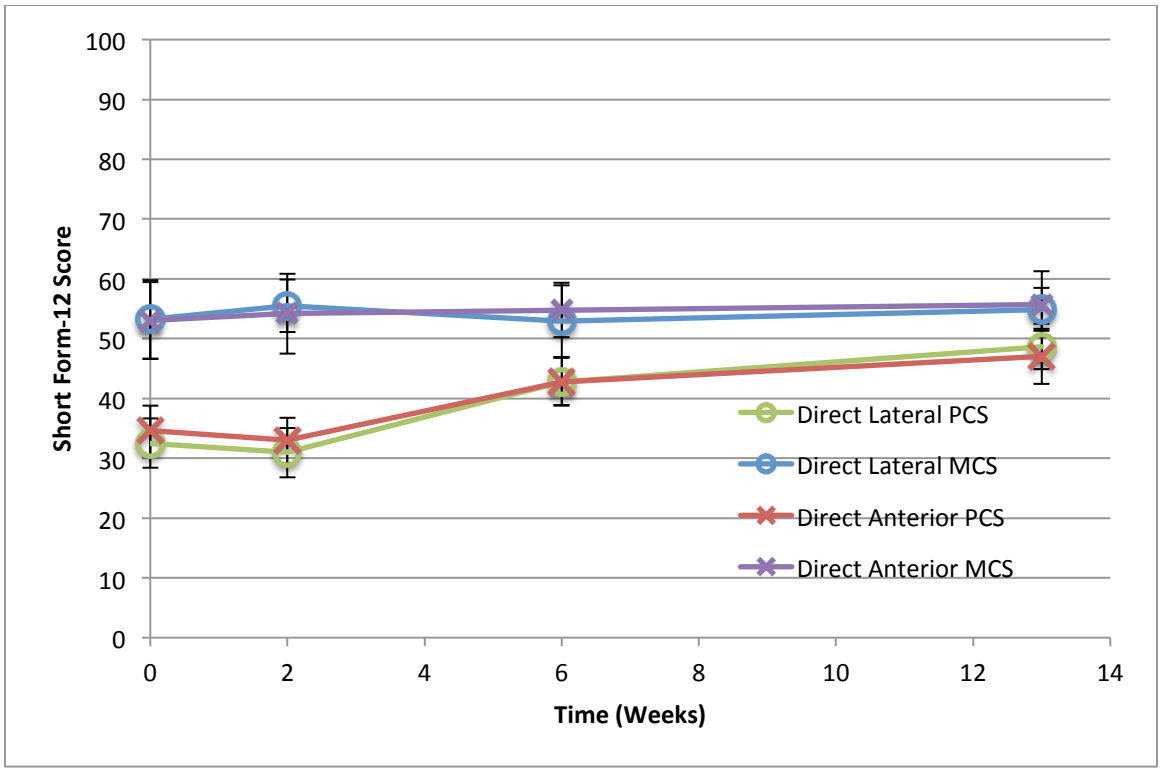

Figure 13: Short Form-12 scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals), PCS = physical component score, MCS = mental component score

5.4.6 Pain

There were no significant differences found between the groups at discharge, two weeks, six weeks or three months, for the VAS pain scores (Table 12). Similar results were found with non-parametric tests. Figure 14 presents unadjusted mean VAS scores at all follow up time points with 95% confidence intervals. Mean pain scores improved for both groups at all time points after surgery. There was still no significant difference between the groups when comparing day one pain scores collected from the diaries.

Table 12: Visual Analog Scale Pain scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (adjusted means)

Time	Direct Lateral (mean ± SE)	Direct Anterior (mean ± SE)	Adjusted Mean Difference (95% CI)	p-Value
Preop	5.6 ± 1.8	5.5 ± 2.5		
DC	2.7 ± 0.7	4.5 ± 0.7	1.7 (-0.71 to 4.16)	0.16
2w	1.7 ± 0.5	2.5 ± 0.5	0.8 (-0.6 to 2.1)	0.24
6w	0.8 ± 0.5	1.7 ± 0.5	1.0 (-0.4 to 2.3)	0.16
3m	0.2 ± 0.3	1.0 ± 0.3	0.8 (-0.1 to 1.7)	0.08

Abbreviations. SE = standard error, CI = confidence interval, Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

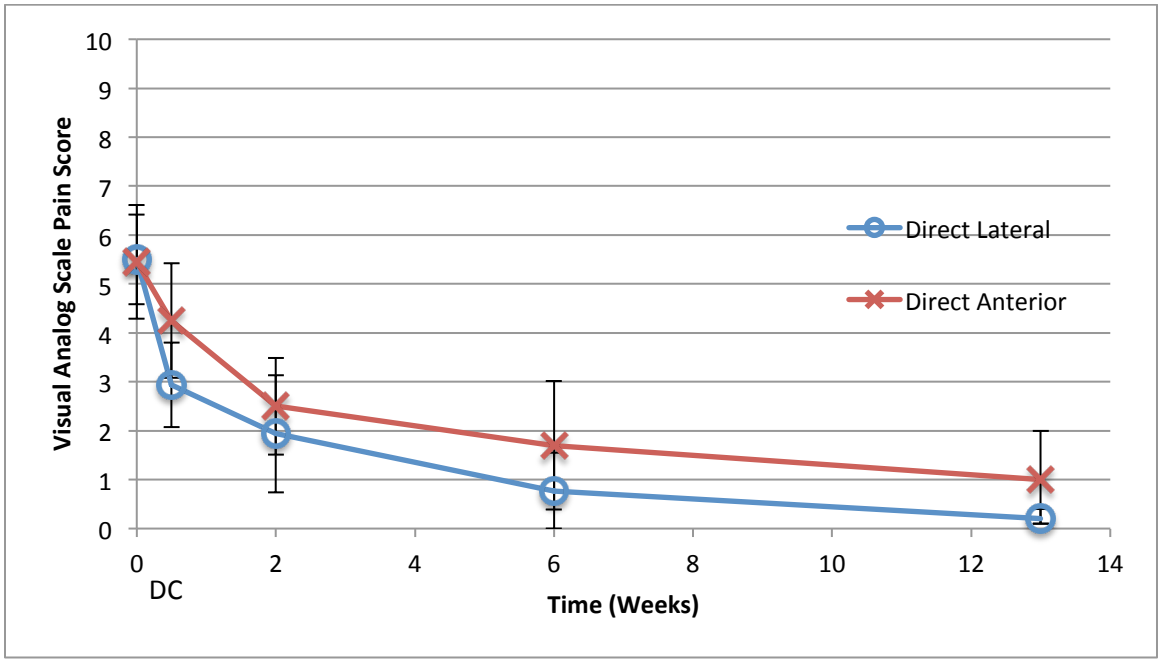

Figure 14: Visual Analog Scale Pain scores following total hip arthroplasty through the direct lateral and direct anterior surgical approaches (unadjusted means, 95% confidence intervals), DC = discharge

There was a significant difference between the groups for time to no pain medication use after surgery (Table 13). There were no significant differences between the groups for time to no pain, indicated as five or less out of 100 on the VAS scale, or time to no pain or pain medications.

Table 13: Time to no pain or pain medication in weeks following total hip arthroplasty through the direct lateral and direct anterior surgical approaches

	Direct Lateral (mean ± SD)	Direct Anterior (mean ± SD)	Mean Difference (95% CI)	p-Value
No Pain	6.5 ± 4.8	9.1 ± 4.4	2.6 (-0.4 to 5.5)	0.09
No Pain Meds	3.9 ± 3.5	7.1 ± 4.3	3.2 (0.7 to 5.7)	0.02
No Pain or Pain Meds	7.2 ± 4.8	9.6 ± 4.3	2.4 (-0.5 to 5.3)	0.10

Abbreviations. SD = standard deviation, CI = confidence interval

5.5 Gait Aid Use

Gait aid use was similar between the groups at discharge (Table 14). At two weeks, a greater proportion of participants did not use a gait aid in the DA group compared to the DL group and more participants in the DL group used a walker. At six weeks post-surgery a greater proportion of participants in the DA group did not use a gait aid while more participants in the DL group remained reliant on a cane or crutch. At three months post-surgery no participants were still using a gait aid.

Table 14: Gait aid use following total hip arthroplasty through the direct lateral and direct anterior surgical approaches

Time	Gait Aid, n (%)	Direct Lateral	Direct Anterior
Preop	None	15 (75)	19 (95)
	Cane/Crutch	5 (25)	1 (5)
	Crutches	0	0
	Walker	0	0
DC	None	0	0
	Cane/Crutch	1 (6)	0
	Crutches	2 (12)	4 (22)
	Walker	14 (82)	14 (78)
2w	None	2 (11)	8 (44)
	Cane/Crutch	4 (21)	6 (33)
	Crutches	8 (42)	4 (22)
	Walker	5 (26)	0
6w	None	7 (37)	17 (89)
	Cane/Crutch	11 (58)	2 (11)
	Crutches	0	0
	Walker	1 (5)	0
3m	None	20 (100)	20 (100)
	Cane/Crutch	0	0
	Crutches	0	0
	Walker	0	0

Abbreviations. Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

5.6 Living Arrangements

All participants were discharged to home following surgery with no participants living alone (Table 15). At two weeks and six weeks one participant in the DL group was living alone and all participants in the DA group were living with a spouse or partner. By three months post-surgery, two participants in the DL group and none in the DA group were living alone.

Table 15: Living arrangements following total hip arthroplasty through the direct lateral and direct anterior surgical approaches

Time	Living with, n (%)	Direct Lateral (n=20)	Direct Anterior (n=20)
Preop	Alone	3 (15)	0
	Spouse/Partner	16 (80)	20 (100)
	Family (Includes Extended)	1 (5)	0
	Friend/Non-Family	0	0
DC	Alone	0	0
	Spouse/Partner	16 (80)	20 (100)
	Family (Includes Extended)	3 (15)	0
	Friend/Non-Family	1 (5)	0
2w	Alone	1 (5)	0
	Spouse/Partner	16 (80)	20 (100)
	Family (Includes Extended)	3 (15)	0
	Friend/Non-Family	0	0
6w	Alone	1 (5)	0
	Spouse/Partner	16 (80)	20 (100)
	Family (Includes Extended)	3 (15)	0
	Friend/Non-Family	0	0
3m	Alone	2 (10)	0
	Spouse/Partner	16 (80)	19 (95)
	Family (Includes Extended)	2 (10)	1 (5)
	Friend/Non-Family	0	0

Abbreviations. Preop = baseline, DC = discharge, 2w = 2 weeks, 6w = 6 weeks, 3m = 3 months

5.7 Adverse Events

One adverse event occurred in the DL group and two occurred in the DA group. The participant in the DL group developed a skin rash approximately one week post-surgery after reacting to the medication given to reduce the risk of blood clots (Xarelto). The rash resolved by the six-week follow-up visit after the medication was stopped and with treatment with Benadryl. One participant in the DA group developed trochanteric bursitis ten weeks post-surgery, which had not yet resolved at the three-month follow-up visit, but was expected to resolve without treatment. Another participant suffered a fall one-week prior to the three-month follow-up visit that caused a broken wrist and various bruises and scratches to the face and body. There was no evidence of damage to the replaced hip.

Chapter 6

6 Discussion

We aimed to compare the early postoperative outcomes of patients who underwent total hip arthroplasty using the direct anterior or direct lateral surgical approach. We assessed participant function (including gait velocity, step length symmetry, single-limb support symmetry and time to complete the TUG), quality of life and pain. We found significant differences in favour of the DA group for gait velocity, single-limb support symmetry and time to complete the TUG, but time to no pain medication use was significantly shorter in the DL group.

We expected the DL group to have a slower gait velocity than the DA group because the DL approach detaches and subsequently repairs the abductor muscles that play a significant role in walking, gluteus medius and minimus. In line with the hypothesis, we found that the DA group walked faster at six weeks post-surgery compared to the DL group with a mean difference of 0.17m/s at six weeks. A meta-analysis by Bohannon *et al.* reported the minimally clinically important difference (MCID) within group for comfortable gait velocity is between 0.08-0.26m/s with a median of 0.14m/s[93]. Goldsmith *et al*. states that a between group difference is approximately 20% of the within group difference[94], which would mean that a difference between the groups of approximately 0.016-0.052m/s or 0.028m/s would be considered meaningful. Using the median value, the difference that we found at six weeks is considered to be not just statistically significant, but also meaningful.

A study by Lugade *et al*. found similar results when comparing an anterior and anterolateral (modified Hardinge) approach for THA[44]. They included 12 participants in the anterior group and 11 in the modified Hardinge group in an expertise-based prospective design. They performed gait analyses preoperatively and at six and 16 weeks post-surgery using 3D motion analysis. They also reported a slower gait velocity with the modified Hardinge group at six (mean difference 0.11m/s) and 16 weeks (mean difference 0.02m/s) post-surgery, although the differences did not reach significance[44]. Varin *et al*. also investigated 3D gait kinematics and kinetics between the lateral and

anterior surgical approaches[75]. They used a previously recruited cohort of 20 participants who had a THA through the lateral approach and compared them to a prospectively recruited cohort of 20 patients having THA with an anterior approach. Gait analyses were performed approximately ten months post-surgery. They found that the DL group walked significantly slower than the DA group at ten months post-surgery (mean difference 0.17m/s)[75].

It is possible that the difference in gait velocity that we found is partially explained by the difference in gait aid use between groups at six weeks, as almost all of the DA group (17/19), but only seven of 19 in the DL group were no longer using any gait aids. Walking speed is fastest when no gait aid is required and is subsequently reduced with the use of a cane, crutches and walker[26]. The fact that a greater proportion of patients in the DA group had sufficient confidence and ability to give up their gait aid also speaks to the potential advantages of this approach.

Finally, while gait velocity can be influenced by pain, we did not find significant differences between the groups for pain at any time point. In addition, we recorded the last time the patient took their pain medication prior to gait testing at discharge in case pain was being masked by pain medication for some patients and not others. When we used this data to adjust the analysis of gait velocity at discharge, there was no evidence that this variable influenced the results. Therefore, the differences between the groups for gait velocity cannot be explained by inadequate or incomplete pharmaceutical pain control.

Step length symmetry ratios between -1 and 1 indicate longer non-operative step lengths, ratios less than -1 and greater than 1 indicate longer operative step lengths and a ratio of 1 indicates equal step length on each limb. We expected both groups to have longer operative step lengths and therefore step length symmetry ratios less than -1 and greater than 1 because patients tend to protect their operative limb by spending more time on their non-operative limb during the immediate postoperative period. While no significant differences were found between the groups for step length symmetry ratios, only the DL group had negative ratios. Negative step length ratios indicate negative step lengths on

the non-operative limb; meaning that when the participants attempted to step with the non-operative limb (single leg stance required on operative leg), the foot on the non-operative side did not pass the foot of the operative limb. This is common with those who use a walker because placement of the walker can prevent a full step

For single-limb support ratios, values between 0 and 1 indicate more time spent on the non-operative limb, values greater than 1 indicate more time spent on the operative limb and a value of 1 indicates equal time spent on both limbs. We expected both groups to have ratios less than 1 since patients tend to put less weight on their operative limb. In fact, we found that both groups had ratios less than 1 at all follow-up time points except for the DA group which had a ratio of 1.01 ± 0.01 at three months post-surgery. In addition, because no muscles are cut with the DA approach, we expected the DA group to have single-limb symmetry ratios closer to 1 than the DL group. We found that the single-limb support ratios were significantly different (and closer to 1 for the DA group) between the groups at all post-discharge follow-ups.

Robinson *et al*. proposed a criterion value of 10% deviation from perfect symmetry for discriminating between patients with and without pathological gait asymmetry[106]. When applying this criterion to our symmetry ratios, asymmetry would be classified as any value between -0.9 and 0.9, less than -1.1 or greater than 1.1. With this criterion in mind, both groups had asymmetric step lengths at discharge and two weeks post-surgery. The DL group was also asymmetric at six weeks. For single-limb support both groups were asymmetric at discharge, and the DL group was also asymmetric at two weeks. In both cases the DA group reached symmetry earlier. Consistent with our findings, Lugade *et al*. also found single limb support to be more symmetric in the DA group, but this did not reach significance[44]. Step length was also significantly more symmetric in the DA group at six and 16 weeks post-surgery. Recovery of gait symmetry after THA can be important to avoid later injury[81].

The length of stay (LOS) in the hospital was significantly different between the groups with the DA group spending an average of one day less than the DL group. This was expected as the standard protocol at our institution is to discharge patients on day one or

as an outpatient on the same day as surgery if they have undergone THA via DA. On the other hand, patients who have undergone THA via DL are discharged on day two. All three studies that have investigated LOS between the two groups had patients follow the same discharge criteria regardless of technique. Alecci *et al.* performed a retrospective analysis on 198 patients who underwent THA via a lateral approach and 221 patients who had an anterior approach[1]. They investigated perioperative outcomes such as operative time, complications, blood loss, LOS and pain. Similar to our findings, they also reported a significantly shorter LOS for the DA group compared to the DL group, however both groups had a significantly longer LOS than our sample[1]. A study by Restrepo *et al*. randomly assigned 100 patients to the two approaches and investigated differences in operative time, blood loss and LOS[5]. They found no difference in LOS between the groups and also reported LOS longer than our sample[5]. A study by Berend *et al.* also compared early outcomes between the anterior and lateral approaches[64]. They performed a retrospective analysis on 372 lateral and 258 anterior hips and looked at operative time, blood loss, complications and LOS. Conversely, they reported a similar average LOS to our study, but they found no significant difference between the groups[64]. Although we suspect that our finding of a reduced LOS would remain if discharge criteria were standardized between groups, we have no way to separate the effects of the institution's practices from our results.

In addition to influencing LOS results, practice preferences may also have influenced walk tests completed on the same day of surgery because patients still under local anaesthetics injected during surgery may not yet fully appreciate the extent of the injury to the hip caused by surgery. On the other hand, those tested on day two or later may be more aware of the pain and disability caused by the surgery.

There were no differences found between the groups for the HHS, the pain, stiffness or function domains of the WOMAC, or for the PCS and MCS scores from the SF-12. While we hypothesized that we might observe differences in patient reported outcomes because of the disruption of the hip abductors in the DL group, this was not the case. Conversely, the study by Restrepo *et al.* that followed patients at six weeks, six months and one year post-surgery with the HHS, WOMAC and SF-36, found the DA group to

have significantly higher scores compared to the DL group for all three outcome measures at six weeks and six months post-surgery. The HHS and WOMAC were also significantly different at one year post-surgery[5]. The study by Berend *et al*. also found the DA group to have significantly higher HHS at six weeks post-surgery[64].

The DA group took less time to complete the TUG at two and six weeks post-surgery compared to the DL group. The minimally detectable change (MDC_{90}) for the TUG is reported as 2.49s[100]. All participants in both groups had TUG times at three months that were less than the MDC_{90} away from baseline, and the same proportion (6/20) in each group had three-month TUG times less than baseline by more than the MDC_{90}. This indicates that any functional advantages provided by the DA approach disappeared by three months post-surgery.

It is possible that the differences between the groups for the TUG at two and six weeks can be explained by differences in the proportion of patients using gait aids. Gait aid use is a proxy for functional ability. Patients at our institution are not required to continue using gait aids until pre-specified time points. At two weeks, there were still five of 19 participants in the DL group using a walker while no participants in the DA group required the use of a walker. In fact, at two weeks post-surgery almost half of the DA group (8/19) were not using a gait aid while only two of 19 participants in the DL group no longer used a gait aid. At six weeks almost all of the DA group were walking independently (17/19) while only seven of 19 participants in the DL group did not require a gait aid and one DL participant still required a walker.

The TUG can be used as a predictor for risk of falls, but cut-off values have yet to be agreed upon[99]. Studies that looked at the distribution of TUG scores for fallers versus non-fallers suggest a cut-off of 13.5s[107,108] delineates the groups and scores above this value are predictive of future falls. In our study, both groups were at risk for falls at discharge from the hospital and the DL group remained at risk at two weeks post-surgery.

We suspected that the DA group may have less pain than the DL group because there is less muscle damage, but in fact, we found that pain scores measured with the VAS were not different between groups at any follow-up time point. Alecci *et al.* reported pain

scores on the first day post-surgery and reported a mean difference of 0.9 in favour of the DA group, which is opposite to what we found[1]. While our results were not statistically significant, we found the DL group to have consistently lower pain scores at all follow-up time points. The DA group may experience more pain due to the use of retractors to hold the flexor muscles out of the way of the surgical site. Another potential explanation may be that the DA group is more active than the DL group and patients in this group may be pushing themselves harder. Investigation into activity levels may help to support this claim.

Participants in the DA group were quicker to cease the use of gait aids, however, all participants in both groups were independent of gait aids by three months. A study by Taunton *et al.* investigated differences in the attainment of functional milestones after THA with the anterior and mini-posterior approaches[63]. They prospectively randomized 27 patients to each of the two groups and followed them up to one year post-surgery. With the use of a patient-completed diary, they found the DA group to cease the use of gait aids on average approximately six days earlier than the mini-posterior group[63]. The mini-posterior approach, like the DL approach, involves the disruption of the short external rotator muscles involved in walking and therefore it would be expected that the approach that does not violate the muscle attachments would have better and quicker functional rehabilitation following surgery. In future, a more accurate recording of gait aid use would be a useful indicator of functional milestones. In our study, we only recorded what gait aids were used at each visit when conducting walk tests, gait aid use could have been added to our diary collection forms for a more accurate representation of when use was stopped.

The type of anaesthetic used during surgery was different between the groups and this was based on surgeon preference. All of the patients in the DA group had general anaesthesia while the majority of the DL group had spinal anaesthesia (16/20). General anaesthesia allows patients to get up earlier after surgery, as it does not have lingering effects on motor control or sensation. This is the reasoning behind the DA surgeon choosing this anaesthesia as it allows him to discharge his patients from the hospital earlier. Spinal anaesthesia can have lingering effects on motor control and sensation that

generally require patients to wait until late on the day of surgery or the next day to get up. Standardization of the type of anaesthesia used during surgery would help eliminate possible biases at the discharge time point and equalize length of stay between the groups.

This study is unique in its design as there were early postoperative follow-ups and extensive functional tests. Only two previous studies have compared the DA and DL approaches for gait parameters and neither looked at differences as early as we have[44,75]. Very early differences could be important to patients as earlier recovery of gait speed and symmetry may allow for earlier return to independence in activities of daily living. Overall, very few studies have directly compared these specific DA and DL surgical approaches and more extensive research should be conducted to elicit patient important differences and provide surgeons with the information needed to make an informed decision as to which approach to use.

6.1 Limitations

There were a number of limitations present with this study including small sample size and unsuccessful blinding. The most prevalent limitation was the small sample size. This was, however, a preliminary analysis of the first 40 participants to complete the study. A larger sample size would provide greater certainty in the outcomes measured.

Another limitation was the unsuccessful blinding of the outcome assessors of the gait tests. While we initially attempted to implement blinding of the outcome assessors, the surgeons were usually present in clinic at the time of testing and thus the assessors were aware of the patient's group. It was also common to have the surgeons present at discharge to help out with testing for safety reasons. There were many occasions when the assessors were not available and the research coordinator was required to run the gait tests. Unsuccessful blinding could lead to over- or underestimation of the effect size if the assessor had conscious or unconscious ideas of which approach should do better.

Not standardizing the LOS in hospital was another limitation of our study. Patients in the DA group were always discharged earlier than the DL group and were therefore tested

earlier post-surgery for the discharge follow-up time point. Testing earlier after surgery could have affected how the patients performed as they may not yet feel the full extent of their injuries, which could have biased the results in favour of the DA group. However, those in the DL group tested later may have had more practice walking after surgery and been less tentative when attempting the walk tests. The DL group may also have had better pain control as there would have been more time to figure out the correct medications and dosages. Testing on day one post-surgery may have been a better time point for follow-up as it would have standardized the testing and eliminated many potential sources of bias that could favour either group.

We also did not specifically collect information regarding injury to the lateral femoral cutaneous nerve as an adverse event. This information should have been caught with our adverse event form, but may have been overlooked because the result of this injury is numbness, which patients may not have reported. Under-reporting of nerve injury could have made the DA group look better with fewer reported adverse events. Studies that reported high incidences of femoral cutaneous nerve injuries also reported similar function and pain in patients with and without nerve injury[45,48,49].

Chapter 7

7 Conclusion

Our study compared functional outcomes, quality of life and pain in 40 patients who underwent total hip arthroplasty through a direct anterior (n=20) or a direct lateral surgical approach (n=20). Though our results were underpowered, we found the anterior group to significantly outperform the lateral group for most of the functional outcomes at early postoperative time points including gait velocity, time to complete the Timed Up and Go and single-limb support ratio. Both groups reported similar improvements in all quality of life and pain measures. These results are preliminary, so more definitive conclusions will be made after full completion of the study.

7.1 Future Directions

In the future, we will complete data collection to include the entire 80 patients we had proposed as our sample size with 40 patients in each group. This will strengthen our conclusions and provide more certainty around our estimates of effect size. We will also perform a cost analysis to determine if there are significant differences in cost between the two approaches.

Future research in this area should include a randomized rather than expertise-based study design. This will eliminate any potential effects of surgeon expertise and better balance patient characteristics between the groups, although this did not appear to be a factor in our study. Another improvement for future studies would be to create less stringent exclusion criteria as this, along with the addition of more surgeons, will make the results more generalizable to the total hip arthroplasty patient population. Patient important outcomes such as return to normal activities are also a potential area for future research.

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Appendices

Appendix A: Ethics Approval

LAWSON
HEALTH RESEARCH INSTITUTE

LAWSON FINAL APPROVAL NOTICE

LAWSON APPROVAL NUMBER: R-14-122

PROJECT TITLE: A prospective cohort study investigating functional recovery after total hip arthroplasty for patients with osteoarthritis using a direct anterior versus direct lateral surgical approach.

PRINCIPAL INVESTIGATOR: Dr. Brent Lanting

LAWSON APPROVAL DATE: April 30, 2014

Health Sciences REB#: 104897

Please be advised that the above project was reviewed by the Clinical Research Impact Committee and Lawson Administration and the project:

Was Approved

Please provide your Lawson Approval Number (R#) to the appropriate contact(s) in supporting departments (eg. Lab Services, Diagnostic Imaging, etc.) to inform them that your study is starting. The Lawson Approval Number must be provided each time services are requested.

Dr. David Hill
V.P. Research
Lawson Health Research Institute

All future correspondence concerning this study should include the Lawson Approval Number and should be directed to Sherry Paiva, Research Administration Officer, Lawson Approval, Lawson Health Research Institute, 750 Baseline Road, East, Suite 300.

cc: Administration

Western Research

Research Ethics

Use of Human Participants - Initial Ethics Approval Notice

Principal Investigator: Dr. Brent Lanting
File Number:104897
Review Level: Delegated
Protocol Title:A prospective cohort study investigating functional recovery after total hip arthroplasty for patients with osteoarthritis using a direct anterior versus direct lateral surgical approach
Department & Institution: Schulich School of Medicine and Dentistry\Surgery,London Health Sciences Centre
Sponsor:
Ethics Approval Date: March 17, 2014 **Expiry Date:**November 30, 2019
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Other	Summary of the outcome measures used and the follow up appointments at which they will be administered.	2013/11/15
Other	Speech for what will be said to patients when contacted via telephone.	2014/01/08
Instruments	Harris Hip Score.	2014/01/08
Instruments	Western Ontario McMaster Osteoarthritis Index.	2014/01/08
Instruments	Timed up and go form.	2014/01/08
Other	Patient withdrawal form.	2014/01/08
Other	Patient screening form.	2014/01/08
Instruments	Short Form 12	2014/01/08
Instruments	Surgical information form.	2014/01/08
Instruments	Numeric rating scale for pain.	2014/01/08
Other	Patient demographic information.	2014/01/08
Other	Contact Information	2014/01/08
Instruments	Cost questionnaire.	2014/01/08
Other	Missed visits form	2014/01/08
Other	Collection of comorbidity information	2014/01/08
Instruments	Data collection form for results of gait test.	2014/01/08
Instruments	Details of the patient's discharge from hospital.	2014/01/08
Other	Adverse Events Report	2014/01/08
Instruments	Daily use of medications and rehabilitation.	2014/01/08
Instruments	Weekly use of medications and rehabilitation.	2014/01/08
Western University Protocol		2014/01/13
Response to Board Recommendations	Responses to recommendations.	2014/02/14
Letter of Information & Consent	Revised LOI	2014/03/04

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the University of Western Ontario Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]

Ethics Officer to Contact for Further Information

Erika Basile [redacted]	Grace Kelly [redacted]	Mina Mekhail [redacted]	Vikki Tran [redacted]

This is an official document. Please retain the original in your files.

Appendix B: Letter of Information and Consent

London Health Sciences Centre

LETTER OF INFORMATION

Title of Research:

A prospective cohort study investigating functional recovery after total hip arthroplasty for patients with osteoarthritis using a direct anterior versus direct lateral surgical approach.

Lead Researchers:

Dr. Brent Lanting
London Health Sciences Centre, University Hospital, The University of Western Ontario,
London, Ontario, Phone: [redacted]

Dr. James Howard,
London Health Sciences Centre, University Hospital, The University of Western Ontario,
London, Ontario, Phone: [redacted]

Dr. Dianne Bryant
Kirkley Centre, University Hospital, The University of Western Ontario
London, Ontario, Phone: [redacted]

Dr. Susan Hunter
Elborn College, The University of Western Ontario
London, Ontario, Phone: [redacted]

Information:

You are being invited to participate in a research study because you have been booked to undergo surgery for a total hip replacement (THR). The purpose of this study is to compare outcomes (gait, function, quality of life and cost) between patients who receive THR with the direct lateral surgical approach versus those who have the direct anterior surgical approach. Both of these approaches are part of normal standard procedure for THR and will be determined by your surgeon regardless of whether or not you participate in this study. This study is designed to look at whether or not there is a difference in the recovery of gait velocity between the two surgical approaches. To determine whether one procedure is better than the other, we will follow you as you recover from your surgery. Eighty (80) patients will participate in this study from University Hospital.

Eligibility:

To participate in this study you must be between the ages of 18 and 75. You cannot have had a previous THR on the same hip and you cannot be anticipating a THR of your other hip within the next 3 months. If you are currently participating in another research study, you must inform your surgeon and the research assistant.

Description of the Study:

Visits for this study will coincide with follow-up visits that you would already attend with your

surgeon. These occur after your surgery at discharge from the hospital, 2 weeks, 6 weeks and 3 months. We will also collect information from you at your pre-admission appointment. Before each visit, you will be asked to complete questionnaires online, along with a cost diary, and two walk tests. Completing these questionnaires will take approximately 30 minutes of your time and the walk tests will take approximately 15 minutes.

The walk tests that we ask you to perform will require you to walk a specified distance at a speed that is comfortable for you. Any gait aids that you normally use will be permitted during these tests. The first test is called the Timed Up and Go or TUG and will ask you to get up from a chair, walk three (3) metres to a point marked on the floor, turn around and return to sitting in the chair. The second test is a gait test involving an eight (8) metre long mat with embedded sensors across which we will ask you to walk three (3) times. The mat will record information about how you walk including speed and step length.

The questionnaires that you will complete will collect information about your recovery such as pain, costs, quality of life, psychological health and function. We will also have you complete a diary throughout the length of your recovery, which will track your use of medication and rehabilitation. This information will be recorded daily for the first two weeks after surgery and then weekly until three months.

Alternatives to Participation:
If you do not choose to participate in this study, you will receive the usual total hip replacement surgery and follow-up provided by your surgeon.

Risks:
You could fall or injure yourself while performing tests, however, the risks are no greater than those encountered with typical postoperative rehab protocols. There are no other known health risks associated with this study. The data that is collected from you is protected by a username and password. It travels in a scrambled format to a server (storage computer) that is located in Montreal, Quebec, Canada. The company that houses the server is a professional company with extremely high standards of physical and virtual security. We want to let you know however, that even with this high level of security, there is always a remote chance that your information, including personal identifying information like your date of birth, could be accessed or “hacked” by someone who is not supposed to have your information. If we became aware that this had happened, we would inform you immediately.

Benefits:
There are no direct benefits to you for participating in this study; however your participation will help inform surgeons and physiotherapists as to which surgical procedure offers patients who undergo total hip replacement the best outcome.

London Health Sciences Centre

Cost/Compensation:
You will not be compensated for your participation in this study.

Voluntary Participation:
Your participation in this study is voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect on your future care. Should you choose to withdraw from this study, we will keep all data obtained up to the point that you chose to withdraw.

Participation in this study does not prevent you from participating in any other research studies at the present time or future. If you are participating in another research study, we ask that you please inform of us of your participation. You do not waive any legal rights by signing the consent form.

Confidentiality:
All information will be kept in strict confidence. While we will do our best to protect your information there is no guarantee that we will be able to do so. The inclusion of your date of birth may allow someone to link the data and identify you. Data that is collected will be username and password protected and stored on a server located in Montreal, Quebec, Canada through a scrambled format. Your identifying information will not appear on the database used to analyze data. In any publication, presentation or report, your name will not be used and any information that discloses your identity will not be released or published.

Representatives of The University of Western Ontario Health Sciences Research Ethics Board may require access to your study related records or may follow up with you to monitor the conduct of the study.

London Health Sciences Centre

Questions:

If you have questions about the conduct of the study or your rights as a research participant, you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute [redacted]

If you have questions or concerns about your surgery or physiotherapy, please contact your orthopaedic surgeon or physiotherapist. If you have any questions about this research, please contact Bryn Zomar at [redacted] or [redacted] or Dr. Brent Lanting at [redacted] or [redacted].

This letter is yours to keep.

Sincerely,

Dr. Brent Lanting, MD
Dr. James Howard, MD
Dr. Dianne Bryant, PhD
Dr. Susan Hunter, PhD
Bryn Zomar, MSc (can.)

London Health Sciences Centre

CONSENT FORM

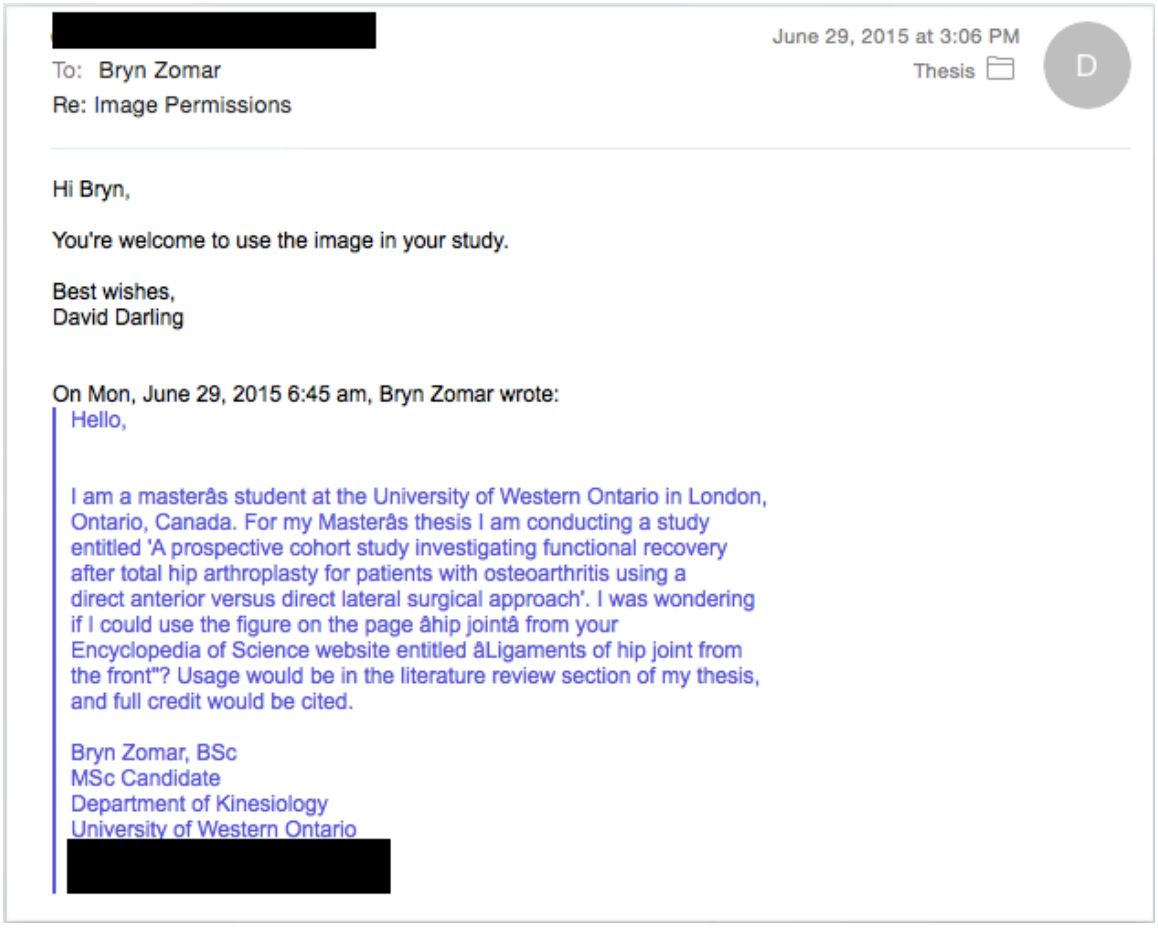
Title of Research:

A prospective cohort study investigating functional recovery after total hip arthroplasty for patients with osteoarthritis using a direct anterior versus direct lateral surgical approach.

I have read the letter of information, have had the nature of the study explained to me, and I agree to participate in the study. All questions have been answered to my satisfaction. I will receive a copy of the Letter of Information and this signed consent form.

_____	_____	_____
Printed Name of the Participant	Signature of the Participant	Date
_____	_____	_____
Printed Name of the Parent or Legally Authorized Representative (if required)	Signature of the Parent or Legally Authorized Representative (if required)	Date
_____	_____	_____
Printed Name of the Person Responsible for Obtaining Informed Consent	Signature of the Person Person Responsible for Obtaining Informed Consent	Date

Appendix C: Image Permissions



[redacted]

June 29, 2015 at 3:06 PM

To: Bryn Zomar

Thesis

Re: Image Permissions

Hi Bryn,

You're welcome to use the image in your study.

Best wishes,
David Darling

On Mon, June 29, 2015 6:45 am, Bryn Zomar wrote:

> Hello,
>
> I am a masterâs student at the University of Western Ontario in London, Ontario, Canada. For my Masterâs thesis I am conducting a study entitled 'A prospective cohort study investigating functional recovery after total hip arthroplasty for patients with osteoarthritis using a direct anterior versus direct lateral surgical approach'. I was wondering if I could use the figure on the page âhip jointâ from your Encyclopedia of Science website entitled âLigaments of hip joint from the front"? Usage would be in the literature review section of my thesis, and full credit would be cited.
>
> Bryn Zomar, BSc
> MSc Candidate
> Department of Kinesiology
> University of Western Ontario
> [redacted]

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From: Edward Vasarhelyi [redacted]
Subject: Re: Image Permissions
Date: June 28, 2015 at 4:20 PM
To: [redacted]

EV

Hi Bryn,

Of course, more than welcome to.

Ted

On Jun 28, 2015, at 4:10 PM, Bryn Zomar <[redacted]> wrote:

> Hi Dr. Vasarhelyi,
>
> For my Master's thesis I am conducting a study entitled 'A prospective cohort study investigating functional recovery after total hip arthroplasty for patients with osteoarthritis using a direct anterior versus direct lateral surgical approach'. I was wondering if I could use the figure on p.130 (Illustration of the location of the incision for the direct anterior approach) and the figure on p.132 (Illustration of the location of the incision for the direct lateral approach) from "Surgical approach in primary total hip arthroplasty: anatomy, technique and clinical outcomes" by Petis, Howard, Lanting and Vasarhelyi published in the Canadian Journal of Surgery? Usage would be in the literature review section of my thesis, and full credit would be cited.
>
> Thank you very much,
>
> Bryn Zomar, BSc
> MSc Candidate
> Research Assistant
> Division of Orthopaedics
> London Health Sciences Centre
> [redacted]

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June 15, 2015 PE Ref #190825

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Dear Bryn Zomar:

You have permission to include content from our text, ***PHYSICAL EXAMINATION OF THE SPINE & EXTREMITIES, 1st Ed. by HOPPENFELD, STANLEY,*** in your Master's Thesis "A Prospective Cohort Study Investigating Functional Recovery After Total Hip Arthroplasty for Patients with Osteoarthritis using a Direct Anterior Versus Direct Lateral Surgical Approach" for your study at UNIVERSITY OF WESTERN ONTARIO.

Content to be included is:
P. 164 Figure 56 The Trendelenburg Test Left: Negative, Right: Positive

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Sincerely,

Mary Ann Vass, Permissions Specialist

Curriculum Vitae

BRYN ZOMAR

EDUCATION

Master of Science	Kinesiology, Sports Medicine University of Western Ontario, London, ON September 2013 – July 2015
Bachelor of Science *Dean's List*	General Biology Thompson Rivers University, Kamloops, BC Class of 2013

RESEARCH EXPERIENCE

University Hospital London, ON **Research Assistant** June 2015 – Present	University Campus, London Health Sciences Centre *Division of Orthopaedics* Conduct research studies including data collection, patient recruitment, ethics submissions and renewals.
University of Western Ontario London, ON **Thesis Project** 2013 – Present	University Hospital, London Health Sciences Centre *Under the supervision of Dr. Dianne Bryant and Dr. Susan Hunter and co-advisory of orthopaedic surgeons Dr. Brent Lanting and Dr. James Howard.* Conduct a prospective cohort study investigating functional recovery after two different surgical approaches for total hip arthroplasty. Responsible for patient recruitment, follow-up, data collection and entry, statistical analysis.
Vancouver General Hospital Vancouver, BC **Research Assistant** June – August 2013	*For orthopaedic trauma surgeon Dr. Gerard Slobogean* Assisted with the submission of manuscripts to peer-reviewed medical journals and the preparation of academic presentations. Prepared the site for the introduction of a new study involving the creation of study binders and editing the proposed protocol.

CONFERENCES

Toronto, ON **Presenter** May 2014, 2015	*Bodies of Knowledge Graduate Student Conference* Presented thesis work regarding functional recovery after total hip arthroplasty through two different surgical approaches.

London, ON **Poster** April 2015	*Kinesiology Graduate Students Association Symposium* Contributed a poster outlining thesis work regarding functional recovery after total hip arthroplasty through two different surgical approaches.
London, ON **Poster** March 2015	*Faculty of Health Sciences Research Day* Contributed a poster outlining thesis work regarding functional recovery after total hip arthroplasty through two different surgical approaches.
London, ON **Presenter** April 2014	*Three-Minute Thesis Competition* Presented the proposal for my thesis work regarding Functional recovery after total hip arthroplasty through two different surgical approaches.
Kamloops, BC **Poster** March 2013	*4th Annual TRU Respiratory Health & Sleep Science Conference* Contributed a poster outlining the link between short sleep duration and obesity.

TEACHING EXPERIENCE

University of Western Ontario London, ON **Teaching Assistant** Winter 2014 and 2015, Fall 2014	*Systemic Approach to Functional Anatomy* Kinesiology 2222A/B
University of Western Ontario London, ON **Teaching Assistant** Fall 2013	*Introductory Biomechanics: A Qualitative Approach* Kinesiology 2241A

HONOURS & AWARDS

2015	Kinesiology Graduate Travel Award
2013-2015	Western Graduate Research Scholarship
2014, 2015	Faculty of Health Science Travel Award
2009-2013	TRU Dean's List: Faculty of Science