CHANGES IN GAIT BIOMECHANICS AND MUSCULAR TORQUE AFTER TOTAL HIP ARTHROPLASTY IN OSTEOARTHRITIC HIP PATIENTS

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ABSTRACT

**Purpose:** Osteoarthritis is a prevalent hip disease primarily affecting older populations, causing pain, muscle weakness, contracture, and gait abnormalities. When conservative treatments have failed, total hip arthroplasty (THA) is often the prescribed treatment to correct osteoarthritic changes. Although THA can reduce pain and improve function, gait abnormalities persist long after surgery. Therefore, the purpose of this study was to evaluate the effects of THA on hip biomechanics, muscle torque, gait velocity, and pain in osteoarthritic hip patients preoperatively and postoperatively.

**Methods:** Biomechanical gait analysis was completed for 15 THA and 11 healthy control participants using a three-dimensional motion capture system. Gait, hip muscle torque, walking velocity, and pain data were collected during six sessions: preoperatively; and postoperatively, at three and six weeks, and at three and six months.

**Results:** Differences in hip extension angle, external hip extension moment, hip flexion, extension, and abduction torque, walking velocity, and pain were revealed between groups. The THA group demonstrated lower values and significantly higher improvements postoperatively than the experimental group. Initial decreases in hip flexor torque were observed within the first three weeks postoperatively. Six weeks postoperatively, a reduction in pain combined with increased extension angle contributed to improved muscle torque and gait characteristics.

**Conclusions:** Osteoarthritic hip patients demonstrated diminished gait characteristics and muscular torque when compared to controls. While these gait characteristics improved post operatively they did not return to control values with the exception of hip extension and abduction torque, walking velocity, and pain level at six months postoperatively.

**Key Words:** Total hip arthroplasty, hip kinematics, hip kinetics, Harris Hip Function Scale, hip muscle torque
TABLE OF CONTENTS

ACKNOWLEDGMENT ................................................................. i

ABSTRACT ................................................................................. ii

List of Tables .............................................................................. v

List of Figures ............................................................................. vi

Part I ......................................................................................... 1

Introduction .............................................................................. 1

Methods ..................................................................................... 3

Research Design .......................................................................... 3

Participants .................................................................................. 3

Instruments .................................................................................. 4

Data Collection Procedures ....................................................... 5

Statistical Analysis ....................................................................... 6

Results ......................................................................................... 7

Discussion .................................................................................... 12

Part II .......................................................................................... 17

Review of Literature. ................................................................. 17

Appendix A: Institutional Review Board Informed Consent Forms . . . . 46

Appendix B: Questionnaires ....................................................... 68

Appendix C: Data Collection Forms ............................................ 71

Appendix D: Specific Testing Protocols ....................................... 74

Appendix E: Visual Analog Scale ................................................ 75
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1.</td>
<td>THA and control group means and standard deviations for Age, BMI (Body Mass Index), Height, and Weight</td>
<td>3</td>
</tr>
<tr>
<td>Table 2.</td>
<td>Peak Hip Angles (°) During Gait</td>
<td>7</td>
</tr>
<tr>
<td>Table 3.</td>
<td>Maximum External Hip Moments (Nm/kg) During Gait</td>
<td>8</td>
</tr>
<tr>
<td>Table 4.</td>
<td>Hip Muscle Torque (ft-lbs)</td>
<td>9</td>
</tr>
<tr>
<td>Table 5.</td>
<td>Walking Velocity (m/s) and Harris Hip Function Scale</td>
<td>10</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.</td>
<td>Hip Flexion Torque for THA over Time</td>
<td>13</td>
</tr>
<tr>
<td>Figure 2.</td>
<td>Hip External Extension Moment for THA over Time</td>
<td>13</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>Hip Flexion Torque for THA and Control Group</td>
<td>14</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>Max Hip Extension Angle for THA and Control Group</td>
<td>15</td>
</tr>
</tbody>
</table>
Part I

Introduction

Osteoarthritis (OA) is the most prevalent degenerative joint disease in the United States [1-3]. Approximately 27% of Americans suffer from OA, more specifically, about 10% of people over 45 years of age suffer from symptomatic hip OA [1]. Although several risk factors have been identified, the cause of OA is still unknown. Risk factors, such as increased age, have been associated with cellular changes in bone growth and cartilaginous repair, propagating damage to the hip joint surfaces over time. [2, 4, 5] Other risk factors include prolonged obesity, injury to weight bearing joint surfaces, and repeated mechanical stress. Osteoarthritis requires frequent treatment, follow-up, and ultimately total hip arthroplasty (THA) to replace damaged joint surfaces after conservative measures have failed. [3-5]

Hip OA has previously been reported to cause several muscular and gait changes during walking. Specifically, the onset of OA is related to slower gait velocity and reduction in hip strength, leading to compensatory movements when compared to healthy individuals. Hip extension and hip abduction range of motion is often reduced, as well as hip abduction moments as OA progresses. [6-9] Pain avoidance strategies can contribute to altered gait patterns, encouraging shortened stance time on the involved limb and decreased moments in an effort to reduce time and pressure on the affected joint [10-12]. Limited hip extension range of motion often causes contractures of the hip flexor muscles, leading to inadequate hip flexor torque used normally to control trunk motion and provide stability during walking gait. [13, 14].
Osteoarthritic gait characteristics have been found to persist even after treatment or corrective surgery has been administered [8, 10, 11]. Although results from THA have shown greater patient satisfaction and pain reduction [10, 15-18], the cause of decreased joint function post THA remains unknown. Consequently, THA improvements do not mimic control participant levels even up to a year postoperatively [10, 11, 17]. Gait variables associated with OA such as decreased walking velocity, external hip extension and abduction moments, and hip muscle torques have been reported to improve as early as six weeks post THA however, these results do not match normative values [7, 10-13].

Despite good clinical results, hip flexor weakness and contracture due to lack of range of motion prolong the aforementioned postoperative gait deficits [12, 13, 16, 17]. The inability to return to normal gait may be attributed to prolonged preoperative pain reduction compensatory techniques such as decreased hip extension and abduction angles, and hip abduction moments [8, 10, 11]. To our knowledge, combined gait analysis and sagittal plane muscle torque values have not been investigated together in THA patients postoperatively. Therefore, the purpose of this study was to assess hip kinetic and kinematic gait variables, muscle torque, gait velocity, and pain in osteoarthritic hip patients preoperatively and postoperatively: at three and six weeks, and at three and six months. We hypothesized that increased hip muscle and hip flexion torque, sagittal plane joint angles and moments would be observed along with increases measured preoperatively and postoperatively periodically.
Methods

Research Design

A prospective longitudinal analysis of biomechanical gait characteristics, muscle torque, gait velocity, and pain of OA patients was conducted preoperatively and postoperatively at three and six weeks and three and six months. The independent variables were group (THA and control) and time period. The dependent variables were gait biomechanics, muscle torque, walking velocity, and pain.

Participants

Fifteen patients diagnosed with hip OA and scheduled to undergo THA (63.03 ± 9.99 years, 8 male and 7 female) and eleven healthy controls subjects from the local community (62.22 ± 3.77 years, 7 male and 4 female) volunteered for the study. Demographic information is provided in Table 1. The same board certified physician screened, diagnosed and performed all THAs in this study.

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>BMI (kg/m²)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>THA (n=15)</td>
<td>62.87 ± 10.37</td>
<td>26.66 ± 4.29</td>
<td>1.66 ± 0.11</td>
<td>73.77 ± 14.90</td>
</tr>
<tr>
<td>Control (n=11)</td>
<td>62.00 ± 3.92</td>
<td>26.13 ± 2.23</td>
<td>1.65 ± 0.08</td>
<td>70.84 ± 8.07</td>
</tr>
</tbody>
</table>

There were no significant differences between groups.

Inclusion criteria consisted of: (1) no history of previous lower extremity joint replacements, (2) no history of rheumatoid or inflammatory arthritis, (3) ability to walk without the use of an aid, and (4) below 85 years of age. Control subject inclusion criteria consisted of no history of OA or any of the aforementioned inclusion criteria.
Prior to participation, all subjects were informed about the nature of the study and signed informed consent and HIPPA release forms approved by the hospital and university’s institutional review boards.

**Instruments**

A Vicon motion capture system (Vicon, Inc., Centennial, Colorado, USA) and Vicon Nexus software (Vicon, Inc., Centennial, Colorado, USA) were used to capture, reduce, and analyze kinematic data. Two force plates (Advanced Mechanical Technology Incorporated, Boston, Massachusetts, USA) embedded flush with the floor were used to collect kinetic data during walking trials. Kinematic data were collected at 240Hz and time synchronized with kinetic data collected at 480Hz and smoothed using a Woltring filter with a 10 MSE cut-off. Speedtrap II (Brower Timing Systems, Draper, Utah, USA) infrared sensors placed four meters apart were used to assess walking velocity. A Hoggan Health Microfet Digital Hand Held Dynamometer (HHD) (Hoggan Health Industries, West Jordan, UT) was used to collect all muscle torque and pain data were assessed after each muscle torque trial using the visual analog scale (Appendix E). Prior to each data collection period, each participant completed the Harris Hip Function Scale (HHFS) to assess function and pain during activities of daily living (Appendix B).

**Data Collection Procedures**

All data were collected in the Human Performance and Gait Laboratory at the University by National Athletic Trainers’ Association/Board of Certification certified
athletic trainers. Anthropometric data were collected at each visit and consisted of: age, height, weight, leg lengths, and knee and ankle joint widths. The Harris Hip Function Scale (HHFS) (Appendix B) data were separated into a functional and pain component. The pain score is based on a scale of 0-44 with a score of 44 meaning that the participant had no pain.

Participants were fitted with 27 infrared retro reflective markers (18mm in diameter) attached to the following anatomical locations: clavicle, C7 spinous process, T10 spinous process, right scapula, xiphoid process, and bilaterally at the acromioclavicular joints, anterior superior iliac spine, posterior superior iliac spine, thigh, medial and lateral knee, tibia, medial and lateral ankle, heel, and toe according to the VICON Plug-in-Gait guidelines (Vicon, Inc., Centennial, CO) [19]. Walking gait was assessed using three successful trials, which has previously been found to be highly reliable [10, 20]. A successful trial was defined as completion of the pass through the four meter field at a self-selected walking speed and landing with one foot completely on the force plate with no obvious change in stride[10, 11, 18, 20].

Muscle torque data were collected bilaterally in eight motions: hip extension, knee flexion, hip adduction, hip abduction, hip flexion, hip external rotation, hip internal rotation, and knee extension (Intratester ICC (2, 1) range = 0.89–0.98, 0.84-0.98, 0.86-0.95 for testers 1 to 3, respectively). The participants were asked to build force over a three second time period, reaching maximal contraction at three seconds [14, 21]. Following a submaximal familiarization trial, three maximal trials were recorded, with a 30 second rest between trials [14, 21-23]. All muscle torque tests were performed in a
gravity dependent position except hip abduction and adduction, which were collected in the gravity neutral position (i.e. supine); due to pain at the surgical site (Appendix D). Joint pain at the location of the HHD was assessed after each muscular torque trial using a visual analog scale (Appendix E) [14].

**Statistical Analysis**

Descriptive statistics including means, standard deviations and ranges were generated for all demographic characteristics and variables of interest. Comparisons of demographic variables between THA and controls were completed using *t*-tests. All moments were calculated using external moments. Changes in hip kinematics, kinetics, muscle torque, HHFS, and walking velocity over time for the THA group and controls were examined using multiple ANOVA’s. A mixed method, repeated measure ANOVA was run to determine potential interactions between THA and controls over time. Independent *t*-tests were run to determine the difference between controls and the THA group at each time period. All data were analyzed using SPSS v21 (IBM SPSS Statistics, IBM Corporation, Armonk, New York, USA) and significance was set at \( p \leq .05 \) for all analyses.
Results

Hip Kinematics

Analysis of gait kinematics revealed significant increases in maximum hip extension angle in the THA group at six weeks (p = .000), three months (p = .000), and six months (p = .000) postoperatively when compared to preoperative values (Table 2). Maximum extension angle increased from 7.04° of flexion initially to 3.95° flexion at three weeks and 5.06° of extension at six months. Further analysis revealed a significant interaction between groups, F(4, 96)=7.563, for maximum hip extension angle.

Significant differences were indicated between the THA group and control group preoperatively (p = .000). Hip extension during walking was not achieved at the initial visit in the THA group and was reported at 7.04° of flexion as compared to controls at 9.29° of extension. Individual time periods had significant differences between the THA group and the control group at three weeks (p = .000), six weeks (p = .007), three months (p = .018), and six months (p = .040). Frontal plane kinematics did not reveal any significant difference between groups.

Table 2. Peak Hip Angles (°) during Gait: Means, Standard Deviations, and Statistical Results for the THA Group Preoperatively and at Three Weeks, Six Weeks, Three Months, and Six Months Postoperatively.

<table>
<thead>
<tr>
<th></th>
<th>Extension</th>
<th>Flexion</th>
<th>Adduction</th>
<th>Abduction</th>
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<tbody>
<tr>
<td>PRE</td>
<td>7.04 ± 8.89</td>
<td>34.21 ± 6.28</td>
<td>4.39 ± 4.95</td>
<td>-3.90 ± 4.66</td>
</tr>
<tr>
<td>3 WEEKS</td>
<td>3.95 ± 8.66</td>
<td>32.58 ± 7.23</td>
<td>4.97 ± 4.84</td>
<td>.724 ± 4.20</td>
</tr>
<tr>
<td>6 WEEKS</td>
<td>-1.35 ± 6.15</td>
<td>33.66 ± 8.04</td>
<td>4.82 ± 3.72</td>
<td>.731 ± 3.21</td>
</tr>
<tr>
<td>3 MONTHS</td>
<td>-3.83 ± 9.05</td>
<td>34.36 ± 8.52</td>
<td>6.66 ± 3.67</td>
<td>.153 ± 4.49</td>
</tr>
<tr>
<td>6 MONTHS</td>
<td>-5.06 ± 7.35</td>
<td>35.18 ± 6.15</td>
<td>6.58 ± 4.99</td>
<td>.075 ± 3.91</td>
</tr>
</tbody>
</table>

* = significance between time period in the THA group compared to PRE visit; p < .05
Hip Kinetics

Analysis of gait kinetics revealed significant increases in external hip extension moment in the THA group six weeks ($p = .019$), three months ($p = .022$), and six months postoperatively when compared to preoperative values (Table 3). External hip extension moment increased from .67 Nm/kg initially to .76 Nm/kg at three weeks and 1.10 Nm/kg at six months. Further analysis revealed a significant interaction between groups, $F(3.265, 78.359)=2.651$, for external hip extension moment. Significant differences were indicated between the THA group and control group preoperatively ($p = .001$). External hip extension moment at the initial visit in the THA group was reported at .67 Nm/kg as compared to controls at 1.20 Nm/kg. Individual time periods had significant differences between the THA group and the control group at three weeks ($p = .001$), six weeks ($p = .026$), and three months ($p = .011$).

Hip Muscle Torque

Hip flexion torque significantly decreased in the THA group at three weeks ($p = .008$) postoperatively when compared to preoperative values (Table 4). Hip flexion

| Table 3. Maximum External Hip Moments (Nm/kg) during Gait: Means, Standard Deviations, and Statistical Results for the THA Group Preoperatively and at Three Weeks, Six Weeks, Three Months, and Six Months Postoperatively. |
|-----------------|----------------|----------------|----------------|----------------|
|                 | Extension      | Flexion        | Adduction      | Abduction      |
| PRE             | -.67 ± .35     | .56 ± .27      | .92 ± .16      | -.10 ± .11     |
| 3 WEEKS         | -.76 ± .26     | .379           | .54 ± .31      | .793           |
| 6 WEEKS         | -.93 ± .23     | .019*          | .50 ± .24      | .482           |
| 3 MONTHS        | -.98 ± .35     | .022*          | .53 ± .21      | .713           |
| 6 MONTHS        | -1.10 ± .30    | .001*          | .56 ± .25      | .965           |

* = significance between time period in the THA group compared to PRE visit; $p < .05$
torque decreased from 24.92 ft-lbs initially to 15.55 ft-lbs at three weeks and improved to 23.530 ft-lbs at six months. Further analysis revealed a significant interaction between groups, F(4, 96)=4.921, for hip flexion torque. Significant differences were indicated between the THA group and control group preoperatively (p = .002). Hip flexion torque at the initial visit in the THA group was reported at 24.92 ft-lbs as compared to controls at 39.82 ft-lbs. Individual time periods had significant differences between the THA group and the control group at three weeks (p = .000), six weeks (p = .001), and six months (p = .023).

Hip extension torque revealed significant increases in the THA group at three months (p = .004) and six months (p = .001) postoperatively when compared to preoperative values (Table 4). Hip extension torque decreased from 15.51 ft-lbs initially to 14.31 ft-lbs at three weeks and improved to 21.87 ft-lbs at six months. Further analysis revealed a significant interaction between groups, F(4, 96)=11.648, for hip extension torque. Significant differences were indicated between the THA group and control group preoperatively (p = .000). Hip extension torque at the initial visit in the THA group was reported at 15.51 ft-lbs as compared to controls at 31.50 ft-lbs. Individual time periods had significant differences between the THA group and the
control group at three weeks (p = .001), six weeks (p = .003), and three months (p = .011).

Analysis of hip abduction torque revealed a significant decrease in the THA group at three weeks (p = .001) postoperatively when compared to preoperative values (Table 4). Hip abduction torque decreased from 18.64 ft-lb's initially to 13.61 ft-lb's at three weeks and improved to 21.55 ft-lb's at six months. Further analysis revealed a significant interaction between groups, F(3.178, 76.274)=8.007, for hip abduction torque. Significant differences were indicated between the THA group and control group preoperatively (p = .016). Hip abduction torque at the initial visit in the THA group was reported at 18.64 ft-lb's as compared to controls at 25.53 ft-lb's. Individual time periods had significant differences between the THA group and the control group at three weeks (p = .000) and six weeks (p = .030).

**Walking Velocity**

Walking velocity revealed significant increases in the THA group at six weeks (p = .000), three months (p = .000), and six months (p = .000) postoperatively when compared to preoperative values (Table 5). Walking velocity increased from .98 m/s

<table>
<thead>
<tr>
<th></th>
<th>Walking Velocity</th>
<th>HHFS-Total</th>
<th>HHFS-Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>0.98 ± .30</td>
<td>60.1 ± 16.1</td>
<td>21.7 ± 10.6</td>
</tr>
<tr>
<td>3 WEEKS</td>
<td>1.08 ± .19</td>
<td>.099</td>
<td>73.9 ± 13.7</td>
</tr>
<tr>
<td>6 WEEKS</td>
<td>1.22 ± .15</td>
<td>.000*</td>
<td>88.1 ± 11.1</td>
</tr>
<tr>
<td>3 MONTHS</td>
<td>1.29 ± .16</td>
<td>.000*</td>
<td>92.6 ± 8.9</td>
</tr>
<tr>
<td>6 MONTHS</td>
<td>1.36 ± .18</td>
<td>.000*</td>
<td>94.6 ± 4.3</td>
</tr>
</tbody>
</table>

* = significance between time period in the THA group compared to PRE visit; p < .05. HHFS = Harris Hip Function Scale
initially to 1.08 m/s at three weeks and 1.36 m/s at six months. Further analysis revealed a significant interaction between groups, $F(2.681, 68.676)=5.420$, for walking velocity. Significant differences were indicated between the THA group and control group preoperatively ($p = .013$). Walking velocity at the initial visit in the THA group was reported at .98 m/s as compared to controls at 1.24 m/s. Individual time periods had significant differences between the THA group and the control group at three weeks ($p = .005$) and six weeks ($p = .050$). Six months postoperatively the THA group reached normal values and was reported at 1.36 m/s as compared to controls at 1.39 m/s.

**Harris Hip Function Score**

Analysis of the HHFS revealed significant improvement in the THA group at three weeks ($p = .001$), six weeks ($p = .000$), three months ($p = .000$), and six months ($p = .000$) postoperatively when compared to preoperative values (Table 5). Harris Hip Function Score increased from 60.1 initially to 73.9 at three weeks and 94.6 at six months. Further analysis of the HHFS revealed a significant improvement in pain for the THA group at three weeks ($p = .000$), six weeks ($p = .000$), three months ($p = .000$), and six months ($p = .000$) postoperatively when compared to preoperative values (Table 5). Harris Hip Function Score for pain improved from 21.7 initially to 33.3 at three weeks and 41.7 at six months. Pain and functional scores were not collected for any control participants.
Discussion

Gait is dependent on several learned adaptations and movements that vary greatly between individuals [24]. These differences are more apparent between healthy participants and those who suffer from OA [8, 9, 24]. Hip extension and abduction angles as well as hip abduction moments have been identified previously as specific differences between healthy controls and OA patients [9]. These results indicate that patients with OA already exhibit abnormal gait patterns before corrective surgery. For the purpose of this study, preoperative values were collected to establish a baseline for each participant and to analyze over time the effects of THA surgery.

Decreased hip extension angles have been attributed to hip flexor muscle contractures and weakness, however sagittal plane muscle strength data has not been previously collected to support these claims [12, 16, 17]. Foucher et al. [11] speculated that decreased external moments were caused by antagonist muscle weakness, specifically, a lack of hip flexor muscular torque. Our results contradict these findings, with a significant decrease in hip flexion torque and a significant increase in external hip extension moment three weeks postoperatively. This may indicate the improvements in external hip extensor moment and hip extension angle postoperatively are surgical related, due to the possible relief of contracture or reduction of pain allowing more weight acceptance and range of motion at the hip joint. In the current study, a significant improvement of functionality and reduction of pain were found between preoperative and three weeks after surgery but were not at levels comparable to the healthy controls. Significant improvements in function and decreased pain have previously been reported
as early as one week postoperatively [25] and could cause increased range of motion, supporting the increases seen in the current study [20, 26].

Figure 1.

![Hip Flexion Torque in THA Group at PRE, 3 WEEKS, 6 WEEKS, 3 MONTHS, and 6 MONTHS](image)

Figure 2.

![External Hip Extension Moment in THA Group at PRE, 3 WEEKS, 6 WEEKS, 3 MONTHS, and 6 MONTHS](image)
This persistent lack of hip extension in the THA patients compared to controls may explain the significant decrease in hip flexion torque initially within three weeks postoperatively. Several studies have suggested hip flexion, extension, and abduction weakness may be a factor in prolonged gait abnormalities postoperatively, although very few studies have reported muscle torque values with gait analysis [10, 13, 16, 17]. In the present study, preoperatively hip flexion, extension, and abduction torques were significantly lower compared to the control group. Postoperatively, hip extension and abduction torques had significant increases, which returned to comparable values of the control group, indicating a return to more normal gait patterns. However, hip flexion torque did not return to control values, which is consistent with the results by Frost et al. [13]. This lack of hip flexion torque could be related to limited hip extension range of motion, decreasing the demand of the hip flexors during gait. The lower demand of the hip flexors could cause disuse atrophy, leading to further muscular weakness and possible hip flexor tightness or contracture that reduces hip extension angles. [10, 11]

Figure 3.
Compared to controls, significantly reduced walking velocities were observed in the THA participants preoperatively but returned to comparable levels at six months postoperatively. Previous walking velocity literature is inconsistent, reporting walking velocity returning to normal as early as six months postoperatively [12, 16] or remaining below normative values up to a year [17, 27] or ten years [28] postoperatively. Failure to extend the hip has been correlated with decreased walking velocity [17, 28], possibly caused by the avoidance of the closed pack position of the hip [29]. The subsequent reduced forces on the surfaces of the hip joint can decrease pain caused by OA but may be the cause of decreased walking velocities preoperatively. Additionally, along with increased walking velocities, THA patients in the current study had significant increase in external hip extensor moment, which is directly correlated due to reduced forces applied to the joint [12].
In conclusion, an initial decrease in hip flexor torque was observed within the first three weeks postoperatively. This suggests that the significantly lower hip extension angle and walking velocity that was observed in the THA group when compared to controls may contribute to reduced muscle torque early after surgery possibly due to contracture or atrophy. Six weeks postoperatively, a reduction in pain combined with increased extension angle contributed to improved muscle torques and gait characteristics. These findings indicate gait characteristics and strength can improve as early as six weeks postoperatively. Based on these findings, perhaps a more aggressive range of motion therapy in concert with a hip extension and flexion muscle strengthening protocol should be implemented after surgery to increase functionality and strength gains.
Part II

Literature Review

Osteoarthritis (OA) is a debilitating joint disease that affects 27% of the population in the United States [1]. There is no known cause of OA but there are several associated risk factors. Osteoarthritis is commonly treated with corrective surgery, such as total hip arthroplasty (THA), when conservative measures have failed and can provide patients with greater functionality and relief of pain. [2-4, 30] Although THA surgery improves functionality, researchers have found that gait does not return to normal following this procedure [10-12, 28]. This has brought forth great interest in investigating the cause of these results. Several studies have been conducted concerning gait changes after THA surgery and they have found that hip flexors and extensors may play an important role in deterring gait from returning to normal, although no muscle strength was collected [10, 11, 16, 17]. To our knowledge, there have not been any studies conducted investigating hip flexor and extensor strength and how it affects gait after THA surgery.

Epidemiology

Osteoarthritis is the most common type of arthritis and the most prevalent joint disease in the United States [1, 2, 30]. Yearly costs of OA are about three times as much as rheumatoid arthritis and in [2, 3] in 1994 it was estimated that 15.5 billion dollars were spent in treating OA [2]. Osteoarthritis clearly affects a large population of people
throughout the world, which causes great interest in better defining the disease and finding more efficient and improved treatments.

Lawrence et al. [1], using available national health surveys, compiled accurate estimates of the prevalence of OA in several different age and clinical categories. The authors concluded that 27 million Americans suffered from clinical OA in 2005, an increase from 21 million in 1995. This total was 12.1% of the total population of 25-74 year olds in the United States based on U.S. census bureau estimates in 2005. They also found the most accurate estimation of those who suffer from hip OA older than the age of 45 was 27%. These finding are similar to other prevalence studies conducted concerning hip and knee OA.

Quintana et al. [3] used an OA questionnaire sent to a random sample of older adults between the ages of 60-90 years old that lived in an urban province in Northern Spain. From the participants recruited 7,577 completed the survey. An orthopedic surgeon screened participants that responded positive for hip or knee arthritis. The investigators analyzed their data using logistic regression models to make their estimates. They estimated that prevalence for hip OA was 7.4% and that THA was appropriate treatment in 37.7% of men and 52.7% of women with diagnosed OA. Total hip arthroplasty was found to be appropriate in 47.9% of total patients with diagnosed hip OA after conservative measures had failed. The authors confirm the claim of OA being a prevalent disease affecting older populations. Because OA affects so many people, further investigation should be conducted to learn the possible cause of the disease and how to better treat it.
Although the cause of OA is unknown there have been several studies conducted to try to establish risk factors for the disease. Cooper et al. [4] conducted a study on 611 participants that had diagnosed OA that were scheduled for a THA. Each participant completed a questionnaire consisting of medical history and other various questions related to suspected risk factors. A short physical exam was also conducted on each participant. The data that the investigators collected was analyzed using conditional logistic regressions and were summarized by using odds ratios with a 95% confidence interval. The investigators significant findings were that obesity increased the chance of developing OA by 1.7 times, previous hip injury increased the chance of OA 4.3 times, and Heberden’s nodes increased the chance of OA by 1.6 times. They also discovered that previous hip injury was more closely related to unilateral OA as opposed to bilaterally. The investigators also found a weak association in prolonged regular sporting participation and a negative association in smoking in the male participants with OA.[4]

This study establishes some possible causes for development of OA and their findings are in line with previous research although there have been others that have found additional risk factors.

Flugsrud at al. [5] conducted a similar investigation of possible risk factors of OA on a cohort of 50,034 participants with OA in three Norwegian counties. All participants were administered a questionnaire concerning their activity levels at work and at leisure as well as smoking habits. The participants were then screened by nurses who reviewed their surveys with them and took measurements of height, weight, and blood pressure. The questionnaires and medical screenings were analyzed using a Cox proportional
hazards regression model and relative risks were estimated with incident rate ratios. They followed up with all participants on average nine years after the start of the study and 672 participants had a first THA due to primary OA. In result of their study the authors found that a high BMI was a significantly high risk factor for THA. They also found that those with high intensity manual work were at more risk for THA than those with less physically demanding jobs. They found that there was no significant risk in those who participated in highly physical leisure activities.

Further, Felson et al. [2] reviewed the epidemiology of OA and investigated possible risk factors. The authors concluded that risk factors could be considered in two categories: systemic and local biomechanical risk factors. Systemic risk factors are considered to include: age, sex, disease, diet, and genetic factors. Other studies have found that there is a high prevalence of OA in older adults [1, 3]. Felson et al. [2] concluded that this, in part, is because of the cellular changes that occur in older populations. Adults, as they age, do not have as many chondrocytes and their abilities to repair and regenerate cartilage decline. This increases the risk of wearing of the joint capsules and is highly related to development of OA. Women tend to also have more incidences of OA at an older age due to menopausal changes. The change in hormonal balances due to menopause can cause laxity of ligaments of the joints causing more wearing of joint surfaces. These combine to contribute higher risk of OA in older adults due to the inability to repair damaged cartilage. Local biomechanical factors include: mechanical injury, surgery, loading forces, repetitive loaded joint use and body mass. The authors concluded that injury to the joint was the greatest local biomechanical risk
factor. Tears of the meniscus or cruciate ligaments have a high correlation with the development of knee OA. These injuries contribute to damage of the hyaline cartilage of the knee and therefore encourage more wear and eventually development of OA. In the hip, cartilage damage and ligament tears are not as common. The authors suggested that any injury that results in interruption or damage to the joint surface there is an associated risk of developing OA. Joint line disruption can cause uneven or rough surfaces due to scaring which can grind and wear down hyaline cartilage on the weight bearing surfaces of the joints. [2]

Surgery

Total hip arthroplasty is an invasive but effective treatment, which replaces the damaged surfaces of osteoarthritic hips. Researchers have found that hip range of motion and gait do improve after THA surgery but does not reach the level of control participants even up to a year after surgery [11]. Results from THA surgery have shown better patient satisfaction, decrease in pain, greater mobility, and better durability [10, 15-18]. Several different surgical approaches have been developed including: minimally invasive anterior, posterior, and anterolateral approaches, a two-incision approach, and a traditional long incision approach [26, 31, 32]. Recent studies have found that the minimally invasive approach for THA surgeries allows patients a shorter recovery time, less time spent in the hospital, and patient greater satisfaction with THA surgery as a whole [32-34]. Despite the many different techniques, Dorr et al. [33, 35] suggests that
for the best results a minimally invasive technique should be used but the approach should remain the same as the physician’s normal approach.

There have been several studies completed comparing different minimally invasive approaches to THA surgeries. Meneghini et al. [32] conducted a study examining recovery time and functional improvement in the following three approaches: a two incision approach, mini-posterior, and mini-anterolateral. Twenty five participants were randomly assigned to one of the three groups and a THA procedure was performed. Pain and functional outcome measures were analyzed using the HHFS, lower extremity activity scale, WOMAC, and SF-36 questionnaires. Each questionnaire was administered at 6 weeks, 3 months, 6 months, and 1 year after surgery. Functional milestones were also recorded including: discharge from the hospital, discontinuance of walking aids, discontinued need for narcotics, return to work, and return to driving. Several one-way ANOVA’s were conducted to analyze all variables between group and over time. Tukey’s post hoc test was conducted on all significant findings. The authors found that there were significantly faster recovery times for minimally invasive techniques as compared to traditional techniques. Improved pain and functional outcome measures were seen in all three groups. Within minimally invasive procedures there were no significant differences between approaches.

Mayr et al. [36] conducted a randomized assessment of functional recovery and gait changes in THA patients that were assigned to a minimally invasive direct anterior group and an anterolateral group. The authors hypothesized that patients receiving the direct anterior approach would have an earlier functional recovery when compared to the
anterolateral group. Sixteen participants were randomly assigned into the direct anterior group and 17 were randomly assigned into the anterolateral group. Gait analysis was conducted preoperatively and at 6 and 12 weeks postoperatively and was collected using a 6 camera 3D motion capture system at 60hz. Participants walked at a self-selected speed across a 9 m runway and data were collected on 5 separate trials. Non-parametric analysis was performed on all variables due to a non-normal population. Freidman’s test was conducted to analyze variables over time and the Mann-Whitney U test was used to compare between groups. The authors found that at 6 weeks compared to pre-operatively in the minimally invasive direct anterior group there was a significant improvement in single support and stride time. Results also showed that from 6 weeks to 12 weeks the minimally invasive direct anterior group also showed significant improvements in cadence, stride time, stride length, walking speed, hip flexion at foot contact, maximum hip flexion, and total hip range of motion. The traditional anterolateral group did not show any significant results at the 6 week point as compared to the pre-operative period. During the 6 week and 12 week visits the traditional anterolateral group did show significant improvements in opposite foot contact, step time, flexion at foot contact, maximum flexion in swing, and range of flexion in the hip joint. These results suggest that the minimally invasive direct anterior approach shows earlier improvement in gait and also an improvement in a greater number of gait parameters as compared to the traditional anterolateral approach. This study did not consider the role that muscle strength plays in range of motion and how it affects gait. The results showed improvement but not return to normal gait.
Mont et al. [37] suggests that the standard THA approach leaves patients with reduced hip abduction and extension moments as compared to a healthy population without diagnosed OA. The authors also suggest that resurfacing total hip arthroplasty surgery can provide patients with a near normal gait after surgery as compared to those that have had a traditional THA approach. Gait was analyzed and compared between a standard THA group and a resurfacing THA group. In their study they had fifteen patients in a standard THA group, fifteen patients in a resurfacing THA group, ten patients with diagnosed OA, and thirty healthy age matched control patients. They collected and analyzed gait on all participants post-operatively while evaluating temporal-spatial parameters, hip kinematics, and hip kinetics. Paired t-tests were used to analyze all data when two variables were compared. All other variables were analyzed using a one-way ANOVA’s. The researchers found that the patients in the resurfacing group had increased walking velocity that compared with the control group, although they did not find any significant differences with hip abduction or extension moments between the resurfacing and standard THA groups. They also found that the hip kinematics and general functionality were closer to normal in the resurfacing THA group as compared to the standard THA group, which the authors suggested was due to a smaller femoral head component. There were some interesting results in this study although the time period at data collection was different for each patient which may have skewed their results. The mean gait analysis data collection period was at 13 months after surgery. Their results may have been more accurate as well if they had collected data pre-operatively as well. They recorded lack in hip abduction and extension but
failed to collect any data to explain the results. They may have been able to gain more insight if they took into account muscle strength and other possible factors that may affect abduction and extension moments.

There have been several studies claiming that minimally invasive THA approaches have shown greatly increased recoveries as compared to other methods of THA surgery. A study conducted by Krych et al [38] was done to compare the differences between a two-incision THA approach and a mini-posterior THA approach. The authors had interest in the effects of THA approach on gait and muscle damage. Twenty-one patients participated in their study. They were randomly assigned to two groups, eleven patients comprised the two-incision group and ten were in the mini-posterior group. Gait analysis and isometric strength values of the hip were collected pre-operatively and at 6 weeks after surgery. Gait analysis consisted of level walking trials, stair climbing, and descending down stairs. The authors found that there were no significant differences between the two approaches. They found that there was no difference in muscle damage when comparing the two groups. Although there was no significant difference they did find that the mini-posterior group had greater increases in gait velocity from the preoperative visit compared to 6 weeks after surgery. The mini-posterior group also showed greater improvement of gait kinematics while the two-incision approach did not. They also found that the two-incision group had weaker hip extension and flexion values as compared to the mini-posterior approach. According to their findings the mini-posterior approach may allow faster recovery and less muscle damage due to surgery. This study may have shown more in depth results if gait and
muscle strength was analyzed at more data points farther after surgery to track the return to normal gait and muscle strength values.

There have been studies conducted that have compared minimally invasive anterior and anterolateral approaches as well. Klausmeier et al [26] conducted a study comparing minimally invasive anterior and anterolateral approaches. In the anterolateral approach an incision is made directly over the trochanter lateral to the tensor facia latae. The anterior one third of the gluteus medius and minimus are then detached from the trochanter followed by a capsulectomy to expose the joint and allow for adequate dislocation for the surgical procedure. After the procedure is complete the gluteal tendons are reattached to the trochanter and the surgical field is closed. They hypothesized that because of the division and reattachment of the abductor muscles they would find that recovery time would be slower in the anterolateral group as compared to the anterior approach. Data were collected preoperatively and at 6 weeks and 16 weeks after surgery. They collected kinematic and kinetic data on walking trials with 3D motion capture gait analysis software. They also collected isometric hip abduction strength values in a standing position using a dynamometer. A mixed method, repeated measures ANOVA was used to analyze all variables between and within groups. The researchers discovered that hip abduction strength was lower in both surgical groups at all three data collection period when compared to the control group although, an improvement was seen in abduction strength at 16 weeks as compared to preoperatively in the surgical groups. At 6 weeks after surgery the anterior group showed improved gait velocity and peak flexor moments as compared to the anterolateral group but there were
no differences seen between dynamic gait measures and isometric strength values after surgery between the two groups. In accordance to other literature they also came to the conclusion that similar recovery times were seen between minimally invasive anterior and anterolateral approaches therefore indicating that the minimally invasive approach that the surgeon uses does not have significance. [26]

Dorr at al. [15] conducted a study examining the recovery time and functional return to normal after outpatients THA. Fifty two participants who returned home the next day after THA were enrolled in the study. Participants were asked to keep a three week journal and answer a weekly questionnaire consisting of pain level and functional questions, 44 participants completed the three week journal. Six weeks postoperatively all 52 participants completed a pain and satisfaction survey. The mean and standard deviations were analyzed for all questionnaires, surveys, and, milestones using SPSS and compared. The authors found that at six weeks postoperatively 96% of THA patients were satisfied with their surgeries. At three weeks postoperatively the mean pain scale on an analog pain scale was 1.9, 41% walked without any assistance and the remaining 59% only used a cane while walking. Six months after surgery 40 participants followed up and completed a HHFS. The mean total score was 95.6 and the mean pain score was 42.8.

Aarons et al. [25] conducted a similar study investigating short term recovery from hip and knee arthroplasties. The authors measured function, emotional state, and life evaluation preoperatively and at seven and 50 days postoperatively. Function and pain levels were assessed using a WOMAC questionnaire. Fatigue and pain
were also assessed using visual analog scales. Forty hip and 23 knee patients participated in the study. All scores were analyzed using a repeated measures ANOVA comparing hip to knee participants and over time. The authors found that pain was significantly decreased as early as one week after surgery in the THA group. Pain continued to decrease and was even lower at 50 days postoperatively in the THA group. Functional ability was also greatly improved in the THA group 50 days postoperatively but did not improve in the knee group. The authors did not see any significant increase in positive mood or life satisfaction in either group.

**Gait Analysis**

Gait is dependent on several learned adaptations and movements that vary greatly between individuals [24]. These differences are more apparent between healthy participants and those who suffer from OA [8, 9, 24]. Previous researchers have suggested that gait and other biomechanical factors do not return to normal after THA surgery, however the reason remains unknown [10, 16-18, 27]. Some have suggested that the inability to return to normal gait may be attributed to learned or persisting gait characteristics caused by OA such as decreased hip extension and abduction angles, and hip abduction moments [8, 10, 11]. Several studies have been conducted investigating gait changes longitudinally after surgery with all having varied results [10, 11, 18].

Normal gait must be studied and defined before making comparisons to abnormal gait caused by injury or disease. Ko et al. [39] conducted a cross sectional study investigating normal gait patterns in an older population. Fifty two participants that did
not have diagnosed OA or any other disease or injury that would alter their normal gait patterns were enrolled in this study. Each participant was older than 60 years of age and could walk without any aid. Kinematic and kinetic gait analysis was conducted as well analysis of walking velocity and stride length. The kinematic and kinetic data were collected using a 3D motion capture system and was used to calculate mechanical work expenditures in an older population. Cross-sectional associations between gait parameters and age were analyzed by a multiple regression analysis. The investigators found that older age was associated with slower self-selected walking speed and shorter stride length. They also found that older individuals had a greater tendency to land flat footed during the normal gait cycle and that their mechanical work expenditures increased as the participants were older. They concluded that the increase in work expenditure was due to compensations for loss of proprioceptive muscle control. This investigation was helpful in providing work expenditure findings and spatiotemporal results but the authors did not report any kinematic or kinetic values.

Understanding the effects of OA on gait is also important. Watelain et al. [9] in a non-randomized case control study, analyzed compensatory lower limb actions of patients with early stage OA. There was a clinical group consisting of 17 patients with diagnosed OA and a control group consisting of 17 healthy elderly patients. Each patient walked down a 10 meter walkway and two trials were collected and analyzed. Gait was analyzed using a three dimensional motion capture camera system and a set of 15 reflective markers. Two force plates were also utilized to analyze kinetic data. Comparisons between the clinical and non-clinical groups were analyzed using the
students $t$-test for all variables and effects sizes were reported if significant. The authors found a 12.4% slower walking speed in the clinical group as compared to the control group. The pelvis was more upwardly rotated and dropped more in the unsupported limb in the clinical group as compared to the healthy control group. The authors also found that there was more force applied to push off and deceleration in the clinical group as compared to the control group suggesting a more labored gait cycle and compensation for pain. This study shows that even at early stages of OA there are noticeable changes in gait as compared to healthy patients without OA. They did not directly measure muscle strength but used what they found from kinetic data to calculate push off strengths. A comparison of different stages of OA progression over time may have been beneficial to give more insight in the progression of the disease.

Kubota et al. [8] conducted a study analyzing gait parameters, kinematics, and kinetics in older adults with diagnosed OA. The authors compared 12 healthy control participants and 12 participants with diagnosed bilateral OA using 3D motion capture gait analysis technology. Their results indicated that participants with OA had lower walking velocities, step length, and cadence than the participants in the control group. They also found changes in the kinematics and kinetics of the OA group. A more forward tilted pelvis was observed in the OA group along with decreased values in hip extension and abduction angles. A lower peak abduction moment in the hip was also observed in the OA participants. This study gives some valuable information on hip kinematics and kinetics of those who suffer from OA and can be used as a reference when comparing participants who have had a THA surgery. When comparing a THA group and a healthy
control group we may always see diminished gait characteristics that persist long term, but by comparing longitudinally in a THA group to each individual’s baseline before and after surgery we can get a better understanding of gait changes and characteristics over time.

There are still some varied results seen from a multitude of studies looking at the time it takes to return to normal gait after THA surgery. Several researchers report that gait does not return to normal even as long as 16 months after surgery [10, 16, 17]. Varying surgical technique, rehabilitation protocols, and other factors may contribute to the difference of return to normal gait from study to study. Lugade et al. [18] conducted a study investigating whether gait would return to normal after different THA approaches. Twelve participants received an anterior THA, 11 received an anterolateral approach, and 10 participants formed a control group. Gait analysis was conducted preoperatively, and at 6 weeks and 16 weeks postoperatively in both THA groups. The control group participated in data collection twice in the first month only. A minimum of 5 walking trials at a self-selected speed across a 10 m walkway were collected for gait analysis. A two-way mixed method ANOVA was performed with repeated measure to analyze all variables between group and time. A Bonferroni post hoc test was also completed for all comparisons between group and time. The authors found that the anterior approach group showed improved gait mechanics at 6 weeks postoperatively compared to the anterolateral approach group. They also found that at 16 weeks post-op both groups had similar gait as compared to their control group but the surgical group never returned to normal gait.
Similarly, Pospischill et al. [40] conducted a study comparing gait analysis of minimally invasive THA procedures as compared to traditional THA procedure. There were 20 randomized patients in each of the two groups with a total of 40 participants. Gait analysis was conducted preoperatively, at 10 days, and at 12 weeks postoperatively. Gait data were collected using a 3D motion capture camera system and a reflective marker set. The patients walked a distance of 8-10 meters and 5 trials were recorded to analyze gait characteristics. Ground reaction forces were also collected using two force plates. Temporal spatial variables such as velocity, cadence, step length, and stride length were also collected. The researchers found that there were no significant differences between the two groups with regards to the temporal spatial variables that were looked at. They found that in the minimally invasive group there were smaller decreases in range of motion at 10 days compared to the traditional group, although these differences were not significant. The researchers also found that the decrease in range of motion was due to the lack of hip extension. A compensatory pelvic tilt was also seen in both groups. According to the findings it was concluded that there was not any significant difference between minimally invasive hip replacement and the standard techniques. This investigation lacked any recording of muscle torque data which could have been a possible explanation to lack of hip extension that was found. This study was also only conducted over a 12 week period after surgery with also limits the data that was collected.

There have been several gait analysis studies done and all of them have similar results. Beaulieu at al. [10] conducted a study to determine if gait characteristic return to
normal following THA. The authors used a 9 camera 3D motion picture capture system with 45 retro-reflective markers to analyze gait biomechanics. A Woltring filter with a 15 MSE was used to smooth the data. Twenty THA patients and 20 control subjects participated in the study. To capture the participants’ natural gait they were told to walk down a walking path looking straight ahead at a self-selected speed. Several walking trials were completed but six total trials were used, three trials of the right leg and three trials of the left leg. Any trials where the participant altered gait to land on the force plates or did not completely step on the force plates were discarded. A series of one-way ANOVA’s were conducted to analyze all variables between group and time. A Bonferroni post hoc test was conducted to correct alpha levels to determine significance. The authors found significantly lower hip flexion and extension angles in the THA group when compared to controls. Significantly lower hip abduction and external rotation moments were also seen when compared to controls. The authors suggested that this range of motion deficit is because of contracture of the hip flexors muscles. They also noted that the change of gait that they had seen could be caused by antalgic gait, muscle weakness, or muscle contracture. This particular study though failed to record data pre-operatively and they only had one data collection at varied times after surgery ranging anywhere from 6-15 months. They also failed to record any kind of muscle measurements so they could not confirm or deny the cause of their results. Similar flaws are seen in other gait analysis studies.

Similarly, Foucher et al. [11] examined the return to normal gait one year after THA. The authors hypothesized that dynamic hip range of motion and external hip
moments return to normal during walking after THA. Twenty eight participants who were scheduled to have a THA were selected for enrolment in this study. Thirteen participants had a lateral approach while the remaining 15 received a posterior approach. Twenty five age matched healthy control subjects were recruited for this study. Data was collected preoperatively and at one year postoperatively. During each visit each participant was assessed on their passive range of motion, abductor torque, limb length discrepancies and kinematic and kinetic measures. Six retro reflective markers were used and monitored by four optoelectronic cameras for six walking trials across a force plate embedded flush with the ground. Two walking trials were collected at a slow self-selected velocity, two at a normal self-selected velocity, and two at a fast self-selected velocity. Variables of interest included hip range of motion and all external hip moments. The HHFS was also conducted at both data collection periods. These variables were analyzed and found to be non-normal so non-parametric methods were used. Friedman’s test was used to determine the differences in gait variables preoperatively and postoperatively. Spearman correlations were used to tell if preoperative and postoperative values were linearly related. Mann-Whitney tests were used to determine differences between groups for all variables. The authors rejected their null hypothesis because they found that gait kinematics and kinetics did not return to normal levels compared to the control group after THA. Significant increases were seen in sagittal plane range of motion and in all external hip moments with the exception of external hip adduction, abduction, and external rotation moments. Significant correlations were found between range of motion and peak external hip flexion,
abduction, and external rotation moments. The authors suggested that the external moments that did not return to normal even a year after surgery could be the result of persisting gait adaptations due to OA or persistent muscle weakness, namely hip flexion weakness.

Perron et al [17] showed similar results. They noted that gate speed and gait biomechanics did not return to normal even after 18 months after THA surgery. A significant decrease in hip extension was seen. A 14% decrease in gait speed was also noted. Anterior pelvic tilt, knee flexion, and ankle dorsiflexion increases of significance were seen. There was also an ipsilateral bending of the trunk that was seen which suggests abductor weakness. They concluded that the decrease in gait speed and the persistence of abnormal gait patterns one year after the THA were associated respectively with a decrease in the hip extensor moment of force and with a decrease in the range of hip extension or in the hip abductor moment of force. They also failed to measure any type of muscle strength and did not have pre-operative data collection periods. The lack of these measurements weakens the results. Only their gait analysis results are reliable. Any of their suggestions or inferences about muscle contracture or muscle strength are not reliable because they did not test muscle strength in their study. Therefore, more inquiry is required to understand the relationship of gait changes and THA surgery in regards to the reason why gait does not return to normal after surgery.

Nantel et al. [16] conducted another similar gait analysis study. In this study a traditional THA surgery was compared to a surface replacement arthroplasty. Ten participants were assigned to each surgical group as well as to a control group. The
authors collected gait analysis data, hip abductor torque, and clinical outcomes, and radiographic analysis of the hip. Eight optoelectronic cameras were used to collect kinematic and kinetic data 60 Hz along with two force plates at 240 Hz. Participants were asked to walk at a self-selected speed through a 10 meter walkway for data analysis. Four gait cycles were recorded. Clinical outcomes were analyzed using the WOMAC questionnaire. All data between groups were analyzed using one-way ANOVA’s for all variables. Hip abduction strength was measured but all other lower limb torques were not measured. Compared to control group in this study hip abductors were weaker. A decrease in hip ROM was also seen. Surface replacement arthroplasty patients improved gait faster than THA patients although neither group returned to normal up to 6 months after surgery. They suggested that the decrease in hip range of motion is because of muscle contracture and flexor muscle weakness. Similar to the studies mentioned before they failed to measure lower limb muscle strength with the exception of hip abduction strength. They also only measured data in two data collection periods, once pre-operatively and only once at six months after surgery.

Miki et al. [12] conducted a study on 17 participants who underwent unilateral THA surgery. Gait analysis was conducted pre-operatively and at 1 month, 3 months, 6 months, and 12 months after surgery and was compared to the uninvolved leg. Gait parameters, kinematics, and kinetics were collecting using a 3D motion capture camera system and analyzed using VICON software. The researchers found that walking velocities, cadence, step length, and stride length had significant increases after THA surgery and were at comparable levels to preoperatively values. They also found that
reduced range of motion in the affected hip persisted even after 12 months post-operatively. They found that hip extension moment and hip abduction moment were also reduced when compared to the uninvolved limb but became non-significant soon after surgery.

Bennett et al. [28] conducted a similar study on 134 participants at their routine ten year appointment after successful THA surgery and found that abnormal gait patterns persisted even ten years after surgery. Gait parameters and kinematics were collected using a 3D motion capture system to analyze gait characteristics. The authors concluded that in all age groups there were reduced hip flexion/extension range of motion, maximum hip extension, hip abduction/adduction range of motion, and reduced gait velocities and step lengths when compared to healthy elderly adults. The findings in this study suggest that gait characteristics may never return to normal when compared to healthy individuals who do not suffer from OA or have had THA surgery. The authors found some valuable information but they did not include any kinetic or muscle torque in their data. This could have given some insight in the role that muscle strength play in return to normal gait or at the least the role that it may play in return to normal functionality after THA surgery.

McCrory et al. [20] conducted a study examining ground reaction forces of 27 participants who had a THA compared to 35 healthy control participants. Data were collected at least 2 months after surgery in the THA group. Participants were asked to walk for two minutes on a treadmill with two force plated imbedded in the rotating band. Data were collected the last ten seconds of the two minute trial and were collected at 500
Hz and normalized for weight and height. At least three trials for the left leg and three trials for the right leg were collected and averaged for the final statistical analysis.

Several vertical ground reaction forces were analyzed. Multiple ANOVA’s were conducted to analyze all variables between the involved limb and the uninvolved limbs and between the involved limb and the control group. A Tukey’s post hoc test was conducted on all significant variables. The authors found that the THA group has more significant asymmetries than the control group. Bilateral asymmetric limb loading occurred well after THA. They also found that ground reaction forces were an effective means of quantifying antalgic gait in the THA group.

Tanaka et al [27] conducted a study analyzing the factors influencing gait after THA surgery. In this study there was a group of 43 women who suffered from unilateral OA and had received a THA surgery. There was also a control group of 23 age matched women. Gait was analyzed pre-operatively, and at 2, 6, and 12 months after surgery by using ground reaction force plates and a gait scan 8000 system. The patients walked a 5 meter distance and at least three trials were collected each data collection period. Parameters such as velocity, cadence, step length, stride length, single support, and double supports were collected by the gait scan 8000 system. A student $t$-test was used to compare the involved leg to the uninvolved leg for all variables. A linear-regression analysis was performed to evaluate changed in the THA group over time. The results of this study found significant differences in all gait parameters between the control group and the THA group at all data collection times. They also found that by the 12 month data collection period the THA improved greatly in all parameters but never reached the
values in the control group. The study also showed that the greatest time period of improvement was from 2 to 6 months after surgery. Although this study provided useful information muscle strength was not collected and the study only collected information up to a year after surgery. The gait analysis system that they used did not allow for a more in depth analysis of gait and was limited as far as which parameters they could use.

**Muscle Torque/Manual Muscle Testing**

There have been several studies conducted that have analyzed gait and biomechanics after THA surgery. Several of them have noted that gait does not return to normal [10, 16-18]. These studies have given valuable information as to some possible reasons why gait does not return to normal after THA surgery. Some speculate hip flexor weakness and possible contracture due to lack of range of motion prolong post-surgical gait deficits [12, 13, 17]. Although these examples suggest that hip muscle weakness may be the cause of abnormal gait they fail to measure any sagittal plane muscle torque as part of their studies.

Pua et al. [41] conducted a study to investigate the correlation between hip extension strength, pain, hip flexion range of motion, and functionality in OA patients. There were 100 participants that were enrolled in the study. All participants were radiographically diagnosed with OA. Three functionality tests were conducted including a stair climb test, step test, and gait speed test. A digital inclinometer was used to measure the hip flexion range of motion and a force transducer was used to collect hip extension measurements. Separate multiple mediation analysis were conducted to
analyze the 4 different measures of function. They found that there was a positive association between hip extension strength and hip flexion range of motion. They also found that hip flexion range of motion affected functionality greatly. They did not find that hip strength or range of motion caused a significant difference in gait speed. One clear conclusion from this investigation was a positive association between muscle strength, range of motion, and functionality but they did not include any gait analysis in their design. They also failed to record any other muscle torque data of the hip aside from the hip extensors.

Rasch et al. [6] conducted a similar study examining hip muscle torque and cross-sectional areas of hip muscles in those who suffer from OA. Twenty two participants with unilateral OA were enrolled in the study. Measurements were taken on the day before surgery. Isometric strength was collected by having the participant seated on a table with the hip and knee flexed at 90°. Flexion or extension force was then measured with a strain gauge. CT scans were used to determine the cross-sectional area of each muscle and the radiographic density. The HHFS, SF-36, EQ-5D, and a visual analog scale of 0-10 were used to assess pain and clinical outcomes. All variables were analyzed using paired $t$-tests to compare the differences between the involved limb and the healthy limb. The authors discovered a significant (11-29%) weakness of hip flexion, extension, abduction, and adduction and knee extension torque when compared to the healthy limb. The cross-sectional areas of the hip flexors, extensors, adductors, knee extensors, and knee flexors were also significantly reduced (11-19%) in the OA limb compared to the uninvolved limb. The radiographic density revealed reductions in all muscle groups
except for the hip flexors. All clinical outcomes and results from the visual analog scale revealed impairment. The mean score for the visual analog scale for pain was 5.2 on a scale of ten. The authors suggest that muscle weakness combined with pain can cause substantial functional deficits. Reduced cross-sectional areas could not fully account for the weakness in the muscle groups and reduced muscle densities confirmed that adipose tissue or other non-contractile tissue may cause reduced torques as well.

While Pua et al. and Rasch et al. addressed hip muscle torques in those who suffer from OA, Frost et al. [13] conducted a cross-sectional designed study that measured and analyzed isometric strength differences between 22 THA patients after surgery and 38 healthy control group participants. The THA patients were evaluated 4 to 5 months after surgery and had completed on average 13 weeks physical therapy at the time of their data collection session. The isometric strength testing of control participants took place during one data collection session. Isometric strength values were taken for hip extension, hip flexion, and hip abduction using a Biodex system isokinetic dynamometer machine. Paired t-tests were conducted to compare the involved and uninvolved limbs in all muscle torques. The researchers found that there were no significant differences between operated and non-operated hips in the THA group. They did find that hip flexion values were significantly more deficient in bilateral hips in the THA group as compared to the control group. They also found that the hip strength of the THA group was weaker with extension and abduction as compared to the control group at 4 to 5 months but these findings were not statistically significant. The authors claim that there have been few studies that investigate isometric strength after THA surgery, although
they only evaluate three components of hip strength. They also lack any strength progression data that may have been found by having multiple data collection periods over time and before surgery. Although, their findings of weakened hip flexors in THA patients is in accordance with other literature they failed to take in to account any biomechanical gait data, therefore they cannot make any definitive correlations with muscle strength and gait patterns.

Rasch et al. [7] conducted a study to measure muscle strength of the lower limb combined with gait analysis. Twenty two participants with diagnosed OA that were scheduled for a THA were enrolled in this study and data were collected preoperatively and at 6 months and 24 months postoperatively. The researchers measured strength in all hip and knee muscle groups. All muscle torque measurements were collected by use of a padded brace connected to a strain gage. Gait data were collected by using a flat opto-sensor walkway equipped with photocells. These methods are custom designs although the equipment used is reliable and their method produced a 4.5%-7.4% reproducibility (CV%). With utilization of this method they can only analyze gait cycles because the instrumentation can only collect heel strike and toe-off data at the foot. They are not able to collect full gait analysis provided by 3D motion capture cameras. This is important because they are lacking any information from the rest of the limb and torso which plays a pivotal role in understanding and analyzing true gait and biomechanics. Preoperatively there was a 9-27% deficit in all hip and knee muscle groups excluding knee flexion. The researchers found that in the first six months after THA surgery there were persistent significant weaknesses in all muscle groups except for in the hip adductor group and knee
flexor group, reporting a 8-16% deficit. Two years postoperatively the researchers reported that a 15% hip abduction deficit was still seen but all other strength groups had returned to normal when compared to the contralateral side. Stride length was found to be significantly shorter in the involved leg compared to the uninvolved leg preoperatively but no other gait parameters showed significant differences at any other time periods. The researchers also reported that HHFS improved significantly from 52 preoperatively to 86 at the two year visit showing reduced pain and improved function.

Vaz et al. [14] investigated isometric hip abductor torque after THA and its relationship to several functional assessments. These relationships were examined the first 6 months after surgery. Forty three participants (23 male and 20 female) with diagnosed hip OA completed hip abduction torque assessments preoperatively and at 1, 6, 12, and 24 weeks postoperatively. Functional assessments were also completed including: 1.) a functional difficulty scale, 2.) total distance walked (m) during a six minute walk, 3.) the HHFS, 4.) the d’Aubigne scale, and 5.) limp according to the HHFS; at 12 and 24 weeks postoperatively. To measure hip abduction torque a Spark HHD was used. The participant was placed supine on a table and belts were strapped across the legs for stabilization. Three contractions were performed with a one minute rest in between contractions. Verbal instructions of the test were given. During contractions the participant was instructed to build up tension for 2 to 3 seconds then contract maximally for one second. The participant was instructed to report any discomfort they had during contraction and an analog pain scale was used to measure pain levels. The means of the 3 separate contractions were calculated to provide a single score for each test session for
statistical analysis. A repeated measure two-way ANOVA was used to determine significant differences for hip abduction torque over time. Five two-way ANOVA’s were conducted to analyze significant differences over time for the 5 functional assessments. A Pearson product-moment correlation coefficient was used to determine the relationship between hip abduction torque and the functional assessments. The authors found significant improvements in hip abduction torque and functional assessment at each time period after surgery. Correlation was found to be modestly high ($r = 0.48-0.51$) between hip abduction torques and distance walked in 6 minutes. The authors suggest that hip torque is related to function although isometric strength values should not be used solely to predict function.

Hayes et al. [23] conducted a study to measure reliability of a HHD and its relationship with manual muscle testing in patients with chronic knee OA. The study included 43 participants who were participating in a clinical trial for exercise and ultrasound. Knee extension was measure by manual muscle testing and HHD testing. Participants were asked to sit on a table, staying erect, and stabilize themselves by holding onto the table. The manual muscle test was performed by the subject extending their knee against gravity and the examiner would perform a break test proximal to the ankle. All manual muscle tests were graded using a traditional manual muscle testing system. Hand held dynamometer measurements were performed at 80% of the lower leg length with the knee positioned at 65° of flexion. A make test was completed two times for a duration of 4 seconds each with a 30-60 second rest in between tests. The researchers discovered that during the HHD portion of the study subjects produced lower
muscle torque measurements and during manual muscle testing the examiners received a median graded score of good. Test retest reliability between examiners showed little variability and was reported with scores of 0.89-0.98. As the mean HHD torque measurements were calculated using the manual muscle test grade, the HHD measurements increased as manual muscle testing increased. The researchers suggested that due to possible weakness of the examiner HHD scores would also be lower due to the perceived inability of the participant that the examiner cannot match their strength efforts. The researchers concluded that there is sufficient reliability in HHD measurements in patients suffering from OA, while still some variability existed in correct use of the HHD between examiners.

Similarly, Kimura et al, [21] conducted a study testing inter- and intra-tester reliability using chantillion and a microfet HHDs. Eight male and 4 female examiners tested 12 participants in several different muscle groups. Break tests were conducted at the midpoint of range of motion. Knee extensors were tested with the participant seated with their legs hanging over the end of a table. The knee was positioned at 67.5° of flexion. Each muscle test was standardized and proper restraint was used. The researcher held the HHD in between their hand and the participant’s limb and counted out loud from one to three with gradual increase of contraction so maximal contraction would occur at three seconds. A minimum of 30 seconds rest was given in between trial to prevent fatigue. The researchers concluded that both of the HHDs were reliable when testing was conducted by the same researcher. Using both HHDs interchangeably by the same researcher did not yield any reliable results.
Appendix A: Informed Consent Form

INFORMED CONSENT
To Participate in a Research Study
“CONTROL PARTICIPANT”

Department of Kinesiology and Rehabilitation Science, University of Hawaii at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

I. INVESTIGATORS
Principal Investigators: Iris F. Kimura, PhD, ATC, PT; Cass K. Nakasone, MD, MSME

Investigators: Rachele E. Vogelpohl, MS, ATC; Kaori Tamura, MS, ATC;
Ryan Molzon, BS, ATC; Sienna Handegard, ATC; Bryant Hoer, ATC;
Catherine Rose, ATC;

II. TITLES
Functional Recovery and Gait Biomechanics following Total Hip Arthroplasty: a Longitudinal Study
Risk Factors for Total Knee Arthroplasty Failure: Prospective Investigation

III. INTRODUCTION
The following information is being provided to help you decide if you would like to participate in this study. This form may have words that you do not understand. If you have questions, please ask us. The purpose of this study is to look at the biomechanical and functional gait (walking) characteristics of patients who have received either total hip or knee replacement surgeries, and compare them to “normal” gait of individuals (control participants) who do not have hip or knee replacement surgery.

IV. DESCRIPTION OF PROCEDURES
You will be asked to fill out a Medical History Questionnaire and four other questionnaires regarding your physical and mental health relative to your ability to participate in this arthritis (osteoarthritis) study as a “control” participant prior to the first day of data collection. Your responses to the above questionnaires will be screened (reviewed) by a medical doctor. If you are cleared for participation and you choose to participate in this study you will then be asked to report to the University of Hawaii at Manoa, Kinesiology and Rehabilitation Science Laboratory (Gait Lab) (Sherriff 100) for all testing sessions. When you arrive at the Gait Lab, you will be asked to perform the following four tasks: (1) walk for 6 m (20 feet) at a comfortable speed 6-10 times (Gait Analysis); (2) balance on one leg at a time, 1-3 times each (Trendelenburg); (3) stand up from a seated position in a chair, walk 3m (10 feet), then return to the chair, 1-3 times
(Up and Go Test); (4) push your leg into the researcher’s hand and/or muscle testing
device (dynamometer) for 3 sec for 8 different leg movements (Isometric Strength). The
entire procedure will take approximately 60 minutes. You will be asked to return to the
Gait Lab for seven more data collection sessions over the next three years to repeat this
procedure (please see Table 1 below).

<table>
<thead>
<tr>
<th>Control Subjects (n=50)</th>
<th>Initial Visit</th>
<th>3 Weeks</th>
<th>6 Weeks</th>
<th>3 Months</th>
<th>6 Months</th>
<th>1 Year</th>
<th>2 Years</th>
<th>3 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait Analysis</td>
<td>X</td>
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<tr>
<td>Trendelenburg</td>
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<tr>
<td>Up and Go Test</td>
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<tr>
<td>Isometric Strength</td>
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<tr>
<td>Paper/Pencil Tests</td>
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</table>

**V. RISKS**
Due to the level of physical activity involved, there is a “slight” risk of injury.
You may have pain in your affected joint during testing. You may also have some
discomfort, muscle cramping or soreness during or after test sessions. Although we have
a fall prevention system, there is a chance of falling during the walking test. There is a
very remote chance of cardiac arrest and/or death.

The investigators are National Athletic Trainers’ Association, Board Of
Certification certified athletic trainers and First Aid/CPR/AED trained. In the event of
any physical injury from the research, only immediate and essential medical treatment is
available including an AED. First Aid/CPR and a referral to a medical emergency room
will be provided. In the event of any emergency incidence outside the lab as a result of
this research, contact your medical doctor and inform the principal investigators: Iris F.
Kimura, PhD, ATC, PT at 956-3797, Rachele E. Vogelpohl, MS, ATC, or Kaori Tamura,
MS, ATC at 956-3801. You should understand that if you are injured in the course of
this research process that you alone will be responsible for the costs of treating your
injuries.

**VI. BENEFITS**
You may not receive direct/immediate benefits. However, you will obtain
information regarding your walking gait, functional activity capacity, hip muscular
strength, and behavioral characteristics. Results of this study may assist physicians,
physical therapists, and athletic trainers to ensure the optimal clinical outcomes (results)
following total hip or knee replacement surgery.

**VII. COMPENSATION**
You will receive 20 dollars for your trouble and transportation (parking etc.) to
and from the University of Hawaii Gait Laboratory each time you come to a data
collection session.

**VIII. CONFIDENTIALITY**
Your research records will be confidential to the extent permitted by law. Agencies with research oversight, such as the University of Hawaii Committee on Human Studies, have the right to review research records.

An identification number will be used to identify you during the study, which will be known only to you and study personnel. In addition, all data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Rehabilitation Science at the University of Hawaii at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. You will not be personally identified in any publication arising from this study. Personal information about your test results will not be given to anyone without your written permission.

IX. CERTIFICATION

I certify that I have read and I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent participation and to discontinue participation in the project or activity at any time without prejudice.

I herewith consent to participate in this project with the understanding that such consent does not waive any of my legal rights, nor does it release the principal investigator or institution or any employee or agent thereof from liability for negligence.

I attest that I do not believe that I am currently pregnant and that should I become pregnant during participation in this study that I will voluntarily withdraw from further participation.

If you have any questions related to this study, please contact any of the principal investigators: Iris F. Kimura, PhD, ATC, PT at 956-3797 or Rachele E. Vogelpohl, MS, ATC at 956-3801 at any time.

__________________
Participant Name (print)

__________________  ____________
Signature of Participant          Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai‘i at Manoa, 1960 East-West Rd., Biomed Bldg. Ste. B-104, Honolulu, Hawaii 96822, Phone (808) 956-5007.
INFORMED CONSENT
To Participate in a Research Study

Department of Kinesiology and Rehabilitation Science, University of Hawaii at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

IX. INVESTIGATORS
Principal Investigators: Iris F. Kimura, PhD, ATC, PT; Cass K. Nakasone, MD, MSME

Investigators: Rachele E. Vogelpohl, MS, ATC; Kaori Tamura, MS, ATC;
Jennifer Sutherland, MA, ATC; Karin Carido, ATC; Eryn Burkholder,
ATC;
Alex Rhinehart, ATC; Jeffery K. Harpstrite, MD

X. TITLE
Functional Recovery and Gait Biomechanics following Total Hip Arthroplasty: a Longitudinal Study

XI. INTRODUCTION
The following information is being provided to help you decide if you would like to participate in this study. This form may have words that you do not understand. If you have questions, please ask us. The purpose of this study is to compare the biomechanical and functional gait outcomes from the direct anterior and traditional THA surgical procedures.

XII. DESCRIPTION OF PROCEDURES
You will be asked to fill out a Medical History Questionnaire and three other questionnaires regarding your osteoarthritis and state of mind (behavior) prior to the first day of data collection. You will then be asked to report to the University of Hawaii at Manoa, Kinesiology and Rehabilitation Science Laboratory (Gait Lab) (Sherriff 100) for all testing. When you arrive at the Gait Lab, you will be asked to perform the following four tasks: (1) walk for 6 m (20 feet) at a comfortable speed 6-10 times (Gait Analysis); (2) balance on one leg at a time, 1-3 times each (Trendelenburg); (3) stand up from a seated position in a chair, walk 3m (10 feet), then return to the chair, 1-3 times (Up and Go Test); (4) push your leg into the researcher’s hand and/or muscle testing device (dynamometer) for 3 sec for 8 different leg movements (Isometric Strength). The entire procedure will take approximately 60 minutes. You will be asked to return to the Gait Lab for seven more data collection sessions over the next three years to repeat this procedure (please see Table 1 below).
### Table 1. Data Collection Session Time Line

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<td>Gait Analysis</td>
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<td>Trendelenburg</td>
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<td>Up and Go Test</td>
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<td>Isometric Strength</td>
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<tr>
<td>Paper/Pencil Tests</td>
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</table>

**Health Insurance Portability and Accountability Act (HIPAA)**

In addition, you will be asked to complete and sign the Health Insurance Portability and Accountability Act (HIPAA) Release Form if you authorize the release of your X-ray and surgically related information to the researchers. Your doctor will only take X-rays that are necessary for the THA surgical procedure. You will not be asked to take any additional X-rays as a result of this study.

### XIII. RISKS

Due to the level of physical activity involved, there is a risk of injury. You may have pain in your affected joint during testing. You may also have some discomfort, muscle cramping or soreness during or after test sessions. Although we have a fall prevention system, there is a chance of falling during the walking test. There is a very remote chance of cardiac arrest and/or death. These activities are approved by Dr Nakasone and Dr. Harpstrite and will not affect the participants’ recovery from the surgery. In addition, all participants will be cleared by Dr Nakasone or Dr. Harpstrite for each data collection session.

The investigators are NATABOC certified athletic trainers and First Aid/CPR/AED trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available including an AED. First Aid/CPR and a referral to a medical emergency room will be provided. In the event of any emergency incidence outside the lab as a result of this research, contact your medical doctor and inform the principal investigators: Iris F. Kimura, PhD, ATC, PT at 956-3797, or Rachele E. Vogelpohl, MS, ATC at 956-3801. You should understand that if you are injured in the course of this research process that you alone will be responsible for the costs of treating your injuries.

### XIV. BENEFITS

You may not receive direct/immediate benefits. However, you will obtain information regarding your walking gait, functional activity capacity, hip and knee muscular strength, and behavioral characteristics. Results of this study may assist physicians, physical therapists, and athletic trainers to ensure the optimal clinical outcomes following THA surgery.

### XV. COMPENSATION
You will receive 20 dollars for your trouble and transportation (parking etc.) to and from the University of Hawaii Gait Laboratory each time you come to a data collection session.

XVI. CONFIDENTIALITY

Your research records will be confidential to the extent permitted by law. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review research records.

An identification number will be used to identify you during the study, which will be known only to you and study personnel. In addition, all data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Rehabilitation Science at the University of Hawaii at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. You will not be personally identified in any publication arising from this study. Personal information about your test results will not be given to anyone without your written permission.
XVII. CERTIFICATION

I certify that I have read and I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent participation and to discontinue participation in the project or activity at any time without prejudice.

I herewith consent to participate in this project with the understanding that such consent does not waive any of my legal rights, nor does it release the principal investigator or institution or any employee or agent thereof from liability for negligence.

I attest that I do not believe that I am currently pregnant and that should I become pregnant during participation in this study that I will voluntarily withdraw from further participation.

If you have any questions related to this study, please contact any of the principal investigators: Iris F. Kimura, PhD, ATC, PT at 956-3797 or Rachele E. Vogelpohl, MS, ATC at 956-3801 at any time.

___________________
Participant Name (print)

___________________
Signature of Participant              ______________

Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai‘i at Manoa, 1960 East-West Rd., Biomed Bldg. Ste. B-104, Honolulu, Hawaii 96822, Phone (808) 956-5007.
RESEARCH SUBJECT INFORMATION AND CONSENT FORM

TITLE: A PROSPECTIVE COMPARISON OF THE BIOMECHANICAL AND FUNCTIONAL GAIT CHARACTERISTICS OF INDIVIDUALS UNDERGOING EITHER A DIRECT ANTERIOR OR MINI-INVASIVE POSTERIOR TOTAL HIP ARTHROPLASTY: A LONGITUDINAL, MULTI CENTERED STUDY.

PROTOCOL NO.: None
WIRB® Protocol #20100778

SPONSOR: University of Hawaii
Honolulu, Hawaii
United States

INVESTIGATOR: Cass Nakasone, M.D.
888 South King Street
Honolulu, Hawaii 96813
United States

SITE(S): Straub Clinic and Hospital Bone and Joint Center
888 South King Street
Honolulu, Hawaii 96813
United States

University of Hawaii, Manoa
PE/A Complex Room 231
1337 Lower Campus Road
Honolulu, Hawaii 96822
United States

Queens Medical Center
Suite 608
1380 Lusitana Street
Honolulu, Hawaii 96813
United States

STUDY-RELATED PHONE NUMBER(S): Cass Nakasone, M.D.
808-522-4232
This consent form may contain words that you do not understand. Please ask the study doctor or the study staff to explain any words or information that you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

**SUMMARY**

You are being asked to be in a research study. The purpose of this consent form is to help you decide if you want to be in the research study. Please read this consent form carefully. To be in a research study you must give your informed consent. “Informed consent” includes:

- Reading this consent form
- Having the study doctor or study staff explain the research study to you
- Asking questions about anything that is not clear, and
- Taking home an unsigned copy of this consent form. This gives you time to think about it and to talk to family or friends before you make your decision.

You should not join this research study until all of your questions are answered.

Things to know before deciding to take part in a research study:

- The main goal of a research study is to learn things to help patients in the future.
- The main goal of regular medical care is to help each patient.
- No one can promise that a research study will help you.
- Taking part in a research study is entirely voluntary. No one can make you take part.
- If you decide to take part, you can change your mind later on and withdraw from the research study.
- The decision to join or not join the research study will not cause you to lose any medical benefits. If you decide not to take part in this study, your doctor will continue to treat you.
- Parts of this study may involve standard medical care. Standard care is the treatment normally given for a certain condition or illness.
- After reading the consent form and having a discussion with the research staff, you should know which parts of the study are experimental and which are standard medical care.
- Your medical records may become part of the research record. If that happens, your medical records may be looked at and/or copied by the sponsor of this study and government agencies or other groups associated with the study.

After reading and discussing the information in this consent form you should know:

- Why this research study is being done;
- What will happen during the research;
- Any possible benefits to you;
• The possible risks to you;
• How problems will be treated during the study and after the study is over.

If you take part in this research study, you will be given a copy of this signed and dated consent form.

PURPOSE OF THE STUDY

The purpose of this research study is to analyze the walking biomechanical and functional characteristics following a total hip replacement to determine when patients return to normal.

PROCEDURES

If you decide to take part in this study:

You will be asked to complete 9 data collection sessions over the next three years:

1.) before surgery, 2.) 2 weeks, 3.) 4 weeks, 4.) 6 weeks, 5.) 3 months, 6.) 6 months, 7.) 1 year, 8.) 2 years, and 9.) 3 years following your total hip replacement.

<table>
<thead>
<tr>
<th>Table 1. Data Collection Session Time Line</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Hip Patients (n=100)</td>
</tr>
<tr>
<td>Gait Analysis</td>
</tr>
<tr>
<td>Trendelenburg</td>
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<tr>
<td>Up and Go Test</td>
</tr>
<tr>
<td>Isometric Strength</td>
</tr>
<tr>
<td>Paper/Pencil Tests</td>
</tr>
</tbody>
</table>

At each data collection session you will be asked to:

1. Complete 3 questionnaires about your osteoarthritis and your state of mind. These questionnaires include: the Harris Hip Function Score, the Western Ontario and McMaster Universities Osteoarthritis Index, and the Short Form Health Survey.
2. Push as hard as you can into a non-moving strength measuring device in 8 different leg motions: hip flexion, extension, abduction, adduction, internal rotation, external rotation, knee flexion, and extension. This will be done on both legs.
3. Walk 6 meters (about 20 feet) 6 to 10 times at a self selected (natural) walking speed.
4. Balance on one leg 3 times, and then repeat on the opposite leg.
5. Perform the Timed Up and Go test. This test is a timed test where you will be asked to sit in a chair, then stand, walk 3 meters (about 10 feet), turn around, and return to a seated position in the chair.

One data collection session will take approximately 60 minutes.
Information will also be collected from your medical records and stored on the secured database at Straub Clinic and Hospital. The following items will be reviewed and entered into a data collection spreadsheet:

1. History of total hip replacement surgery and other leg surgeries
2. Age, height, weight, and body mass index at the date of total hip replacement surgery
3. Pre-operative diagnosis
4. Hospital length of stay
5. Discharge disposition
6. Anesthesia physical status and analgesic medications used before and following surgery
7. Arthrotomy component characteristics
8. Tourniquet time
9. Anesthesia type
10. Hip radiographs
11. Pre-discharge blood transfusions, hematocrit and hemoglobin levels
12. Peri-operative physical therapy outcomes
13. Surgical complications
14. Date of discharge from physical therapy

**RISKS AND DISCOMFORTS**

Due to the level of physical activity involved, there is a risk of injury. You may have pain in your affected joint during testing. You may also have some discomfort, muscle cramping or soreness during or after test sessions. Although we have a fall prevention system, there is a chance of falling during the gait trials, the balancing test, and the Up and Go test. There is a very remote chance of cardiac arrest and/or death. These risks are comparable to your routine rehabilitation and activities of daily living, and will not affect your recovery from the surgery.

You cannot participate in this study if you are pregnant because the walking biomechanics collected may not accurately represent your normal walking characteristics. If you are unaware that you are pregnant, participation in this study will result in no more danger to the mother or fetus than normal activities of daily living. However, if you become pregnant or think you might be pregnant during the course of this study, you must inform the researchers, and you will be taken out of the study.

**NEW INFORMATION**

You will be told about anything new that might change your decision to be in this study. You may be asked to sign a revised consent form if this occurs.
BENEFITS
You will not receive direct/immediate benefits from participating in this study. However, you will obtain information regarding your walking gait, functional activity capacity, hip and knee muscular strength, and behavioral characteristics. Results of this study may assist physicians, physical therapists, and athletic trainers to ensure the optimal clinical outcomes following total hip replacement surgery.

PAYMENT FOR PARTICIPATION
You will receive $5 for each data collection session. This money can be applied to your parking and transportation to and from the University of Hawaii Gait Laboratory. You will be paid only for the visits you have completed.

COSTS
You will be responsible for parking and transportation to and from the University of Hawaii, Manoa, Kinesiology and Rehabilitation Science, Human Performance and Gait Laboratory (Sherriff 100). You will be given $5 per data collection session that can be applied toward the parking fee or transportation; however, the money will be given after you arrive at the facility, so it is a reimbursement. The fee for parking at the University of Hawaii, Manoa parking structure is $4 during the week and $5 on the weekends. Any other cost associated with parking/transportation over and above the $5 provided will be your responsibility.

You might have unexpected expenses from being in this study. Ask your study doctor to discuss the costs that will or will not be covered by the sponsor. This discussion should include who will pay the costs of treating possible side effects.

ALTERNATIVE TREATMENT
This is not a treatment study. Your alternative is not to participate in this study. Your follow-up care is the same whether or not you are in this study.

AUTHORIZED TO USE AND DISCLOSE INFORMATION FOR RESEARCH PURPOSES
What information may be used and given to others?
The study doctor will get your personal and medical information. For example:
- Past and present medical records
- Research records
- Records about your study visits.
- Information gathered for this research about:
  Data collection sessions
  Questionnaires
Who may use and give out information about you?
- The study doctor and research assistant that will be reviewing your medical records at Straub Clinic and Hospital.

Who might get this information?
- The research team at the University of Hawaii, Manoa, Department of Kinesiology and Rehabilitation Science
- Representatives of outside groups hired by Straub Clinic and Hospital or the Western Institutional Review Board for audits to make sure studies are done as required.

Your information may be given to:
- The University of Hawaii, Committee on Human Studies
- Hawaii Pacific Health
- Western Institutional Review Board® (WIRB®)

Why will this information be used and/or given to others?
- To do the research
- To study the results, and
- To see if the research was done right.

If the results of this study are made public, information that identifies you will not be used.

What if I decide not to give permission to use and give out my health information?
- Then you will not be able to be in this research study.

May I review or copy my information?
- Yes, but only after the research is over.

May I withdraw or revoke (cancel) my permission?
- Yes, but this permission will not stop automatically.

You may withdraw or take away your permission to use and disclose your health information at any time. You do this by sending written notice to the study doctor. If you withdraw your permission, you will not be able to stay in this study.

When you withdraw your permission, no new health information identifying you will be gathered after that date. Information that has already been gathered may still be used and given to others.

Is my health information protected after it has been given to others?
There is a risk that your information will be given to others without your permission.
COMPENSATION FOR INJURY

The study doctors are National Athletic Trainers’ Association/Board of Certification certified athletic trainers and First Aid/CPR/Automated External Defibrillator (AED) trained. In the event of any physical injury from the research, only immediate and essential medical treatment will be available including an AED. First Aid/CPR and a referral to a medical emergency room will be provided. In the event of any emergency incidence outside the gait lab as a result of this research, contact your medical doctor and inform the study doctor: Dr. Cass Nakasone at 808-522-4232. You should understand that if you are injured in the course of this research process that you alone will be billed for the costs of treating your injuries.

VOLUNTARY PARTICIPATION AND WITHDRAWAL

Your participation in this study is voluntary. You may decide not to participate or you may leave the study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled.

Your participation in this study may be stopped at any time by the study doctor or the sponsor without your consent for any of the following reasons:

- it is in your best interest;
- you do not consent to continue in the study after being told of changes in the research that may affect you;
- or for any other reason.

If you leave the study before the planned final visit, you may be asked by the study doctor to have some of the end of study procedures done.

SOURCE OF FUNDING FOR THE STUDY

This research study is sponsored by the University of Hawaii, Manoa.

QUESTIONS

Contact Dr. Cass Nakasone at 808-522-4232 for any of the following reasons:

- if you have any questions about this study or your part in it
- if you feel you have had a research-related injury or
- if you have questions, concerns or complaints about the research
If you have questions about your rights as a research subject or if you have questions, concerns or complaints about the research, you may contact:

Western Institutional Review Board® (WIRB®)
3535 Seventh Avenue, SW
Olympia, Washington 98502
Telephone: 1-800-562-4789 or 360-252-2500
E-mail: Help@wirb.com.

WIRB is a group of people who perform independent review of research.

WIRB will not be able to answer some study-specific questions, such as questions about appointment times. However, you may contact WIRB if the research staff cannot be reached or if you wish to talk to someone other than the research staff.

Do not sign this consent form unless you have had a chance to ask questions and have gotten satisfactory answers.

If you agree to be in this study, you will receive a signed and dated copy of this consent form for your records.

CONSENT

I have read this consent form. All my questions about the study and my part in it have been answered. I freely consent to be in this research study.

I authorize the use and disclosure of my health information to the parties listed in the authorization section of this consent for the purposes described above.

By signing this consent form, I have not given up any of my legal rights.

________________________________________
Subject Name (printed)

CONSENT SIGNATURE:

_____________________________  
Signature of Subject  

Date

_____________________________  
Signature of Person Conducting Informed Consent Discussion  

Date
A PROSPECTIVE COMPARISON OF THE BIOMECHANICAL AND FUNCTIONAL GAIT CHARACTERISTICS OF INDIVIDUALS UNDERGOING EITHER A DIRECT ANTERIOR OR MINI-INVASIVE POSTERIOR TOTAL HIP ARTHROPLASTY: A LONGITUDINAL, MULTI CENTERED STUDY.
INTRODUCTION
You are being asked to participate in this research study as a “control subject” because you are around the same age as the population that we are studying, you do not have arthritis (osteoarthritis) or a joint replacement, and you are able to walk normally. The following information is being provided to help you decide if you would like to participate in this study. This consent form may have words that you do not understand. If you have questions, please ask us. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision. The purpose of this study is to look at the biomechanical and functional gait (walking) characteristics of subjects who have received a total hip replacement, and compare them to “normal” gait of individuals (control subjects) who do not have a hip or knee replacement.

DESCRIPTION OF PROCEDURES
You will be asked to fill out a medical history questionnaire and four other questionnaires regarding your physical and mental health relative to your ability to participate in this arthritis (osteoarthritis) study as a “control subject” before the first day of data collection. Your responses to the above questionnaires will be screened (reviewed) by a medical doctor. If you are cleared for participation and you choose to participate in this study, you will then be asked to report to the University of Hawaii at Manoa, Kinesiology and Rehabilitation Science Laboratory (Gait Lab) (Sherriff 100) for all testing sessions. When you arrive at the Gait Lab, you will be asked to perform the following four tasks: (1) walk for 6 m (20 feet) at a comfortable speed 6-10 times (Gait Analysis); (2) balance on one leg at a time, 1-3 times each (Trendelenburg); (3) stand up from a seated position in a chair, walk 3m (10 feet), then return to the chair, 1-3 times (Up and Go Test); (4) push your leg into the researcher’s hand and/or muscle testing device (dynamometer) for 3 sec for 8 different leg movements (Isometric Strength). The entire procedure will take approximately 60 minutes. You will be asked to return to the Gait Lab for seven more data collection sessions over the next three years to repeat this procedure (please see Table 1 below).

<table>
<thead>
<tr>
<th>Table 1. Data Collection Time Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Subjects (n=50)</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Gait Analysis</td>
</tr>
<tr>
<td>Trendelenburg</td>
</tr>
<tr>
<td>Up and Go Test</td>
</tr>
<tr>
<td>Isometric Strength</td>
</tr>
<tr>
<td>Paper/Pencil Tests</td>
</tr>
</tbody>
</table>

RISKS
Due to the level of physical activity involved, there is a risk of injury. You may also have some discomfort, muscle cramping or soreness during or after test sessions. Although we have a fall prevention system, there is a chance of falling during the walking test. There is a very remote chance of cardiac arrest (heart attack) and/or death.
NEW FINDINGS
You will be told about any new information that might change your decision to be in this study. You may be asked to sign a revised consent form if this occurs.

BENEFITS
You will not receive direct/immediate benefits. However, you will obtain information regarding your walking gait, functional activity capacity, hip and knee muscular strength, and behavioral characteristics. Results of this study may assist physicians, physical therapists, and athletic trainers to ensure the optimal clinical outcomes (results) following total hip replacement surgery.

PAYMENT FOR PARTICIPATION
You will receive $5 for each data collection session. This money can be applied to your parking and transportation to and from the University of Hawaii Gait Laboratory. You will be paid only for the visits you have completed.

COSTS
You will be responsible for your parking and transportation to and from the University of Hawaii, Manoa, Kinesiology and Rehabilitation Science, Human Performance and Gait Laboratory (Sherriff 100). You will be given $5 per data collection session that can be applied toward the parking fee or transportation; however, the money will be given after you arrive at the facility, so it is a reimbursement. The fee for parking at the University of Hawaii, Manoa parking structure is $4 during the week and $5 on the weekends. Any other cost associated with parking/transportation over and above the $5 provided will be your responsibility.

ALTERNATIVES
This is not a treatment study. Your alternative is to not be in this study.

COMPENSATION FOR INJURY
The study staff are National Athletic Trainers’ Association, Board of Certification certified athletic trainers and First Aid/CPR/AED trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available including an AED. First Aid/CPR and a referral to a medical emergency room will be provided. In the event of any emergency incidence outside the lab as a result of this research, contact your medical doctor and inform the study doctor: Dr. Cass Nakasone at 808-522-4232. You should understand that if you are injured in the course of this research process that you alone will be billed for the costs of treating your injuries.

SOURCE OF FUNDING
Funding for this research study will be provided by University of Hawaii, Manoa.
VOLUNTARY PARTICIPATION/WITHDRAWAL
Your participation in this study is voluntary. You may decide not to participate or you may leave the study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled.

Your participation in this study may be stopped at any time by the study doctor or the sponsor without your consent for any of the following reasons:

- if it is in your best interest;
- you do not consent to continue in the study after being told of changes in the research that may affect you;
- or for any other reason.

CONFIDENTIALITY
Your research records will be confidential to the extent permitted by law. Agencies with research oversight, such as the University of Hawaii Committee on Human Studies and Western Institutional Review Board® (WIRB®), have the right to review research records.

An identification number will be used to identify you during the study, which will be known only to you and study personnel. In addition, all data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Rehabilitation Science at the University of Hawaii at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. You will not be personally identified in any publication arising from this study. Personal information about your test results will not be given to anyone without your written permission.

AUTHORIZATION TO USE AND DISCLOSE INFORMATION FOR RESEARCH PURPOSES

What information may be used and given to others?
The study doctor will get your personal and medical information. For example:

- Research records
- Records about phone calls made as part of this research
- Records about your study visits.
- Information gathered for this research about:
  - Gait lab data collection sessions
  - Questionnaires

Who may use and give out information about you?
The study doctor and the study staff.

Who might get this information?
The sponsor of this research. “Sponsor” means any persons or companies that are:

- working for or with the sponsor, or
- owned by the sponsor.
Your information may be given to:
- The U.S. Food and Drug Administration (FDA),
- Department of Health and Human Services (DHHS) agencies,
- Governmental agencies in other countries,
- Hawaii Pacific Health, and
- Western Institutional Review Board® (WIRB®)

Why will this information be used and/or given to others?
- to do the research,
- to study the results, and
- to make sure that the research was done right.

If the results of this study are made public, information that identifies you will not be used.

What if I decide not to give permission to use and give out my health information?
Then you will not be able to be in this research study.

May I review or copy my information?
Yes, but only after the research is over.

May I withdraw or revoke (cancel) my permission?
Yes, but this permission will not stop automatically.

You may withdraw or take away your permission to use and disclose your health information at any time. You do this by sending written notice to the study doctor. If you withdraw your permission, you will not be able to stay in this study.

When you withdraw your permission, no new health information identifying you will be gathered after that date. Information that has already been gathered may still be used and given to others.

Is my health information protected after it has been given to others?
There is a risk that your information will be given to others without your permission.

QUESTIONS

If you have any questions, concerns or complaints related to this study or if at any time you feel you have had a research-related injury, please contact: Dr. Cass Nakasone at 808-522-4232.
If you have questions about your rights as a research subject or if you have questions, concerns or complaints about the research, you may contact:

Western Institutional Review Board® (WIRB®)
3535 Seventh Avenue, SW
Olympia, Washington 98502
Telephone: 1-800-562-4789 or 360-252-2500
E-mail: Help@wirb.com

WIRB is a group of people who perform independent review of research.

WIRB will not be able to answer some study-specific questions, such as questions about appointment times. However, you may contact WIRB if the research staff cannot be reached or if you wish to talk to someone other than the research staff.

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai‘i at Manoa, 1960 East-West Rd., Biomed Bldg. Ste. B-104, Honolulu, Hawaii 96822, Phone 808-956-5007.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

If you agree to be in this study, you will receive a signed and dated copy of this consent form for your records.

CONSENT
I have read this consent form. All my questions about the study and my part in it have been answered. I freely consent to be in this research study.

I authorize the use and disclosure of my health information to the parties listed in the authorization section of this consent for the purposes described above.

By signing this consent form, I have not given up any of my legal rights.
I attest that I do not believe that I am currently pregnant and that should I become pregnant during participation in this study that I will voluntarily withdraw from further participation.

______________________________________________
Subject Name (printed)

______________________________________________
Subject Name (print)

______________________________________________    ______________
Signature of Subject                    Date

______________________________________________
Person Conducting Informed Consent Discussion Name (print)

______________________________________________    ______________
Signature of Person Conducting Informed Consent Discussion   Date
Appendix B: Questionnaires

ID#____________________ Date_________ Data Collection Period 0 1 2 3 4 5 6 7

Harris Hip Function Scale (Harris, 1969)

<table>
<thead>
<tr>
<th>Pain (44 Possible Points)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. None/ignores</td>
<td>44</td>
</tr>
<tr>
<td>b. Slight, occasional no compromise in activity</td>
<td>40</td>
</tr>
<tr>
<td>c. Mild, no effect on ordinary activity, rarely moderate pain with unusual activity, may take simple pain medication</td>
<td>30</td>
</tr>
<tr>
<td>d. Moderate pain, tolerable, accepts limitations caused by pain. Some limitation of common activities or work. Occasionally takes pain stronger than aspirin</td>
<td>20</td>
</tr>
<tr>
<td>e. Marked, serious limitations of activities</td>
<td>10</td>
</tr>
<tr>
<td>f. Totally disabled, crippled, pain in bed, bedridden</td>
<td>0</td>
</tr>
</tbody>
</table>
### Harris Hip Function Scale (Harris, 1969)

**Function (33 Possible Points)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gait (walking maximum distance)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>1. Limp</strong></td>
<td></td>
</tr>
<tr>
<td>a. None</td>
<td>11</td>
</tr>
<tr>
<td>b. Slight</td>
<td>8</td>
</tr>
<tr>
<td>c. Moderate</td>
<td>5</td>
</tr>
<tr>
<td>d. Severe/Unable to walk</td>
<td>0</td>
</tr>
<tr>
<td><strong>2. Support</strong></td>
<td></td>
</tr>
<tr>
<td>a. None</td>
<td>11</td>
</tr>
<tr>
<td>b. Cane for long walks</td>
<td>7</td>
</tr>
<tr>
<td>c. Cane most of the time</td>
<td>5</td>
</tr>
<tr>
<td>d. One crutch</td>
<td>4</td>
</tr>
<tr>
<td>e. Two canes</td>
<td>2</td>
</tr>
<tr>
<td>f. Two crutches</td>
<td>0</td>
</tr>
<tr>
<td>g. Unable to walk</td>
<td>0</td>
</tr>
<tr>
<td><strong>3. Distance Walked</strong></td>
<td></td>
</tr>
<tr>
<td>a. Unlimited</td>
<td>11</td>
</tr>
<tr>
<td>b. Six blocks</td>
<td>8</td>
</tr>
<tr>
<td>c. Two to three blocks</td>
<td>5</td>
</tr>
<tr>
<td>d. Indoors only</td>
<td>2</td>
</tr>
<tr>
<td>e. Bed and chair</td>
<td>0</td>
</tr>
</tbody>
</table>

**Functional Activities (14 Possible Points)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Stairs</strong></td>
<td></td>
</tr>
<tr>
<td>a. Normally without using a railing</td>
<td>4</td>
</tr>
<tr>
<td>b. Normally using a railing</td>
<td>2</td>
</tr>
<tr>
<td>c. In any manner</td>
<td>1</td>
</tr>
<tr>
<td>d. Unable to do stairs</td>
<td>0</td>
</tr>
<tr>
<td><strong>2. Socks and tie shoes</strong></td>
<td></td>
</tr>
<tr>
<td>a. With ease</td>
<td>4</td>
</tr>
<tr>
<td>b. With difficulty</td>
<td>2</td>
</tr>
<tr>
<td>c. Unable</td>
<td>0</td>
</tr>
<tr>
<td><strong>3. Sitting</strong></td>
<td></td>
</tr>
<tr>
<td>a. Comfortably in ordinary chair one hour</td>
<td>5</td>
</tr>
<tr>
<td>b. On a high chair for 1/2 hour</td>
<td>3</td>
</tr>
<tr>
<td>c. Unable to sit comfortably in any chair</td>
<td>0</td>
</tr>
<tr>
<td><strong>4. Enter public transport</strong></td>
<td></td>
</tr>
<tr>
<td>a. Able to use public transportation</td>
<td>1</td>
</tr>
<tr>
<td>b. Unable to use public transportation</td>
<td>0</td>
</tr>
</tbody>
</table>

ID#____________________  Date_________  Data Collection Period  0  1  2  3  4  5  6  7  8

**Absence of Deformity--4 points are given in the patient demonstrates (requires all four)**

<table>
<thead>
<tr>
<th>Deformity</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Less than 30° fixed flexion contracture</td>
<td>4</td>
</tr>
<tr>
<td>2. Less than 10° fixed adduction</td>
<td>0</td>
</tr>
<tr>
<td>3. Less than 10° fixed internal rotation in extension</td>
<td></td>
</tr>
<tr>
<td>4. Limb length discrepancy less than 3.2 cm</td>
<td></td>
</tr>
</tbody>
</table>
### Range of motion (5 Possible Points)

1. **Flexion**
   - a. 0° to >90° 3
   - b. 0°--90° 2
   - c. 0° to <90° 1
   - d. 0° 0

2. **Abduction**
   - a. >20° 2
   - b. <20° 1
   - c. 0° 0

Total Points _____________________
Appendix C: Data collection Forms

**Anthropometric Data**

Subject ID#: _______________ Date_________
Age_________________ Gender: F / M

Data Collection Period  0  1  2  3  4  5  6  7  8
Center: Control / Straub / Queens
Patient’s Operated leg: L / R Dominant Leg: L / R
Date of Surgery______________
Weeks after Surgery______________

Vicon/Nexus Measurements

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td></td>
</tr>
<tr>
<td>Height (mm)</td>
<td></td>
</tr>
<tr>
<td>Age (yrs)</td>
<td></td>
</tr>
<tr>
<td>Left leg length (mm)</td>
<td></td>
</tr>
<tr>
<td>Left knee width (mm)</td>
<td></td>
</tr>
<tr>
<td>Left ankle width (mm)</td>
<td></td>
</tr>
<tr>
<td>Right leg length (mm)</td>
<td></td>
</tr>
<tr>
<td>Right knee width (mm)</td>
<td></td>
</tr>
<tr>
<td>Right ankle width (mm)</td>
<td></td>
</tr>
</tbody>
</table>
Data Collection Form

Subject ID#: ________________

Data Collection Period  0  1  2  3  4  5  6  7  8

Patient’s Operated leg: L / R     Dominant leg: L / R

Center: Control / Straub / Queens

Total Trials: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

<table>
<thead>
<tr>
<th>Walking Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>
## Data Collection Form

Subject ID#: _______________

Data Collection Period  0  1  2  3  4  5  6  7  8

Patient’s Operated leg: L / R  
Dominant leg: L / R

Center: Control / Straub / Queens

<table>
<thead>
<tr>
<th></th>
<th>Left Leg</th>
<th></th>
<th>Right Leg</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hip flexion</td>
<td>Knee extension</td>
<td>Hip adduction</td>
<td>Knee flexion</td>
</tr>
<tr>
<td></td>
<td>/</td>
<td>/</td>
<td>/</td>
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</tr>
</tbody>
</table>

Trial 1
Score (ft-lb)
Pain Score (HHD/Jt)

Trial 2
Score (ft-lb)
Pain Score (HHD/Jt)

Trial 3
Score (ft-lb)
Pain Score (HHD/Jt)
## Appendix D: Specific testing protocols

### Position of Patient, HDD, and Stabilization for Isometric Muscular Strength Test

<table>
<thead>
<tr>
<th>Movement</th>
<th>Patient position</th>
<th>HDD position</th>
<th>Stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip extension</td>
<td>Prone with full hip and knee extension, ankle DF, with neutral rotation</td>
<td>Posterior thigh at 80% of the distance between the greater trochanter and the lateral knee joint</td>
<td>Pelvis</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>Sitting on the edge of the examination table with thighs fully supported and legs hanging over the edge in 110° hip and 90° knee flexion (arms supporting sides)</td>
<td>Anterior surface of the thigh at 80% of the distance between the greater trochanter and the lateral knee joint line</td>
<td>N/A</td>
</tr>
<tr>
<td>Hip abduction</td>
<td>Supine, with both legs positioned in neutral position. Full hip extension, full knee extension, full ankle dorsiflexion with hip and knee in neutral rotation</td>
<td>Lateral thigh at 80% of the distance between the greater trochanter and the lateral malleolus</td>
<td>Pelvis and trunk</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>Supine, with non-test leg in 20° abduction. Full hip and knee extension. The test leg in neutral position with full hip and knee extension and ankle dorsiflexion with hip and knee in neutral rotation</td>
<td>Medial thigh at 80% of the distance between the greater trochanter and the lateral malleolus</td>
<td>Non-test leg and pelvis</td>
</tr>
<tr>
<td>Hip external rotation</td>
<td>Sitting on the edge of the examination table with thighs fully supported and legs hanging over the edge in 110° hip and 90° knee flexion (arms supporting sides) with test leg in neutral hip external rotation</td>
<td>Medial surface of the shank at 80% of the distance between the medial knee joint line and the medial malleolus</td>
<td>Lateral surface of the distal femur, just proximal to the knee joint</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>Same as above with test leg in neutral hip internal rotation</td>
<td>Lateral surface of the shank at 80% distance between the lateral knee joint line and the lateral malleolus</td>
<td>Medial surface of the distal femur, just proximal to the knee joint</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>Prone with test leg in 45 of knee flexion, angle in full dorsiflexion and hip and knee in neutral rotation</td>
<td>Posterior shank at 80% of the distance between the lateral knee joint and the lateral malleolus</td>
<td>Pelvis</td>
</tr>
<tr>
<td>Knee extension</td>
<td>Sitting on the edge of the examination table with thighs fully supported and legs hanging over the edge (arms supporting sides) with test leg in 65 of knee flexion</td>
<td>Anterior shank at 80% of the distance between the lateral knee joint line and the lateral malleolus</td>
<td>Both thighs</td>
</tr>
</tbody>
</table>
Appendix E: Visual Analog Scale

Wong-Baker Faces Pain Rating Scale

Several times during the test, we will ask you to rate your pain, according to the pain rating scale. You will be asked to choose a number that describes how much pain you are experiencing. A rating of “0” corresponds to no pain and a rating of “10” corresponds to the worst pain you could possibly experience.

At the end of every set during strength testing, we will ask you to give local muscular ratings for perceived pain in your legs and joints.
Worst possible pain

Severe pain

Moderate pain

Mild to moderate pain

Mild pain

No pain
References


32. Meneghini, R.M. and S.A. Smits, *Early discharge and recovery with three*


