1999

Two Case Studies: Evaluation of Balance following Unilateral Total Knee Arthroplasty

Michelle Overbo

University of North Dakota

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TWO CASE STUDIES: EVALUATION OF BALANCE FOLLOWING UNILATERAL TOTAL KNEE ARTHROPLASTY.

by

Michelle Overbo
Bachelor of Science in Physical Therapy
University of North Dakota, 1998

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
1999
This Independent Study, submitted by Michelle Lynn Overbo in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Signature)
(Faculty Preceptor)

(Signature)
(Graduate School Advisor)

(Signature)
(Chairperson, Physical Therapy)
PERMISSION

Title TWO CASE STUDIES: EVALUATION OF BALANCE FOLLOWING UNILATERAL TOTAL KNEE ARTHROPLASTY.

Department  Physical Therapy

Degree  Master of Physical Therapy

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Date   12/11/99
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ABSTRACT

Balance is a critical part of daily activities and essential for independent function. The purpose of this study is to determine if there is a balance difference between subjects at twelve to sixteen weeks following unilateral knee arthroplasty and normal community dwelling controls. This study measures balance ability using five functional tests from the NeuroCom Balance Master® 6.1 system. Twelve subjects between the ages of 65 and 80 were tested. The two case study subjects with total knee replacements were between 12 and 16 weeks post-operatively. The control group consisted of ten healthy community dwelling adults. Results showed noticeable differences between the two groups in weight bearing and walking speed.
CHAPTER 1
INTRODUCTION

Osteoarthritis is a common degenerative process that affects many elderly (65 and older) individuals. The breakdown of cartilage results in decreased shock absorption and eventually leads to a bone on bone articulation, which can cause extreme pain and decreased mobility. Because of its strong weight bearing capacity, the knee is one of the most common sites for osteoarthritis. In elderly individuals with osteoarthritis, total joint replacements are usually the best option to relieve pain, increase mobility and improve the quality of life. Since people are living longer and have a strong desire to remain as active and independent as possible, total knee arthroplasties have become a common surgical procedure.

Approximately 120,000 TKA are performed each year with the majority of the patients being elderly. Surgical procedures have advanced in recent years and patients are now achieving higher functional outcomes post TKA. Because of technological advances and increasingly better surgical results, more older patients with less severe knee impairments are electing to undergo surgery. The results of TKA include diminished pain levels, and improved function in terms of joint motion, muscle strength, standing posture, and gait, all of which can help an individual maintain independence. TKAs have been found to have a significant impact in improving the quality of life in patients with osteoarthritis.
Research is now beginning to validate successful outcomes with total knee replacement. While most of the results show an increase in functional ability when compared to the individual's pre-surgical condition, some limitations become apparent when compared to healthy age related controls. A study by Walsh et al examined subjects who had undergone TKA and found that physical impairments and functional limitations still exist one year following surgery. Their study measured the knee muscle peak torque, self-paced walking, and stair climbing performance of subjects who had undergone TKA and compared them to normal age related controls. Results from this study showed that subjects at one year following TKA had a slower walking speed, decreased stair climbing ability, and deficits in knee extensor and flexor peak torques. Improved outcomes and gains following TKA are well documented in the literature, but not much exists comparing limitations in individuals following TKA to normal control subjects with no knee disease.

Balance is an essential component necessary for independent function. Balance impairments can lead to an increased risk for falls or injury. While many studies have been done regarding proprioception following total joint replacement, few studies have been done looking exclusively at balance. It is important to identify physical impairments such as balance deficits especially in the elderly population. Elderly individuals may already be at an increased risk for falls because of declines in sensory, proprioceptive, and musculoskeletal systems due to the aging process. Identifying additional impairments that may exist following TKA, such as balance deficits could lead to new and more effective treatment approaches with better outcomes. The NeuroCom
Balance Master® system has been used to provide more objective data in an attempt to quantify balance ability.

The purpose of this study is to use the NeuroCom Balance Master® to determine if balance differences exist between two case study subjects following TKA compared to an age related control group. Research questions that will be addressed include: 1) Is there a difference in balance between the normal control group and the case study subjects who have undergone TKA?; and 2) Is there a difference in balance ability between the two case study subjects? The null hypothesis states that there is no significant difference in balance between subjects who have had TKAs and normal controls. The alternative hypothesis is that subjects who have had TKA show decreased balance ability when compared to that of normal controls.
CHAPTER 2
LITERATURE REVIEW

BALANCE

Balance is critical for performing functional activities safely and maintaining independent function. While most people understand the broad concept of balance there are countless definitions for the word, balance. Some clinicians simply view balance as a set of autonomic reactions that prevent a patient from falling and may classify balance into general categories such as good, fair, or poor. Pam Duncan, PhD, PT, defined balance as “a complex motor control task, requiring integration of sensory information, neural processing and biomechanical factors”.

To maintain balance, the body’s center of mass must remain within the limits of stability. Stability limits have been described as the maximum displacement a person can undergo without having to alter his base of support. Various sensory input and motor output systems must coordinate and work together to function effectively and maintain stability.

Balance requires input from a variety of sensory systems including the visual, vestibular, and somatosensory systems. These systems provide input to the central nervous system about how the body is positioned and what movements or adjustments need to be made.
The visual system supplies information concerning the surrounding area and identifies the position of the head and body in relation to the environment.\textsuperscript{13} Adequate vision allows detection of movements in the external environment. Visual field deficits and decreased visual acuity can affect balance and postural stability.\textsuperscript{9} The vestibular system provides sensory information about the alignment of the head and neck in relation to gravity. Important components of this system include the semicircular canals which sense angular acceleration of the head and rapid head movements and the otoliths which sense slow head movements and give input regarding linear acceleration. Problems with the vestibular system may result in dizziness or unsteadiness.\textsuperscript{12}

Another important system related to balance is the somatosensory system. Lord and associates\textsuperscript{14} identified peripheral sensation as the most important factor in maintaining static posture. The somatosensory system is composed of proprioceptive, cutaneous, and joint receptors that provide information about body segments and their relationship to one another.\textsuperscript{13} These receptors can be found in ligaments and structures throughout the body.\textsuperscript{9} In total knee arthroplasty, the posterior cruciate ligament is removed and other structures including the joint capsule are affected. These procedures may alter components of the somatosensory system and have an effect on balance ability.

The musculoskeletal system is the main effector component of balance control. To maintain balance, adequate range of motion, strength, and flexibility are needed. The speed, strength, flexibility, and timing of involved muscles affect the quality of motor output.\textsuperscript{12} Deficits in any of these areas may lead to a reduction in balance ability.
Another important component of balance is the central processing system, which integrates all of the information. This system monitors incoming sensory input and gives output to the musculoskeletal system regarding the appropriate response to take. Reaction time is one of the tests that has been used in an attempt to quantify and measure central processing control ability.

Studies have cited poor proprioception and vibration, slow reaction time, and diminished lower extremity strength as factors associated with falling and loss of balance. To prevent falling, the body must continually adapt and make minor adjustments to maintain the center of gravity within the base of support. The ankle, hip, and stepping strategies are commonly used to maintain balance. The ankle strategy is used most frequently especially when only small adjustments are required to keep the center of mass inside the stability limits. The hip strategy comes into play when greater disturbances occur. It involves flexing and extending the hip to move the center of mass forward and backward. The stepping strategy is one of the last resorts to maintain balance. It is used when stability limits have been exceeded and a step is needed to move the support base under the center of mass.

Stelmach and Worringham identified sensory input, response selection, and response execution as the three stages that control postural stability. Sensory input is the result of visual feedback, proprioception, and vestibular sensation. Response selection is not directly observable but reaction time has been used in an attempt to measure the individual's ability to process information. The response execution stage involves movement planning, motor time and movement time.
Postural control is achieved through a complex interaction of the various stages and processes. A change at any one of these stages may have an impact on balance ability. Deficits in visual ability, proprioception, or vestibular sensation may have a negative effect on the quality of sensory input and thus impact balance ability.

Age related changes may have an effect at all of the stages. Some of the various physiological components of balance have been found to decline with normal aging. Lord et al reported that sensori-motor ability decreases significantly with age. Other studies have found that strength, endurance, and reaction time also deteriorate with age. Other studies have found that proprioception is less accurate and declines significantly with normal aging. Reduced muscle strength and speed of movement may also be the result of age related changes, such as muscle atrophy or loss of fast-twitch fibers. Duncan and associates attributed the decline of functional ability in elderly subjects to an accumulation of deficits in the sensory, effector, or central processing components. This suggests that a multitude of the systems contributing to balance are affected during the aging process. This is important because total knee replacements are most often performed in the elderly population who may already show a decline in balance ability.

Proprioception is one component that may be affected by aging but disagreement exists within the literature. In one study evaluating joint motion sensation in an aging population, Kokmen and researches concluded that there is no major decline in joint motion sensation with aging. But other studies have reported that proprioception is less accurate and declines significantly with normal aging.21-24
PROPrioception

The knee relies strongly on the somatosensory system for sensory input. This system consists of proprioceptive, cutaneous, and joint receptors that provide information about body segments and their relationship to one another.13 Deep sensory receptors such as the muscle spindle, golgi tendon organ, pacinian corpuscles and joint receptors are located in muscles, tendons and joints. The function of these receptors include posture, position sense, proprioception, muscle tone, speed, and direction of movement.9 The knee depends on proprioceptive feedback to function normally. Osteoarthritis and total knee replacement may alter proprioceptive feedback in the knee resulting in decreased balance. In TKA the joint capsule and other structures such as the posterior cruciate ligament are affected. This may interfere with the somatosensory receptors and result in decreased proprioception and balance ability.

Many studies assessing proprioceptive ability in elderly subjects, subjects with osteoarthritis, and subjects post-TKA have been done documenting various results. Some studies have concluded that joint position sense is significantly less accurate in those who are diagnosed with osteoarthritis.23,25 Other studies have been done to determine how total joint replacement affects proprioception. Barrack et al.22 reported that total knee arthroplasty did not result in proprioception decline. He also found no significant difference between the various TKA surgical procedures and suggested that “the amount of capsular destruction was not important”.22 This statement is notable because some of the structures that are affected in TKA have been determined to have proprioceptive capabilities.26 Simmons and researchers27 found no significant proprioceptive differences between TKAs involving posterior cruciate ligament (PCL)-retaining and PCL
substituting procedures. Ishii et al\textsuperscript{28} reported no significant difference between subjects with different TKA surgical procedures. He also found no difference between any of the arthroplasty groups and an age-matched control group, and concluded that “TKA has no effect on joint position sense”\textsuperscript{28}.

There isn’t always agreement in the literature though. A study by Barrett et al\textsuperscript{23} found that joint position sense in a group of subjects who had total knee replacements was slightly better than the pre-operative osteoarthritic group. Other studies have found no significant proprioceptive difference between the operated and non-operated knee in patients diagnosed with bilateral osteoarthritis.\textsuperscript{24,27} This suggests that the osteoarthritis is the cause of the proprioceptive decreases and total joint replacement doesn’t have much of an impact.

Even though research has shown decreased strength and proprioception in people with osteoarthritis, few studies have been done looking exclusively at balance.\textsuperscript{29} Wegener\textsuperscript{29} was one of the first researchers to address balance deficits in subjects with knee osteoarthritis. She found that individuals with bilateral knee osteoarthritis had significantly greater postural sway than controls.\textsuperscript{29}

Balance is not easily measureable and there is no universally accepted way to assess balance.\textsuperscript{13} Studies have used various tests in an attempt to assess or measure balance ability. One-legged stand, eyes open or closed, postural sway, functional reach, timed up and go tests, walking, and stair climbing have all been used in an attempt to quantify balance ability.\textsuperscript{29-31} The Balance Master®, which is a high tech machine consisting of forceplates that measure the center of gravity displacements, is now being
used to provide more objective data regarding balance particularly for evaluation purposes.  

Balance is an integral part of everyone's life and a requirement for independent function. More research needs to be done to determine the impact that various surgical procedures have on balance.
CHAPTER 3
METHODOLOGY

SUBJECTS

Ten healthy subjects and two subjects with unilateral total knee arthroplasties between the ages of 65 and 80 volunteered to participate in this study. Subjects who agreed to participate responded to signs posted Altru Health Institute, local stores, and the Senior Citizen’s Center. All subjects provided written informed consent in accordance with guidelines established by Altru Health Systems and the University of North Dakota's Institutional Review Board, prior to participating in this study (Appendix A).

The control group consisted of ten healthy older adults (6 males and 4 females). The mean age for the control group was 69.9 (SD ±3.63, range 65-71) years. The two case study participants were referred from a participating physician. Both subjects had a total knee replacement secondary to osteoarthritis within the last 16 weeks and reported no other lower extremity joint replacements. Subject A was a 71 year-old female who was 16 weeks post-op right TKA. Subject B was a 74 year-old female who was 15 weeks post-op left TKA. The referring physician used Osteonics’s® (Osteonics Corp, Allendale, NJ) Scorpio™ total knee system as the knee component. The surgical procedure involved complete removal of the posterior cruciate ligament.
After subjects agreed to participate, they were asked to go to Altru Health Institute where the NeuroCom Balance Master® equipment was set up. Once at the facility, subjects completed a pre-screening medical questionnaire (Appendix A) regarding previous falls, history of dizziness, joint problems, previous surgeries and possible medications that may adversely affect balance. To participate in this study, all subjects had to be able to stand independently for two minutes, ambulate independently with no assistive device, achieve at least ninety degrees of knee flexion, and report no history of falls in the last six months. Subjects also needed to have adequate visual ability to allow for viewing the commands on the computer screen.

**INSTRUMENTATION**

The NeuroCom Balance Master® (NeuorCom International, Clackamas, OR) with 6.1 version software was used in this study. This system is designed to assess balance and mobility skills in individuals with a variety of diagnoses and provide objective information regarding balance ability. The NeuroCom Balance Master® operates on a forceplate that consists of two 9 inch by 60 inch footplates. Underneath each footplate are two force transducers with the axis orientated vertically. These transducers are located along the front to back center of each footplate and measure the horizontal and vertical forces. The NeuroCom Balance Master® utilizes complex equations to calculate body sway angles and stability limits. Results can be summarized and depicted in charts and graphs. A computer monitor is positioned at eye-level at one end of the forceplates to provide written commands and relay visual feedback regarding center of gravity displacement.
The system has an internal calibration system and self-calibrates upon start up when no weight is on the forceplates. Many studies evaluating the validity and reliability of the NeuroCom Balance Master® have been done. The results of these studies show that the limits of stability, sit-to-stand, and step up and over have moderate to high reliability for the normal adult and elderly population. The weight bearing test demonstrates high reliability on the same population while the walk test showed poor to moderate reliability. Hageman et al reported that the test-retest reliability for sway measurements and movement time was high in 12 normal subjects. Clark et al concluded that the limits of stability test is a reliable test of dynamic balance ability in healthy older adults. The NeuroCom Balance Master® also has a high learning curve with some improvements resulting from increased repetition and learning how to control the cursor.

PROCEDURE

Following completion of the pre-screening questionnaire (Appendix B), height measurements were taken and a pre-test assessment (Appendix B) was done. Range of motion measurements were taken for ankle plantar flexion and dorsiflexion, knee flexion and extension, and hip flexion, extension, abduction and adduction. All measurements were taken with subjects in the position recommended by Norken and White, except for hip extension, which was measured in the side-lying position. This was done because we felt that the TKA case study subjects may find the prone position uncomfortable. Circumferential measurements were taken at the joint line, as well as the suprapatellar
and infrapatellar borders. Subjects also completed a visual analogue scale\textsuperscript{36} regarding the current level of pain in their knees. MCCormack et al\textsuperscript{36} reported retest reliability of the visual analogue scale to be .94.

Testers, who had received instruction in the NeuroCom Balance Master® system and performed reliability studies prior to this research, provided verbal instructions. Subjects were also given a brief warm up period to familiarize them with the NeuroCom Balance Master® system. This allowed the subjects to see the relationship of how to move the cursor on the screen by altering their center of gravity. To help compensate for the high learning curve, subjects were taken through the assessment twice, with only the second trial being used for scoring purposes and data analysis. A standardized script (Appendix B) was used for each subject to explain and guide the assessment procedures and prevent bias due to possible researcher cueing. For safety reasons, each subject wore a gait belt during evaluation on the NeuroCom Balance Master®, and although the participant was allowed some balance disturbances, a spotter was present to help prevent a possible fall. Individuals needed to be challenged by the tests completed to allow for an accurate picture of balance skills, so mild balance disturbances were allowed. The entire testing procedure including the pre-screening questionnaire and pre-test measurements took approximately 45 minutes to complete.

Five tests were chosen to assess balance. These tests were chosen due to their functional nature and incorporation into daily living activities. The five tests were bilateral weight bearing, limits of stability (LOS), walk test, step up and over, and sit-to-stand. The sit-to-stand and walk test address balance and motor control.\textsuperscript{37} The step up and over test and the weight bearing test are used to look at weakness and proprioception.
while the LOS measures voluntary center of gravity control. The sit-to-stand test is found in the level one assessment, while the other four tests are found in level two, which is considered to be a moderate level in the NeuroCom Balance Master® system.

Prior to each test, the subject’s feet were placed in the appropriate position on the forceplate. Foot position was carefully monitored by the tester and readjusted if deviation occurred from the pre-set position. For each assessment test, the NeuroCom Balance Master 6.1 software system calculated specific parameters (i.e. movement velocity, end sway, etc.) from the forceplate data. Each parameter was reported as the average of the three trial scores.

**Weight Bearing**

The weight bearing test measured the percentage of weight borne by each leg with the subject standing erect, with knees flexed to 30 degrees, and finally with knees flexed to 60 degrees. The subject was instructed to squat down until the desired angle was reached and then asked to hold that position until the system assessed the weight bearing percentages. Two goniometers, one fixed at 30 degrees and the other at 60 degrees, were used to assure that the subject was in the appropriate amount of knee flexion.

**Limits of Stability**

Because the ability to control the center of gravity within the base of support is essential for normal balance, the limits of stability (LOS) test was used to provide information about the subject’s balance ability and degree of control. The LOS test measures the subject’s ability to move towards eight peripheral targets, represented by visual square targets displayed on the computer monitor. The targets are positioned in a circle and the subject attempts to move toward them in eight directions; forward, right
forward, right, right back, back, left back, left, and left front. Continuous visual feedback was provided by a cursor representing the subject's center of gravity. Subjects were instructed to control the cursor by weight shifting and leaning while keeping arms relaxed by sides. The subject was instructed to begin in the center target and move towards the highlighted outer target as soon as the visual cue, a blue circle, appeared. Subjects were instructed to move towards the target as quickly and accurately as possible and hold the attained position until the blue circle disappeared. If the subject was unable to reach the outside target, he was told to move as close to the target as possible. This test measured reaction time, movement velocity (average COG movement), maximum excursion (furthest distance traveled by COG), and directional control (comparison of amount of movement in intended direction to the amount of extra movements).

**Sit-to-Stand**

The sit to stand test is a functional test that measures the mean weight transfer, rising index, and COG sway velocity. It also evaluates right and left symmetry, which is the difference in weight borne on each leg when coming to stand. The subject was positioned on a bench in a seated position with the knees bent to approximately 90 degrees and toes slightly behind the knees. The feet were positioned at equal distances from the midline of the forceplates. The subject was instructed to sit erect with good posture, stand up quickly when the "go" sign appeared, and then maintain the standing position as steadily as possible until the "hold steady" sign disappeared from the screen. This was repeated three times with the mean values for the three trials being reported.
Walk

The walk test was used to identify several gait characteristics including step length, step width, cadence velocity, and mean end sway. The subject was positioned at the end of the forceplate opposite of the monitor with both feet on the forceplates. The patient was instructed to stand in that position until the “go” sign appeared and then walk quickly to the opposite end of the forceplate and stand motionless until the “hold steady” cue disappeared from the screen. For the first trial the subject was told to begin with either foot. For subsequent trials the subject was instructed to begin with the same foot that was used for the first trial.

Step Up and Over

The final performance test was the step up and over test using an eight-inch curb. The height of the curb can be adjusted if needed. Measured parameters of this assessment include rising index, movement time, and impact index. These characteristics are measured as the individual steps up onto the curb with one foot, swings the other foot over the curb and down to the forceplates and then down with the curb foot to a level, erect standing posture. The height of the curb can be adjusted. All of the control subjects and subject A used and eight inch curb. Subject B used a four inch curb due to fear and apprehension with use of the higher curb. This test includes three trials with the right foot leading and three with the left foot leading. Subjects were instructed to wait for the “go” cue, perform the movement and remain still after the movement until the “hold steady” cue disappeared from the screen.
DATA ANALYSIS

The SPSS (SPSS Inc.; Chicago, IL) computer program was used to calculate results. Using the SPSS computer program, descriptive statistics of means and standard deviations were calculated for the control group and the case study participants. Means of the various tests for the control group were compared to the scores of the TKA case study subjects.
CHAPTER 4

RESULTS

The results of this study were calculated by taking the data collected for the control group (n=10) and calculating means and standard deviations. The data for each TKA subject was compared to the data of the control group. The two case study subjects were also compared to each other. There were no subjects, TKA or control, that needed to be excluded from this study. Subjects were tested one time, and all subjects were able to complete all of the tests.

In the following section each test will be highlighted. The data collected for the control group will be presented and will be followed by a comparison to the TKAs. For ease of reading, the case study subject with the right TKA will be identified as "A" and the case study subject with the left TKA will be identified as "B". Please refer to the tables provided in Appendix C if additional numbers are desired.

Sit to Stand Test

For this test, several variables including mean weight transfer, rising index, center of gravity sway velocity, and right/left weight symmetry were recorded by the NeuroCom Balance Master® 6.1 software. The largest difference between groups was found in the left/right weight symmetry. It was expected that equal body weight would be borne on
each leg when coming to a stand. In the control group, six subjects had more weight on the left leg with a mean difference of 5.2% (SD ±1.1), and the remaining four had more weight on the right with a mean difference of 4.7% (SD ±1.25). For subject A 13% more than expected body weight was on the left, while subject B displayed 15% more body weight on the right. A graphic representation of the results is found in Figure 1.

The rising index is the average amount of force exerted by the legs during the rising phase expressed as a percentage of body weight. Both TKA case study subjects demonstrated less rising force than the control group. Subject A had a force of 14% body
weight while subject B demonstrated 10%. The control group had a mean force of 16.2% (SD ±1.78, range 7-24). The case study subjects also displayed a greater center of gravity (COG) than the control group. Subject A and B averaged 4 and 5.5 degrees per second respectively while the control group demonstrated a COG sway velocity of 3.8 degrees per second (SD ±0.31, range 1.30-4.70).

**Weight Bearing/Squat Test**

The weight bearing test assessed the percent of body weight on each leg. There were greater differences in this test with the knees flexed to 30 degrees and flexed to 60 degrees. Table 1 contains the results of this test. Subject A showed only a four percent difference between right and left weight bearing with the knees extended. At 30 and 60 degrees of knee flexion, there was greater asymmetry as evidenced by a 16% and 12% difference respectively. Subject B showed a 14% difference between left and right weight bearing with knees extended and a 20% difference at 30 degrees of knee flexion. At 60 degrees knee flexion, there was a 14% difference between right and left weight bearing.

| Table 1: Percent of Body Weight on the Legs During the Weight Bearing/Squat Test |
|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| **Subject** | **Knees extended** | **Knees Flexed 30°** | **Knees Flexed 60°** |
|                | **Right** | **Left** | **Right** | **Left** | **Right** | **Left** |
| Subject A     | 48%       | 52%       | 42%       | 58%       | 44%       | 56%       |
| Subject B     | 57%       | 43%       | 60%       | 40%       | 43%       | 57%       |
| Control Group | 46%       | 54%       | 48%       | 52%       | 47%       | 53%       |
Walk Test

The control group data was first complied together in aggregate, but with closer examination there were large ranges with some of the parameters. For this reason the control group was divided according to gender, and the mean for step length changed. The results are reported in Table 2. Subject A and subject B showed noticeable deficits in walk speed compared to the control group. Step length, step width, and endsway were comparable between subjects and the control group.

<table>
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<th>Subject</th>
<th>Endsway (deg/sec)</th>
<th>Speed (cm/sec)</th>
<th>Step Length (cm)</th>
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</table>

Step Up and Over

The results for the control group and the case study subjects were similar for most aspects of this test. The lift up index, which is the average maximum force exerted by the step leg expressed as a percentage of body weight, for the TKA subjects was lower than the control group. Subject A showed 26% body weight on the left and 22% on the right. Subject B displayed values of 16% body weight on both the left and right. These values compare to a control group lift up index of 39.5% (SD ±3.48, range 23-62) on the left and 40.1% (SD ±2.76, range 28-57) on the right. Subject B had impact index values of 17%
on the left and 23% on the right while the control group displayed mean indexes of 40.5% (SD=4.0366, range 23-60) on the left and 40.9% (SD ±4.43, range 24-64). It should be noted that subject A and the control group used an eight inch curb, while subject B used a four inch curb. Due to this variation, an accurate comparison cannot be made with subject B's results.

Limits of Stability

Several parameters were recorded for this test and these results are reported in appendix C. The only difference reportable was in the maximum excursions for the TKA subjects. Subject A had a value of 107% to the left while the control group had a mean value of 96.8% (SD ±4.69, range 78-127). Subject B had a value of 101% to the right while the control group displayed mean excursion of 96.4% (SD ±3.32, range 85-114).

Preassessment Tests

There were no noticeable differences between the control group and the TKA subjects for the lower extremity range of motion measurements taken. The visual analogue scale showed no noticeable difference between the control group and the case study subjects. All subjects marked towards the no pain end of the scale. Since subjects were tested in normal attire, some of the clothing worn restricted the ability to take accurate knee joint circumferential measurements. For this reason, it was felt that the girth measurements taken were not accurate, but no gross abnormalities of the knee joint were noted in the control subjects. The two case study subjects were both measured and showed no major girth differences between the right and left knee joint.
CHAPTER 5
DISCUSSION

The results of this study showed noticeable differences between the TKA subjects and the normal control group especially with weight bearing symmetry and walking speed. The two case study subjects demonstrated increased asymmetry with the weight bearing test. Both TKA subjects noticeably favored their surgical side and put an increased amount of weight on their non-surgical side, thus altering their body’s center of mass and normal postural alignment.

The 5% average asymmetry for the control group on the sit-to-stand test agrees with previous studies. A study by Engart and Olson\textsuperscript{39} showed a 5\% discrepancy between right and left weight bearing for normal individuals during the sit-to-stand test. The two TKA subjects demonstrated diminished rising force during the sit-to-stand test. This could be attributed to pain, swelling, or a decrease in strength.

For the walk test, both case study subjects demonstrated a marked difference in step length and walking speed compared to the control group and normative data. This agrees with a study by Walsh et al\textsuperscript{5} that showed a decline in walking speed for individuals with a previous TKA. The average walking speed for the control group was similar to numbers published by the NeuroCom Balance Master® system,\textsuperscript{32} which reported a 60.9 cm/sec average for individuals 60-69, and a 55.8 cm/sec average for those to numbers reported in the NeuroCom Balance Master operator’s manual.\textsuperscript{32}
Balance deficits in subjects following total knee arthroplasty could possibly be the result of increased joint effusion, decreased range ages 70-79. The results regarding end sway, step length, and step width were also similar of motion, or increased amount of pain. We measured each of these variables to determine if they could be correlated to balance ability but could find no noticeable correlation. This is likely due to our limited numbers. One of the variables that our study did not measure was strength. According to Brown et al., diminished lower extremity strength is associated with decreased gait speed, balance, stair climbing ability, and rising from a seated position.

There were many limitations for this study. First of all, only subjects with unilateral total knee arthroplasty and no additional lower extremity joint replacements were allowed to participate. This excluded many possible participants and limited our numbers. Because of the small sample size (two TKA subjects), generalizations about the population from which the sample was selected can not accurately be made.

Balance ability varies from person to person. We were unaware of the subject’s balance ability prior to this study so any differences in results could be due to pre-existing balance differences between the groups. For the walk test, step up and over test, and the sit-to-stand test, the NeuroCom Balance Master ® reported the data as the average of three trials. For some subjects, specific parameters such as step length or end sway showed a large variation between the three trials. This may be because daily activities and submaximal tests have been shown to have a greater variability. Another factor that may have skewed the results was the possibility of a learning curve. Some subjects may have gotten a feel for the system faster than others. This would result in higher scores for the subjects who were able to learn more quickly.
Future studies could be done to assess balance by testing subjects with severe osteoarthritis prior to surgery and then again following TKA to determine if there is a significant change. This would take into account individual differences and lead to greater reliability.

CONCLUSION

The two TKA case study subjects showed a consistent decrease in their weight bearing percentages on the surgical side throughout the various tests. The TKA subjects also showed a marked difference in their walking speed and step width when compared to the control group and normative data.

While the TKA case study subjects definitely showed deficits in some areas, there isn’t enough evidence to convincingly show that TKA has an adverse effect on balance ability. More research needs to be done to accurately determine the impact of TKA on balance ability.
INFORMATION AND CONSENT FORM

TITLE: Evaluation of Balance Following Unilateral Total Knee Arthroplasty using the NeuroCom Balance Master®

You are being invited to participate as a normal age-related control subject in a study conducted by Michelle Overbo, Jeremy St. Aubin, and Cathy Siegfried, physical therapy students at the University of North Dakota. The purpose of this study is to examine the effects of one-sided knee arthroplasty on balance using a specialized computer analysis program and equipment developed for evaluating balance. We hope to evaluate balance skills of persons with a total knee replacement and compare them to persons with normal knees. Community dwelling subjects without previous joint replacements, balance deficits, or medical diagnosis affecting balance will be asked to participate in this study for establishing baseline balance skill levels.

You will be evaluated on the Balance Master® equipment using five (5) different tasks. You will be asked to complete two trials on the equipment. The first trial will be used to familiarize you with the tests and using the Balance Master®. The second trial will be the same tasks and results will be recorded for further analysis.

The study will take approximately an hour of your time for each trial. Testing will be done at the Physical Therapy department at Altru Rehabilitation Institute at an assigned time. You will be asked to fill out a short questionnaire concerning your past medical history and previous balance problems. We will first record age, sex, and height and assign a number for your results. A pre-assessment will be completed by the tester consisting of joint range of motion, joint swelling, and pain levels. During the trials, we will be recording balance components utilizing the Balance Master® equipment and program.

Although the process of physical performance testing always involves some degree of risk, the investigators in this study feel the risk of injury or discomfort is minimal. To assess balance, you will be asked to stand on a platform without a walker or cane for assistance. Due to the risk of losing balance, you will wear a gait belt and two spotters will be present during testing to assist in the event that loss of balance does occur.

Your name will not be used in any reports of the results of this study. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The data will be identified by a number known only by the investigators. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms that may be detrimental to his/her health. Your decision whether or not to participate will not prejudice your future relationship with the Physical Therapy Department or the University of North Dakota. If you decide to participate, you are free to discontinue participation at any time without prejudice.
The investigators involved are available to answer any questions you have concerning this study. In addition, you are encouraged to ask any questions concerning this study that you may have in the future. Questions may be asked by calling Michelle Overbo at 772-7170 or Cathy Siegfried at 777-9170. If you have any questions regarding your rights as a research subject, call the chairperson of Institutional Review Board, Altru Health Systems at 780-6161. A copy of this consent form is available to all participants in the study.

In the even that this research activity which will be conducted at Altru Health Institute results in a physical injury, medical treatment will be made available, including first aid, emergency treatment and follow up care as it is to member of the general public in similar circumstances. Payment for any such treatment must be provided by you and your third party payment, if any.

ALL OF MY QUESTIONS HAVE BEEN ANSWERED AND I AM ENCOURAGED TO ASK ANY QUESTIONS THAT I MAY HAVE CONCERNING THIS STUDY IN THE FUTURE. MY SIGNATURE INDICATES THAT, HAVING READ THE ABOVE INFORMATION, I HAVE DECIDED TO PARTICIPATE IN THE RESEARCH PROJECT.

I have read all of the above and willingly agree to participate in this study explained to me by Michelle Overbo, Jeremy St. Aubin or Cathy Siegfried.

________________________________________
Participant's Signature                Date

________________________________________
Witness (not the scientist)                Date
Human Subjects Review Form
For new projects or procedural revisions to approved projects involving human subjects.

Cathy Siegfried
Principal Investigator: Michelle Overbo, Jeremy St. Aubin Phone #: (701)777-2831 Date: 5/18/98
Institution: University of North Dakota Department: Physical Therapy
Research Coordinator: Schawnn Decker Phone #: (701)777-6389
Project Title: Evaluation of Balance Following Unilateral Total Knee Arthroplasty

Funding Agencies (if applicable): none

Type of Project: □ New Project □ Continuation □ Renewal □ Student Research Project □ Dissertation or Thesis Research □ Completed Project □ Reports (Adverse events, deaths, complications) □ Amendments or change in project

Dissertation/Thesis Adviser, or Student Advisor: Schawnn Decker

Proposed Project: □ Involves New Drugs (IND) □ Involves Non-Approved Use of Drug □ Involves a Cooperating Institution □ None of the Above

If any of your subjects fall in any of the following classifications, please indicate the classification:
□ Minors (< 18 Years) □ Pregnant Women □ Mentally Disabled □ Fetuses □ Mentally Retarded □ Prisoners □ Students □ Abertuses □ Control Group

If your project involves any human tissue, body fluids, pathological specimens, donated organs, fetal material, or placental materials, check here ______.

X Expedited Review requested under item 3 (number) of HHS Regulations (see attached explanation)
_____ Exempt Review requested under item ______ (number) of HHS Regulations (see attached explanation)

1. ABSTRACT (Limit to 200 words or less and include justification or necessity for using human subjects. Attach additional sheet if necessary.)

Total knee arthroplasty is a common procedure often used to relieve pain in the knee joint. The individual's painful knee leads to a decrease in functional abilities. Few studies have been done documenting balance skills following TKA. Balance is a necessary component of daily life for ambulation, mobility and personal care tasks. Without proper balance and proprioception, the risks of falls and resulting injury will increase. The purpose of this study is to examine balance skills of elderly subjects following TKA using the NeuroCom Balance Master® 6.1 system. This equipment is a computer system that is commonly used in physical therapy clinics to assess balance and for balance training programs. Individuals who are 12-16 weeks post operative from the arthroplasty will be utilized in this study to gain knowledge of their current balance status. Normal, healthy age-related individuals will also be tested for the establishment of normals. A comparison of the balance skills between the control group and the TKA group will increase the knowledge of static and dynamic aspects of balance and identify any deficits in balance that may exist following unilateral TKA.
PLEASE NOTE:

Only information pertinent to your request to utilize human subjects in your project or activity should be included on this form. Where appropriate attach sections from your proposal including data collection instruments where applicable.

2. PROTOCOL: (Describe procedures to which humans will be subjected.)

SUBJECTS

Thirty subjects who have undergone unilateral TKA and are between the ages of 65 and 80 will be tested for this study. Subjects will be selected by referral from the participating physician (currently Dr. Brian Briggs). To be included in this study, subjects must be able to stand independently for two minutes and be able to achieve 90 degrees of knee flexion bilaterally. Subjects will be given a questionnaire regarding their prior fall and medical history for the purposes of attaining suitable subjects without balance deficits secondary to other causes. Please see the attached questionnaire. Each subject will be required to sign a consent form and complete a questionnaire prior to participating in this study. A control group (n=30) consisting of community dwelling, age-related normal subjects will be utilized for the comparison of scores on the assessments. The first ten subjects will be retested within three days to establish reliability for the testers.

METHODS

We will use the NeuroCom Balance Master™ 6.1 system to assess balance skills of TKA subjects. The equipment is a computer system that is designed to provide objective measurements of balance. This process is achieved through the use of two force plates that interpret balance skills by challenging an individual’s ability to maintain their center of gravity within normal limits.

TKA subjects will be tested between twelve and sixteen weeks post-op. The referring physician and his staff will pre-screen potential participants for history of balance related medical disorders, medications, and other lower extremity joint replacements. A pre-assessment will be completed for each subject including joint range of motion measurements, current pain levels, and joint effusion measurements. Before any scores are recorded, subjects will be given a brief warm-up period to familiarize them to the machine and will be taken through each assessment test to acquaint them with the procedure and account for the high learning curve associated with the Balance Master. The testing session will consist of a series of five tests including bilateral weight bearing, limits of stability, walk test, sit to stand, and step up and over. The control group will also be taken through the same assessment procedure.

Subjects will allowed a break as needed between the familiarization session and the scoring session. There will also be a break between tests to allow for positioning of subject’s feet. During the assessments, two spotters will be present on either side of the subject and a gait belt will be placed around the subject’s waist. The tester will operate the computer and position the subject’s feet properly on the force plates.

Traditional descriptive and analytical statistics characterizing the TKA subjects’ balance skills in comparison with the age-related normal group’s balance skills. Results will be reported in aggregate.
3. BENEFITS: (Describe the benefits to the individual or society.)

The individuals participating in this study will benefit by knowing the degree their balance was affected by TKA. If any significant balance deficits are determined for subject this information will be forwarded to the referring physician for possible implementation of a balance training program. There will also be knowledge gained of how balance after TKA compares to the age-related control group and to other studies concerning functional outcomes of TKA. Data concerning balance assessment will also be useful to physicians, physical therapists, and other healthcare professionals in providing an objective and repeatable measure of balance following TKA. Increasing knowledge of balance can lead to improvements in rehabilitation, functional outcomes, and decrease the risk of falls.

4. RISKS: (Describe the risks to the subject and precautions that will be taken to minimize them. The concept of risk goes beyond physical risk and includes risks to the subject's dignity and self respect, as well as psychological, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, including plans for final disposition or destruction, debriefing procedures, etc.)

During this study there is only minimal risk to the individual. The assessments the subjects will be performing are part of every day activities and will provide challenges to the subjects' dynamic balance control. Subjects will be allowed to experience some instability, but safety and prevention of falls will be a primary concern. To minimize the risk of falls during testing, subjects will wear a gait belt and two assistants will be standing close enough to the force plates to guard the subject from falling if loss of balance does occur.

All subjects in this study will be voluntary participants who will be chosen based on referral from the participating physician and willingness to participate in the study indicated by signing the consent form. Subjects will be allowed to halt testing or withdraw from the study at any time. Data will be assigned a number corresponding to the subject so no subject can be identified and anonymity will be preserved. All data will be stored on 3.5" diskettes and kept by Schawn Decker to ensure confidentiality and the data remains untampered.
5. **CONSENT FORM:** A copy of the CONSENT FORM to be signed by the subject (if applicable) and/or any statement to be read to the subject should be attached to this form. If no CONSENT FORM is to be used, document the procedures to be used to assure that infringement upon the subject's rights will not occur.

Describe who will be obtaining consent, where signed consent forms will be kept, and for what period of time.

The consent forms will be kept by Schawn Decker at the University of North Dakota, Department of Physical Therapy, room 2542, Medical Science North building for a period of two years. A copy of the consent form is attached.

6. For FULL IRB REVIEW, forward the signed original of this completed form and, copies as outlined in the attached instructions to:

For EXEMPT or EXPEDITED REVIEW forward a signed original and a copy of the consent form, questionnaires, etc., and any supporting documentation to:

Eleanor Tveit, IRB Secretary
1000 South Columbia Road
Grand Forks, ND 58201
701-780-6161

The policies and procedures on Use of Human Subjects In Medical Park Institutions apply to all activities involving use of Human Subjects performed by personnel conducting such activities. No activities are to be initiated without prior review and approval of the Medical Park Institutional Review Board.

Signatures:

Principal Investigator: [Signature]
Date: 5/27/98

Project Director: [Signature]
Date: 5/27/98

Student Advisor (where applicable): [Signature]
Date: 5/27/98
Research Project Action Report

Date: June 4, 1998
IRB#: PT-007

Principal Investigator: Cathy Siegfried, Michelle Overbo
Department: Physical Therapy
Phone #: 777-2831

Research Coordinator: Schawn Decker
Phone #: 777-6389

Project Title: Evaluation of Balance Following Unilateral Total Knee Arthroplasty

The above referenced project protocol and informed consent was reviewed by the Medical Park Institutional Review Board on and the following action was taken:

☐ Project approved. Next Scheduled review is on ____________________
If no date is given, then review will be required in 12 months. (See REMARKS SECTION for any special condition.)

☐ Project approved. EXPEDITED REVIEW NO. 3
Next scheduled review is on ____________________

☐ Project approved. EXEMPT CATEGORY NO.
No periodic review scheduled unless so stated in REMARKS SECTION.

☐ Project approval deferred. (See REMARKS SECTION for further information.)

☐ Project denied. (See REMARKS SECTION for further information.)

☐ Amendment approved

REMARKS:

Any changes in protocol, adverse occurrences or deaths in the course of the research project must be reported immediately to the IRB chairperson or the IRB office (780-8161).

[Signature and Date]
Signature of Chairperson or Designated IRB Member
Medical Park Institutional Review Board

If the proposed project is to be part of a research activity funded by a federal agency, a special assurance statement or a completed 596 Form may be required. Contact IRB office to obtain the required documents.
APPENDIX B
# PRE-ASSESSMENT

ID#: __________
Sex: __________
Age: __________
Height: __________
Involved side: __________

<table>
<thead>
<tr>
<th>ROM</th>
<th>right</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flex (supine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip ext (sidelying)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip abd (supine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip add (supine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee flex (supine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee ext (supine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantarflexion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Knee circumferential measurements**

<table>
<thead>
<tr>
<th></th>
<th>right</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>suprapatellar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jt line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>infrapatellar</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Pain Scale Rating**

PAIN AS BAD
AS IT COULD BE
SCREENING QUESTIONNAIRE

Please answer these questions to the best of your knowledge.

1. Have you had two or more unexplained falls in the past six months?  
   Yes No

2. Have you had any symptoms of unexplained dizziness or lightheadedness in the past six (6) months?  
   Yes No

3. Have you experienced any blackouts in the past six (6) months?  
   Yes No

4. Are you currently taking any medications that make you feel dizzy or lightheaded or that you know can cause dizziness and lightheadedness?  
   Yes No

5. Do you have any hip/knee/ankle diseases?  
   Yes No
   If yes, please explain:

6. Have you had any hip/knee/ankle surgeries?  
   Yes No
   If yes, please explain:

7. Have you had any lower extremity joint (knee or hip) replacements?  
   Yes No
   If yes, Which joint/joints?

8. Are you currently using any crutches, canes or walker for assistance in walking in home or out of home?  
   Yes No

9. Please list any disease processes or medical problems:
**SCRIPT**

Remember to introduce self to subject and to refer them as Mr. or Ms. as appropriate.

**Bilateral Weight Bearing**
(position subject on forceplates with feet positioned parallel and align each medial malleolus with wide blue line, and the center of each heel with the M line)

The first test we are going to complete is bilateral standing which will have you stand on the forceplates. This will measure the percentage of body weight on each leg. There will be three trials.

I am going to position your feet on the forceplates.

**Erect**
Please look forward and stand erect with your knees straight. I am starting scoring now.
Relax.
**For 30 degree squat:**
(check foot position)
Now bend both your knees and squat down until I say to hold. *(measure 30 degree angle with goniometer)* Hold position and look forward. Starting scoring now. *(push mouse button)* Relax.
**For 60 degree squat:**
(check foot position)
Bend both knees and squat slightly until I say to hold. *(measure 60 degree angle with goniometer)* Hold position and look forward. Starting scoring now. *(push mouse button)* Relax.

**Limits of Stability**
The next test is limits of stability. This test will measure your ability to voluntarily sway to different positions and hold them. To do this test you need to shift your weight to move the cursor representing you on the screen. Keep your cursor in the center target. When the blue circle appears in the yellow outer target move your cursor as quickly and accurately as you can to the yellow target with the blue circle in it and hold steady there. There will be eight trials, one for each target. Before we start, I need to position your feet. *(position feet)* We are starting trial one now. *(push mouse button)*

After each trial:
I need to recheck the position of your feet. *(check foot position)* Starting the next trial now.

**Walk**
The third test is the walk test. You will be asked to walk the length of the forceplates. There will be three trials of this test. To complete this test, you need to stand on the far
end of the forceplates. *(show subject where to stand)* When the test starts you will see the “HOLD STEADY” sign on the screen. Stand upright and as steadily as possible. When the “GO” sign appears on the screen, walk quickly to the end of the forceplates. Then remain still while the “HOLD STEADY” sign stays on the screen. I am starting the assessment now. *(note which foot the subject leads with)*

After each trial:
Please return to the starting position at the end of the forceplates and the same process will be repeated. Follow the cues on the computer monitor. Please start the test with the same foot, your ______ foot. Starting the test now.

**Step up and over**
The step up and over test will have you step up onto this curb *(point out the curb)* with one foot, swing the other foot over the curb and down onto the floor and then step down with the curb foot. *(demonstrate move to them)* There will be six trials—three with the right foot leading and three with the left foot leading. When the test starts you’ll see the “HOLD STEADY” sign on the screen. Stand upright as steadily as possible. When you see the “GO” sign, quickly step up onto the curb with your ______ foot, swing over the curb and step down with your ______ foot, and then step down with your ______ foot. Stand as steadily as possible until the test is done. Starting scoring now.

After 1st, 2nd, & 4th trials:
Please return to the starting position and begin with your ______ foot. Follow the cues on the screen. Starting scoring now.

After 3rd trial:
Now you will lead with your ______ foot. The same move will be used for stepping over the curb. Step up onto the curb with your ______ foot, swing over the curb and step down with your ______ foot, and then step down with your ______ foot. Follow the cues on the screen. Starting scoring now.

**Sit to Stand**
The last test is the sit to stand test. There will be three trials. You will be seated on the bench on the forceplates. When the test starts you will see the “HOLD STEADY” sign on the screen. Sit as erect as possible. When you see the “GO” sign, stand up quickly and stand as steadily as possible until the scoring is done. *(seat subject on the bench with each foot equidistant from the center line, hips and buttocks forward away from the back of the chair, and knees bent so feet are slightly behind knees)* We will start the test now.

After each trial:
Please sit down again and we will repeat the test. *(reposition according to guidelines above)* Starting the test now.
APPENDIX C
### Table 1: Results of Sit to Stand

<table>
<thead>
<tr>
<th></th>
<th>Weight Transfer (seconds)</th>
<th>Rising Index (% body weight)</th>
<th>COG Sway Velocity (degrees/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject A</td>
<td>0.51</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Subject B</td>
<td>0.4</td>
<td>10</td>
<td>5.5</td>
</tr>
<tr>
<td>Control Group*(n=10)</td>
<td>0.49 ± .092</td>
<td>16.2 ± 1.78</td>
<td>3.8 ± .31</td>
</tr>
</tbody>
</table>

* reported as means ± SD

### Table 2: Results of Step Up and Over Test

<table>
<thead>
<tr>
<th></th>
<th>Lift Up Index (% body weight)</th>
<th>Movement Time (seconds)</th>
<th>Impact Index (% body weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Subject A</td>
<td>22</td>
<td>26</td>
<td>1.81</td>
</tr>
<tr>
<td>Subject B*</td>
<td>16</td>
<td>16</td>
<td>2.13</td>
</tr>
<tr>
<td>Control Group(n=10)</td>
<td></td>
<td></td>
<td>40.1</td>
</tr>
<tr>
<td>Mean</td>
<td>±2.76</td>
<td>±3.48</td>
<td>±0.087</td>
</tr>
</tbody>
</table>

* Subject used a four inch curb height

### Table 3: Circumferential Measurements for TKA Case Study Subjects

<table>
<thead>
<tr>
<th></th>
<th>Subject A</th>
<th></th>
<th>Subject B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Suprapatellar (cm)</td>
<td>45.3</td>
<td>44.1</td>
<td>64.0</td>
<td>64.5</td>
</tr>
<tr>
<td>Knee Joint Line (cm)</td>
<td>43.5</td>
<td>42.0</td>
<td>60.0</td>
<td>61.0</td>
</tr>
<tr>
<td>Infrapatellar (cm)</td>
<td>39.9</td>
<td>38.0</td>
<td>55.0</td>
<td>57.0</td>
</tr>
</tbody>
</table>
Table 3: Results of Limits of Stability: control group reported as means and standard deviations

<table>
<thead>
<tr>
<th></th>
<th>Control Group (n=10)</th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction Times (secs)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>0.82 (±0.074)</td>
<td>0.99</td>
<td>1.36</td>
</tr>
<tr>
<td>Right</td>
<td>1.03 (±0.13)</td>
<td>1.04</td>
<td>1.10</td>
</tr>
<tr>
<td>Back</td>
<td>0.61 (±0.063)</td>
<td>0.85</td>
<td>0.69</td>
</tr>
<tr>
<td>Left</td>
<td>0.91 (±0.094)</td>
<td>1.79</td>
<td>1.13</td>
</tr>
<tr>
<td>Comprehensive</td>
<td>0.85 (±0.062)</td>
<td>1.17</td>
<td>1.07</td>
</tr>
<tr>
<td><strong>Movement Velocity (degs/sec)</strong></td>
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<tr>
<td>Front</td>
<td>4.26 (±0.73)</td>
<td>2.10</td>
<td>1.50</td>
</tr>
<tr>
<td>Right</td>
<td>4.17 (±0.056)</td>
<td>2.30</td>
<td>2.50</td>
</tr>
<tr>
<td>Back</td>
<td>2.38 (±0.33)</td>
<td>2.00</td>
<td>1.30</td>
</tr>
<tr>
<td>Left</td>
<td>4.00 (±0.82)</td>
<td>3.30</td>
<td>1.70</td>
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<tr>
<td>Comprehensive</td>
<td>3.65 (±0.52)</td>
<td>2.40</td>
<td>1.80</td>
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<tr>
<td><strong>Endpoint Excursion (%)</strong></td>
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<tr>
<td>Front</td>
<td>77.40 (±3.85)</td>
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<tr>
<td>Right</td>
<td>77.33 (±3.68)</td>
<td>54</td>
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<tr>
<td>Back</td>
<td>52.00 (±4.15)</td>
<td>38</td>
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<tr>
<td>Left</td>
<td>80.30 (±4.42)</td>
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<tr>
<td>Comprehensive</td>
<td>72.50 (±1.94)</td>
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<td><strong>Maximum Excursion (%)</strong></td>
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<td>99.50 (±3.85)</td>
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<tr>
<td>Right</td>
<td>96.44 (±3.32)</td>
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<td>81.33 (±9.81)</td>
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<td>96.80 (±4.69)</td>
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<tr>
<td>Comprehensive</td>
<td>93.60 (±2.73)</td>
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<tr>
<td>Comprehensive</td>
<td>76.10 (±2.33)</td>
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REFERENCES


