EFFECT OF POST-REHABILITATION EXERCISE ON STRENGTH AND POSTURAL STABILITY FOLLOWING TOTAL HIP ARTHROPLASTY

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN THE GRADUATE SCHOOL OF THE

TEXAS WOMAN'S UNIVERSITY

SCHOOL OF PHYSICAL THERAPY

BY

ELAINE TRUDELLE-JACKSON, M.S.

DENTON, TEXAS

DECEMBER 2001

To my husband Allen, and my children Tim and Jessica

ACKNOWLEDGEMENTS

This study was funded in part by a grant from the Texas Physical Therapy Education and Research Foundation.

Effect of Post-Rehabilitation Exercise on Strength
and Postural Stability Following
Total Hip Arthroplasty

Elaine Trudelle-Jackson, M.S.

December 2001

ASTRACT

Patients with total hip arthroplasty (THA) are treated by physical therapists during the acute phase of their recovery, and their treatment consists mainly of self-care instructions and a standard exercise protocol that emphasizes mobility. The literature suggests that strength and postural stability impairments are present in patients who have undergone THA 1 to 2 years previously. However, little is written about the outcomes of physical therapy programs instituted later in the recovery from THA. The purpose of this study was to investigate the effects of a post-rehabilitation exercise program for patients who had undergone THA. Twenty-eight subjects with a mean age of 59.5 years (SD =11.2) who had THA 4 - 12 months previously were randomly assigned to one of two exercise groups. The control group (n=14) received basic isometric and active ROM exercises while the experimental group (n=14) received strength and postural stability training exercises. Assessments of self-perceived function, fear of falling, muscle strength, and postural stability were performed before and after the 8-week home exercise intervention. The Wilcoxon Signed Ranks, used to test for significance of pre- and post-exercise differences on the hip questionnaire scores, revealed statistically significant differences for the experimental group but not the control group. A McNemar change test revealed that differences in responses to questions about fear of falling pre- and post-exercise were not significant for either group. A 2X2 repeated measures multivariate analysis of variance (MANOVA) used to test pre- and post-exercise differences between and within groups on the strength and postural stability variables revealed a statistically significant group by pre-post test interaction. The multivariate related samples t-test used to test for simple main effects of pre-post differences revealed that differences were significant only for the experimental group. Univariate paired samples t-tests used to test differences between pre- and post-exercise measurements for each muscle strength and postural stability variable in the experimental group, demonstrated significant differences for all variables. The results of this study demonstrated that a physical therapy home exercise program that emphasizes weight bearing and postural stability can improve self-perceived function, muscle strength, and postural stability in patients who are 4 to 12 months post-THA.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Total hip arthroplasty (THA) is one of the most widely performed procedures in orthopedic practice in the United States. An estimated 170,000 total hip arthroplasties are performed annually (Siopack & Jergesen, 1995). THA is most often performed to relieve pain and restore function in patients who have extensive damage to the hip joint as a result of osteoarthritis, rheumatoid arthritis, avascular necrosis, traumatic arthritis, certain hip fractures, or benign and malignant bone tumors (National Institutes of Health Consensus Development Panel on Total Hip Replacement [NIH], 1994). Osteoarthritis alone accounts for 70% of elected THA cases (Siopack & Jergesen).

The most common pre-operative complaints by patients who elect to have THA are pain and loss of mobility. Therefore, the most commonly reported outcomes of THA relate to pain relief and restoration of mobility. Outcome studies of pain reduction and range of motion, usually conducted 3 to 6 months following THA, indicate an overall satisfaction by patients and physicians (Barber, Roger, Goodman, & Schurman, 1996; Gogia, Christensen, & Schmidt, 1994).

Studies of muscle strength and functional outcome following THA are more limited and the results more varied. Shih, Du, Lin, and Wu (1994) measured muscle strength one year post THA surgery in a group of 20 men with a preoperative diagnosis of unilateral osteonecrosis and a group of 20 women with a preoperative diagnosis of unilateral osteoarthritis. The investigators found that strength of the muscles surrounding the operated hip joint was 84-89% of the strength on the uninvolved side in the men, and 79-81% of the strength on the uninvolved hip in the women. Long, Dorr, Healy, and Perry (1993) also reported significant residual muscle weakness in the operated hip 2 years following surgery. Although Long et al. classified the deficits they found as "subclinical," they acknowledged that this persistent weakness could contribute to the higher rates of component loosening that have been reported in active patients. Long et al. found in their study of 18 subjects recovering from THA, that deterioration of the Harris hip score and weakness of muscles during stance were the most consistent findings in subjects who developed loosening of the hip components. The authors acknowledged, however, that whether poor muscle function is a result or cause of component loosening is not clear.

Studies of functional outcomes following THA are even more varied and difficult to interpret because of the wide variety of assessments used to report function. In one study, gait speed and cadence were used to assess functional recovery (Sashika, Matsuba, & Watanabe, 1996). This study revealed that gait speed and cadence improved in patients with THA following a 6-week home physical therapy exercise program.

Gogia et al. (1994) developed their own evaluation system to assess pain and function in patients who underwent THA as a result of osteoarthritis. The results of their study showed excellent overall function 6 months post surgery in patients who had received physical therapy at the hospital and a home exercise program upon discharge.

The evaluation system used to assess function, however, was based mainly on the level of pain or discomfort when performing various activities. In a similar study investigating function 6 months post surgery, Wilcock (1978) found that 80% of patients were pain free and that 90% of his patients could walk long distances, but only 12% could do so without any external support. Furthermore, only 12% were completely independent in activities of daily living such as going outdoors or walking on stairs.

Although postural stability has not typically been addressed as an outcome following THA, Jackson, Emerson, and Smith (2001) studied outcomes of THA in subjects who were 1-year post surgery. These investigators found that postural stability in single stance on the surgical side was significantly lower than on the nonsurgical side. Jackson et al. also found residual strength deficits consistent with those found in other studies of patients who were 1-2 years post THA. The strength deficits found were not statistically significant in the sample of 15 subjects studied by Jackson et al. but these strength deficits could be clinically significant when combined with the postural stability deficits found in the same study.

Duncan, Chandler, Studenski, Hughes, and Prescott (1993) demonstrated that physical function is influenced more by an accumulation of moderate impairments than by a single deficit. Lower extremity strength and postural stability impairments, for example, have been shown to be factors that distinguish fallers from non-fallers in elderly adults (Gehlsen & Whaley, 1990; Overstall, Exton-Smith, Imms, & Johnson, 1977; Whipple, Wolfson, & Amerman, 1987).

Numerous investigators have demonstrated significant differences in postural stability between groups of fallers and non-fallers (Fernie, Gryfe, Holliday, & Llewellyn, 1982; Maki, Holliday, & Topper, 1994; Overstall et al., 1977). Maki et al. demonstrated that the ability to control balance in a lateral direction is the single best predictor of future falls. Although the number of falls following THA has not been studied, Jackson et al. (2001) found that 7 of 15 subjects, 1-year post THA, reported that they had a fear of falling. Fear of falling has been shown to be highly correlated to function and often leads to loss of independence in ADL and an overall reduction in activity level (Tinetti, Mendes de Leon, Doucette, & Baker, 1994).

Exercise programs that emphasize postural control have been shown to improve both strength and postural stability in elderly subjects (Lord, Caplan, & Ward, 1993; Judge, Lindsey, Underwood, & Winsemius, 1993). A group of older women in the study by Lord et al. showed improved stability following an exercise program that consisted of gentle aerobic exercises emphasizing balance and mobility. In another study of elderly women, an exercise program consisting of resistance training, brisk walking, and postural control exercises significantly improved static balance (Judge et al.). The common elements in the exercise programs used in the two studies above, and in other exercise programs that have been shown to be effective in improving postural stability, is that the exercises are (a) performed in a weight bearing position and (b) the focus of the program is on maintaining stability in standing.

Currently, most patients receive physical therapy at the hospital immediately following surgery for THA and many also receive home health physical therapy for 1-3 weeks after hospital discharge. Because patients are still recovering from surgery during this time, their activities are limited. The physical therapy usually consists of self-care instructions, gait training, and isometric and active range of motion exercises (Enloe, Shields, Smith, Leo, & Miller, 1996). Enloe et al. used the Delphi technique to determine a consensus that physical therapy consisting of active hip range of motion and hip and knee isometrics constitutes the standard of acute care following THA. Standard physical therapy programs used during the acute phase of recovery from THA have been shown to be effective for reducing pain and improving function (Gogia et al., 1994), but impairments in muscle strength and postural stability remain at least 1-2 years after surgery (Jackson et al., 2001; Long et al., 1993; Shih et al. 1994).

In the current study, an 8-week long post-rehabilitation exercise program was instituted a minimum of 4 months post-surgery when patients were able to bear weight on the affected hip without pain. The experimental post-rehabilitation program consisted of weight-bearing exercises that emphasized postural stability on the side of the surgically replaced hip. Improved outcomes in patients with THA as a result of the additional focus on weight-bearing and postural stability has not previously been demonstrated. Randomized clinical trials are needed to demonstrate effectiveness of the proposed post-rehabilitation program if the program is to be accepted by orthopaedic physicians who refer patients for physical therapy following THA, as well as by the physical therapists who treat these patients.

Statement of the Problem

Residual strength deficits that persist 1 to 2 years following THA, coupled with postural stability deficits that have been demonstrated in patients 1 year post-surgery, could increase the patients' risk for falling and for loosening of the prosthesis. An exercise program implemented a minimum of 4 months post-surgery might reduce the deficits in strength and postural stability. However, the effectiveness of such an exercise program must first be demonstrated.

Purpose of the Study

The purpose of this study was to investigate the efficacy of a post-rehabilitation program initiated 4 to 12 months following THA. Efficacy of the proposed program was assessed by comparing muscle strength of the hip, postural stability, fear of falling, and self-perceived function in a group of subjects who received the experimental exercise program to a control group of subjects who received basic isometric and active range of motion exercises.

Research Questions

The current study attempted to answer the following research questions:

1. Would an experimental post-rehabilitative exercise program be effective for improving hip muscle strength, postural stability, self-perceived function, and fear of falling in patients with THA?

2. Would a control post-rehabilitative exercise program be effective for improving hip muscle strength, postural stability, self-perceived function, and fear of falling in patients with THA?

Research Hypotheses

The research hypotheses for this study were as follows:

1. An experimental group post-rehabilitative exercise program would significantly improve muscle strength and postural stability in patients with THA.

2. An experimental group post-rehabilitation exercise program would significantly improve self-perceived function in patients with THA.

3. An experimental group post-rehabilitation exercise program would significantly decrease fear of falling in patients with THA.

4. A control group post-rehabilitative exercise program would significantly improve muscle strength and postural stability in patients with THA.

5. A control group post-rehabilitative exercise program would significantly improve self-perceived function in patients with THA.

6. A control group post-rehabilitative exercise program would significantly reduce fear of falling in patients with THA.

Null Hypotheses

The null hypotheses for this study were as follows:

1. There would be no significant difference in muscle strength and postural stability before and after an experimental group post-rehabilitative exercise program in patients with THA.

2. There would be no significant difference in scores of self-perceived function before and after an experimental group post-rehabilitative exercise program in patients with THA.

3. There would be no significant difference in fear of falling before and after an experimental group post-rehabilitative exercise program in patients with THA.

4. There would be no significant difference in muscle strength and postural stability before and after a control group post-rehabilitative exercise program in patients with THA.

5. There would be no significant difference in scores of self-perceived function before and after a control group post-rehabilitative exercise program in patients with THA.

6. There would be no significant difference in fear of falling before and after a control group post-rehabilitative exercise program in patients with THA.

Operational Definitions

For the purposes of this study, the following definitions were used:

Fear of falling was defined as "low perceived self-efficacy or confidence at avoiding falls" (Tinetti, Richman, & Powell, 1990). For the purposes of this study, fear of falling was assessed by asking subjects to respond "yes" or "no" to each of the following two questions: "Are you afraid of falling?" and "Since your surgery, are there any activities that you avoid doing because you are fearful of falling?" Answering "yes" to either one of these questions was interpreted to indicate fear of falling.

"Make test" was the type of test used by the examiner to assess muscle strength using a hand-held dynamometer. In a make test, the examiner held the dynamometer stationary while the subject exerted maximal force against it.

Muscle strength was defined as the maximal amount of force that a muscle could exert isometrically. In this study, muscle strength was measured as the maximal force exerted against a hand held dynamometer during a "make test". Estimated moment arm lengths were used to calculate the torque exerted against the dynamometer in units of Newton·meters.

Self-perceived function was defined as the subjects' perceived ability to perform fundamental daily activities such as walking, climbing stairs, or preparing meals. In this study, self-perceived function was assessed using the 12-Item Hip Questionnaire (Dawson, Fitzpatrick, Carr, & Murray, 1996). Scores on the 12-Item Hip Questionnaire range from 12 to 60 with a low score signifying a high level of function.

Postural stability was defined as the ability to maintain or control the center of mass in relation to the base of support in order to prevent falls. In this study, static balance in single stance was used as the measure of postural stability. A force platform measured postural stability by tracking changes in the center of pressure along two perpendicular axes (lateral and anterior-posterior) as the subject stood on one leg. The ratio of the average movement of the center of pressure to the base of support was used to compute "percent instability." The computed "percent instability" was subtracted from 100% to obtain a score of "percent stability."

Static balance was defined as the ability to maintain a posture such as standing or sitting in one place. In this study, the ability to maintain single stance was used as a measure of postural stability and was measured using a force platform.

Total Hip Arthroplasty (THA) was defined as the unilateral or bilateral surgical replacement of the acetabulum and femoral head with an artificial prostheses.

Assumptions

For the purposes of this study, the following assumptions were made:

1. Subjects with different surgical approaches (anterior, lateral, or posterolateral) would not respond differently to the exercise intervention.

2. Subjects with different prosthetic component fixation methods (cemented or non-cemented) would not respond differently to the exercise intervention.

3. Subjects with different primary diagnoses such as osteoarthritis or osteonecrosis would not respond differently to the exercise intervention.

4. The subjects recruited from local orthopedic practices would be representative of patients who elected to have THA.

5. Subjects who volunteered to be in this study would be representative of patients who underwent THA.

6. Subjects would give maximal effort during strength and postural stability testing.

7. Subjects would respond honestly to the questionnaires.

Limitations

Potential limitations of the study included the following:

1. Exercises were provided to the experimental and control group on-site. However, once patients could perform the exercises correctly and independently, they continued the exercises on their own at home. Patients returned to the facility once every 2 weeks to insure that they were performing exercises correctly and to progress the exercises as needed. Follow-up visits were performed to help maintain patient compliance, but because the intervention was administered mainly as a home exercise program, lack of compliance could have been a limitation.

2. Because of the difficulty in recruiting a large sample of patients with THA, only one intervention was compared to the control exercise program.

3. Because of difficulty in recruiting a large sample of patients with THA, patients with different surgical approaches, different methods of prosthetic fixation, and different primary diagnoses were combined for this study.

Significance of the Study

Currently, most patients receive physical therapy at the hospital immediately following surgery for THA (Munin, Kwoh, Glynn, Crossett, & Rubash, 1995), and some patients continue to receive home physical therapy for 1-3 weeks after hospital discharge.

Because patients are still recovering from surgery during this time, the physical therapy care consists mainly of self-care instructions and a standard exercise protocol that emphasizes mobility (Enloe et al., 1996). The protocol used for the acute rehabilitation of patients with THA has become standard practice because initial outcome studies indicate that these exercises and instructions are effective for achieving early functional goals such as independent transfers and ambulation (Gogia et al., 1994; Vaz, Kramer, Rorabeck, & Bourne, 1993). However, muscle strength and postural stability deficits have been found in patients who had THA 1-2 years previously (Jackson et al., 2001; Long et al., 1993; Shih et al., 1994).

It is critical that an effective intervention is found to reduce these postural stability and strength deficits that remain at least 1-2 years following THA. In a 4 year epidemiological study of 1122 initially healthy subjects, measures of lower extremity function were found to be highly predictive of subsequent onset of disability (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). Furthermore, the persistent muscle weakness that remains in patients with THA can result in aching around the hip and reduce the protection of implant stability (Long et al., 1993). Specifically designed exercise programs have been shown to improve strength and postural stability in elderly subjects, but a post-rehabilitation exercise program to improve strength and postural stability in patients following THA has not been demonstrated.

Improved postural stability could be of particular benefit to THA patients with multiple impairments. Impairments in muscle strength or vision, for example, when added to reduced postural stability on the side of the replaced hip may result in increased risk of falls or fear of falling. Falls and fear of falling are prevalent and present a serious health hazard among the elderly. Evidence suggests that interventions designed to affect factors contributing to fall risk among the elderly can reduce falls and fear of falling (Guralnik et al., 1995; Shumway-Cook, Gruber, Baldwin, & Liao, 1997; Tinetti, Baker, et al., 1994). An exercise program that emphasizes balance and weight bearing such as the experimental group exercise program proposed in the current study, is an example of an intervention that could help older adults who have had THA.

Although a specific link between THA and falling has not been determined, fall related injuries are the leading cause of death from injury in people over the age of 65 (National Safety Council, 1987). Falling is also a serious public health problem among the elderly because of its frequency, the resulting musculoskeletal injuries, and associated health care costs (Department of Health and Human Services [DHHS], 1990; Sattin, 1992). Forty percent of hospital admissions among the elderly are reported to be fall-related, resulting in an average length of stay of 11.6 days. Approximately 50% of the elderly who are hospitalized for fall-related injuries are discharged to nursing homes (Sattin et al., 1990). Although the resulting morbidities and costs associated with falling are staggering, the self-imposed decline in activity and function as a result of fear of falling, may be even more problematic (Kellogg International Work Group, 1987).

Tinetti, Mendes de Leon, et al. (1994) found that score on the Falls Efficacy Scale, which rates the degree of confidence one has in performing ADL without falling, is highly correlated to function. This study by Tinetti et al. demonstrates that the fear of falling often leads to loss of independence in normal activities of daily living. The resulting reduction in activity level has also been shown to be an important risk factor for a number of costly ailments, including heart and vascular disease, hypertension, diabetes, osteoporosis and cancer (DHHS, 1990). Although most patients who elect to have THA do so with the intent of increasing activity level after surgery, a 3-year follow-up study of patients who had THA revealed that participation in physical activities such as walking, swimming, golfing and bowling was significantly reduced after hip surgery (Ritter & Meding, 1987). Research has shown that participation in activities such as walking, swimming, golfing, and bowling do not have an adverse effect on the outcome of THA (Ritter & Meding). Fear of participation in these activities after THA is therefore, unfounded.

If the current study demonstrates that strength and postural stability can be improved by instituting an exercise program later in the rehabilitation process, the current standard of care for physical therapy following THA could be modified to include this second phase of rehabilitation. A post-rehabilitation exercise program that improves muscle strength, postural stability, and fear of falling could encourage participation in activities that are important for overall health and fitness, such as walking, swimming, and golfing.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this study was to determine whether an experimental post-rehabilitative exercise program initiated at least 4 months post-operatively would be more effective than a control exercise program for rehabilitating patients following THA. The experimental exercise program focused on developing strength and postural stability while weight bearing on the affected limb. The control exercise program focused on limb mobility in non-weight bearing positions. This chapter summarizes the literature related to developments in THA hardware and procedures as well as potential causes of failure. Next, outcomes of the surgery are discussed, including pain and mobility, functional outcomes, gait parameters, muscle strength, postural stability, and activity level. Components of postural stability are discussed separately. Finally, studies investigating the use of exercise to improve muscle strength and postural stability are presented.

Total Hip Arthroplasty

Total hip arthroplasty is the surgical replacement of the acetabulum and femoral head with artificial prosthetic components. Specific indications for this surgical procedure include (a) radiographic evidence of joint cartilage damage and (b) persistent moderate to severe pain or disability that has not been relieved by an extended course of non-surgical treatment (National Institutes of Health Consensus Development Panel on Total Hip Replacement [NIH], 1994). Conventional non-surgical management of the hip joint used to reduce pain from damaged joint cartilage includes non-steroidal anti-inflammatory medication, activity modification, physical therapy, and weight reduction. THA is most commonly performed to reduce pain and restore mobility and function in patients with severe osteoarthritis of the hip. Radiographic studies show evidence of moderate to severe osteoarthritis of the hip in 8.4% of men in the 55 to 64 year age group, and in 3.1% of women in the same age group (Gogia et al., 1994). Accordingly, patients between the ages of 60 and 75 years have been the most common recipients of hip replacement. Because of improvements in the design of prosthetic components, materials, and surgical procedures over the last 10 years, however, this age range has broadened to include younger patients as well as more elderly patients (National Institutes of Health Consensus Development Panel on Total Hip Replacement [NIH]). Both extremes of the age range bring additional and different concerns that should be considered in the rehabilitation of these patients. Artificial hips in younger recipients of THA are exposed to higher mechanical stresses over a longer period of time while older recipients have a higher level of comorbidities that lead to poorer outcomes (National Institutes of Health Consensus Development Panel on Total Hip Replacement [NIH]). A review of the evolution of total hip arthroplasty leading up to the current state of the art in terms of design, surgical procedure, and physical therapy management follows.

Historical Perspective

Some form of total hip replacement was devised as early as 1890 in Germany, using an ivory ball and socket joint (Shands, 1976). The first total hip replacement using stainless steel components was described by Philip Wiles, in London, as early as 1938 (Kaye, 1982). The procedure was further refined in the 1950s and 1960s by pioneers such as McKee and Farrar (McKee & Watson-Farrar, 1966) and Sir John Charnley (Charnley, 1970). Charnley pioneered the concept of cement for fixation and a low friction system using a metal femoral component and a polyethylene surfaced acetabulum (Kaye). The small diameter femoral head with a high density polyethylene acetabulum, developed by Charnley, is still considered by many to be the current standard of THA (Siopack & Jergesen, 1995). Charnley was also the first to quantitate the benefits of hip surgery (Charnley & Pusso, 1968). Improvements in THA have focused on meeting the increased demand for hip prostheses to perform better and last longer to accommodate younger, more active recipients. Overall, there has been relatively little change in the actual design of prosthetic components from the original Charnley prosthesis. Much research, however, has centered on the materials used for implants and on different methods of component fixation.

Materials and Surgical Procedures

The two most common surgical approaches used in THA are a posterior approach and an anterolateral approach. Although both approaches provide adequate exposure of the hip joint, different muscles are incised and different portions of the hip capsule are removed with each. With a posterior approach, incision of the skin begins 6-8 cms superior and posterior to the greater trochanter and extends 10-15 cms distally over the posterior aspect of the greater trochanter and then distally along the shaft of the femur

(Hoppenfeld & deBoer, 1994). Portions of the hip external rotators are divided and the superior, posterior, and inferior portions of the capsule are removed. The hip is then dislocated posteriorly (Gore, Murray, Sepic, & Gardner, 1982). With the anterolateral incision, the hip is approached through an area between the gluteus medius and the tensor fascia lata. The incision begins 2-3 cm inferior to the iliac crest and extends distally down the shaft of the femur 10-15 cm in a straight line that is centered over the tip of the greater trochanter (Hoppenfeld & deBoer). The superior, anterior, and inferior portions of the capsule are removed and the hip is dislocated anteriorly (Gore et al.). With both approaches, the head and proximal neck of the femur is excised and the acetabular cartilage and subchondral bone removed. A metal femoral head prosthesis consisting of a stem and small-diameter head is then inserted into the femoral medullary canal. An acetabular cup with a polyethylene articulating surface is inserted into the enlarged acetabular space. The artificial components must then be firmly fixed to the remaining bone. The methods of fixation that are used are (a) polymethylmethacrylate cement, (b) biologic fixation by bony ingrowth, or (c) a combination of cement and bony ingrowth.

The original Charnley arthroplasty used cement to fix the bony components (Siopack & Jergeson, 1995). The conventional cemented arthroplasty allows early weight-bearing and excellent clinical results, as defined by absence of pain, in 80% to 85% of patients observed for 15 to 20 years (Welch, McGann, & Picetti, 1988). There is evidence, however, that cement debris can cause osteolysis with consequent loosening of prosthetic components.

Non-cemented component fixations that rely on bone growth into porous or roughened surfaces were introduced to reduce the incidence of loosening. The NIH Consensus Statement on Total Hip Replacement (1994) reports that cementless fixation procedures for the acetabular component have shown lower loosening rates than cemented procedures over the short term but similar cementless procedures for the femoral component have continued to experience loosening as a consequence of osteolysis. Longer term outcomes of cement versus cementless fixation procedures continue to be monitored. Currently, the "hybrid" THA, consisting of a cemented femoral stem and a non-cemented acetabular cup, has been adopted by many surgeons and is considered the preferred technique for patients older than 60 years (Siopack & Jergeson, 1995).

Typical Post-operative Precautions Following THA

Patients are asked to adhere to specific precautions following surgery for THA. Although some post-operative precautions are common to many patients following THA, the surgical approach and type of fixation used by the physician must be considered (Rouben, 1994). Because the joint capsule and underlying tissues are incised during surgical replacement of the hip, a risk of dislocating the hip exists especially in the weeks immediately following THA. Post-operative precautions are advised to protect the surgically replaced hip from dislocation immediately after surgery. Strict adherence to the restrictions are usually discontinued within 3 months following surgery.

Proper THA precautions are determined by the surgical approach used. Because the posterior approach is the most commonly used procedure, typical THA precautions include avoiding hip adduction beyond neutral, flexion beyond 90°, and internal rotation. The combined motions of adduction, flexion, and internal rotation place the prosthetic hip at greater risk for posterior dislocation (Kampa, 1993). Patients are advised to avoid activities such as bending over to tie a shoe, crossing the legs, or sitting in low seats. Patients may also be advised to sleep on their backs with a pillow between the knees in order to avoid inadvertent hip adduction (Liang, Cullen, & Poss, 1982). If an anterior surgical approach is used, extremes of hip adduction, extension, and external rotation should be avoided.

Other precautions may include limited weight bearing on the operated leg if a cementless or hybrid precedure is used. Weight bearing restrictions are generally recommended to continue several weeks to 3 months. Additionally, some surgeons prefer that no external resistance be used during leg exercises for at least 3 months.

Physical Therapy Management of THA

Currently, many patients receive physical therapy at the hospital immediately following surgery for THA. Some patients also receive home health physical therapy for 1-3 weeks after hospital discharge. Because patients are still recovering from surgery during this time, the physical therapy care consists mainly of self-care instructions and a standard exercise protocol that emphasizes mobility. The standard of care for acute post-operative physical therapy management of THA has been determined and reported via consensus by Enloe et al., (1996). Prior to this report by Enloe et al., inconsistent practice patterns of physical therapy management of THA during the acute phase of recovery were evident in the literature (Burton & Imrie, 1973; Kaye, 1982).

Burton and Imrie (1973) provided a detailed physical therapy rehabilitation program for patients who had undergone a cemented THA. Burton and Imrie, a physician and a physical therapist respectively, stated that "muscles already properly in tone do not require exercising" and therefore, the best exercise following THA is ambulation. This statement by Burton and Imrie, however, is flawed in several respects. First, patients who undergo THA do not have "muscles properly in tone." In general, patients who elect to have THA are debilitated because pain in their hip has restricted their activity and altered their gait pattern. Secondly, no studies were found comparing ambulation to other types of exercise following THA. The statement by Burton and Imrie that ambulation is the best exercise following THA is an opinion not supported in the literature. The physical therapy program recommended by Burton and Imrie included quadriceps and gluteal muscle setting started on the third postoperative day and active-assistive hip flexion, abduction, and external rotation started on the sixth postoperative day. Weight bearing to tolerance ambulation with a walker was started on the seventh postoperative day. The authors discouraged resistive exercises for hip abductors, stating that progressive ambulation provided all the strengthening that was needed for these muscles. Again, Burton and Imrie provided no justification for this statement that appears to be based on their opinion. Ambulation was also considered the major form of postoperative outpatient physical therapy by these authors, though pool therapy was sometimes recommended.

Kaye (1982) provided a description of rehabilitative exercises used post-operatively for cementless THA. The postoperative program described by Kaye was the program used in a general hospital in British Columbia. Although cementless THA had been in common use in Europe since 1975, it was not performed in North America until the early 1980s. Therefore, the description of rehabilitation provided by Kaye represents one of the first programs used following cementless THA performed in North America. Patients who had cementless THA received in-patient physical therapy for one week before being transferred to a rehabilitation ward for an additional 1-2 weeks where they continued to receive physical therapy. Isometric exercises were started on the first post-op day and active hip exercises in bed were started on the fourth postoperative day. Weight bearing as tolerated ambulation with crutches was also started on the fourth postoperative day. During the first week in the rehabilitation ward, active exercises of the hip were performed including hip abduction in sidelying against gravity. Gait training was continued during the same week and pool therapy was started when the sutures were removed approximately 14 days after surgery. During the second week in the rehabilitation ward, resistive exercises for hamstrings and hip abductors were added along with prone hip extension exercises against gravity. At the end of their 2-week stay in the rehabilitation ward, patients were provided with a home exercise program that consisted mainly of daily walks or they continued physical therapy for 2 more weeks on an outpatient basis. Because outcomes of the program described by Kaye were never reported, the description is limited in its usefulness.

In one of the few studies located in the literature that assessed outcomes of THA in patients who had received physical therapy, Gogia et al. (1994) used a self-rating questionnaire to assess pain and function after cemented THA in 22 patients who received physical therapy following surgery. The physical therapy protocol used in this study consisted of ankle pumps, quadriceps sets, gluteal sets, and gait training with a walker beginning the first postoperative day. Range of motion and strengthening exercises were added as tolerated, but the actual exercises were not described by the authors. Patients continued their exercises as a home program and none of the patients in this study received follow-up physical therapy. The self-rating questionnaires administered 3 and 6 months post-operatively revealed an overall improvement of 56% and 64% respectively from the pre-operative rating of function and pain. A Friedman 2-way ANOVA showed that differences between the pre-operative ratings and both post-operative ratings were statistically significant ($p<.05$). Gogia et al. concluded that improvement in function after THA that is followed by physical therapy is excellent. Because no control group was used in this study, however, it is not known whether patients who had cemented THA would have had improvements in function at 3 and 6 months even if no physical therapy was provided. Another weakness in this study is that even if the physical therapy program used by Gogia et al. was effective in improving function, the program used was not described well enough to be replicated by clinicians.

Although the ultimate goal of rehabilitation following THA has always been to maximize functional performance, it is evident from the literature that practice patterns in the physical therapy management of patients with THA have been inconsistent. Not until 1996, was a standardized physical therapy treatment program reported for patients who received total hip replacements because of osteoarthritis (Enloe et al., 1996). Enloe et al. used the Delphi technique to determine via consensus that active hip range of motion and isometrics constitute the standard of care for acute physical therapy practice following THA. The consensus was reached by a panel of 16 physical therapists, 1 physician, and 2 nurses who had expertise in treating patients with total hip and knee replacements. Selection of the 19 panel members was based on recommendations by two orthopaedic surgeons with expertise in joint replacement and five American Physical Therapy Association (APTA) orthopaedic clinical specialists who were experienced in treating patients with total hip and knee replacements. Using the Delphi approach, the panel used three rounds of questioning to arrive at a consensus on physical therapy management of THA. Items included in the final round had to have been selected by at least 50% of the panel members. In the final round, members of the panel had to accept or reject the final treatment program developed from previous rounds. Seventy-six percent of the panel members accepted the total hip program. The panel agreed that ambulation should be initiated 1-3 days after surgery, and the exercises started on post-operative day 2 or 3 should consist of quadriceps and gluteal sets, ankle pumps, active hip flexion and abduction, isometric hip abduction and terminal knee extension. Straight leg raising and resistive exercises were not selected in the consensus process. The consensus on physical therapy management of THA that was determined by the panel is frequently cited in the literature, but it is not known whether it has been widely adopted in clinical practice.

Causes of Failure in Total Hip Arthroplasty

For most patients who undergo THA, the expectation is that they will be able to resume a usual, active lifestyle. These patients share a common goal of wanting to become more active after replacement of their diseased hip joint. This desire to become more active, however, is tempered by a certain amount of apprehension about what types of activities they should or should not participate in (Ritter & Meding, 1987). Though most surgeons advise their patients with THA to avoid "strenuous activities" and participation in sports that involve high impact forces, there is surprisingly little evidence in the literature to support these recommendations (Kilgus, Dorey, Finerman, & Amstutz, 1991).

There are many causes of failure in THA but the most common cause encountered by surgeons is that of component loosening (Beckenbaugh & Illstrop, 1978; Crowninshield, Brand, Johnston, & Milroy, 1980). In a 5-7 year follow-up study of 335 hips, Beckenbaugh and Illstrop reported a 24% incidence of clinical or radiographic loosening. Chandler, Reineck, Wixson, and McCarthy (1981) studied incidence of component loosening in a group of 29 patients younger than 30 years who had undergone total hip replacement between 1970 and 1972. A total of 33 replaced hips were included in this study. The initial follow-up that was performed at 10 months appeared favorable based on a Harris hip score, with 24 hips rated as "excellent" and 9 hips rated as "good". At the 5-year follow-up, however, 5 patients had revision surgeries and 2 more were scheduled for revision. Five additional patients had roentgenographic evidence of component migration but were not symptomatic enough to schedule revision surgery. Five other patients (6 hips) had radiolucent lines that were not present after the initial arthroplasty, but did not have evidence of frank loosening of the components. Altogether, 18 hips or 57% of the hips had actual or potential prosthetic loosening of at least one of the components at the 5-year follow-up. Another interesting finding was that 15 of the problem hips in this study involved the acetabular component. Most studies of loosening problems in older patients have involved the femoral component rather than the acetabular component (Eftekar, 1971; Griffith, Seidenstein, Williams, & Charnley, 1978). Chandler et al. offered poor surgical technique as a possible explanation to the higher than usual incidence of acetabular loosening. The authors noted that only 2 of the 18 problem hips had what they considered good surgical technique on the acetabular side of the arthroplasty. The surgical technique on the femoral side, however, was found to be better in general with 14 hips having good or passable cementing technique.

In their study of younger patients who had undergone THA, Chandler et al. (1981) identified factors that seemed to contribute to actual or potential component loosening at the 5-year follow-up. The factors identified by Chandler et al. included (a) initial diagnosis of avascular necrosis, (b) a previous mold arthroplasty, (c) heavy activity, (d) a unilateral arthroplasty, and (e) body weight of more than 82 kg. (180 lbs.).

Although the criteria for classification of activity as 'sedentary,' 'moderate,' or 'heavy' were not defined by the authors, they described the activity of 8 of the patients with problem hips as "participating in sports such as jogging, baseball, and basketball, or such heavy work as might be required of an automobile mechanic or an electrical contractor." Because of the multiple factors and small sample size, statistical significance of the relationship of each factor to the incidence of component loosening was not calculated and interrelationships between factors were not considered. Additionally, Chandler et al. discussed surgical technique as an explanation for the higher incidence of loosening of the acetabular component compared to the femoral component, but did not identify surgical technique as a factor that could adversely affect long term outcomes of THA in younger patients.

Dubs, Gschwend, and Munzinger (1983) reported very different results after reviewing 152 replaced hips that averaged 5.8 years post-surgery. Subjects were 110 males with a mean age of 55 years, who had unilateral or bilateral cemented THA. Dubs et al. observed a revision rate of 1.6% in the 61 patients who participated in sports regularly, and a 14.3% revision rate in the 49 patients who did not participate in sports. The authors concluded that regular, non-impact physical activity such as hiking, swimming, running, cycling, and tennis following THA does not lead to increased incidence of prosthetic loosening. Dubs et al. hypothesized that the increased physical activity may provide the necessary stress on bone to produce a stimulating effect and therefore, have a beneficial effect on the replaced hip.

Kilgus et al. (1991) compared revision rates in very active patients versus less active patients who had received a conventional, cemented stemmed prosthesis or a resurfacing prosthesis. By reviewing a large hip replacement database, the authors retrospectively compared four different groups of subjects: an active resurfacing group (n=80), a less active resurfacing group (n=248), an active conventional group (n=25), and a less active conventional group (n=663). Patients were classified as "active" if they participated regularly in sports or performed heavy labor in their occupation. Additionally, patients who received a THA as a result of osteoarthritis (OA) were analyzed separately from patients who received THA as a result of diagnoses that were not osteoarthritis (non-OA). Revision rates owing to loosening in the various groups were as follows: active resurfacing, 43%, active conventional, 28%, less active resurfacing, 25%, and less active conventional, 6%. Thus, the authors concluded that the active groups were at increased risk of revision surgery as a result of loosening in the conventional group ($p < 0.013$) as well as in the resurfacing group ($p < 0.059$). When the OA and non-OA subjects were analyzed separately for type of prosthesis and activity level, the subgroups could not be compared separately because of small sample size, especially for the active subjects. Instead, the Cox Multivariate Proportional Hazard model was used to estimate failure rate. Based on this model, the investigators found that OA subjects were at a lower risk of failure than non-OA subjects, but the patients who participated in higher activity levels were at more than twice the risk of loosening than subjects who were less active. The active subjects in the resurfacing group were further sub-divided into a high impact group and a low impact group and analyzed separately for OA versus non-OA using the Cox Proportional Hazards model. This analysis revealed that non-OA subjects in the high and low impact groups had similar risk of loosening with both groups at about 2.5 times greater risk than the less active subjects. For the OA subjects, however, the high impact group demonstrated 2.1 times greater risk of failure than the less active group; whereas, the low impact group was only 1.4 times at greater risk for failure than the less active group. A similar comparison could not be conducted for the conventional prosthetic group because of the small sample of active subjects. The authors stated that the most difficult aspect of this study was to classify patients into activity level group based on stresses placed on their hips by considering frequency, duration, and intensity of reported activities.

Ritter and Meding (1987) retrospectively assessed the effects of physical activity on THA by surveying patients who had undergone hip replacement at least 3 years previously. One hundred and sixty nine patients returned the questionnaire that involved a total of 214 hips. The mean age of the participants was 63.37 years with a range of 21-85 years, and the average follow-up time was 5.84 years. A chi square analysis was used to assess significance of differences between participants versus non-participants in sports and exercise following THA. Ritter and Meding found no statistical differences between subjects who participated in sports and subjects who did not participate in sports on clinical or radiographic variables that included pain, function, and prosthetic loosening. The investigators stated that a total of 55 variables were examined in the participant versus non-participant groups. Because the alpha level used for determination of statistical significance was not specified, it is unclear whether a correction for inflation of Type I error was made. Ritter and Meding concluded that participation in sports such as walking, golf, swimming, biking, and bowling did not affect the outcome of a THA.

The determination of appropriate activity level and types of activities allowed after THA is still unclear. Consequently, surgeons are left to counsel their patients on appropriate activity level based on literature that is sparse and often conflicting. In general, the literature does support avoidance of sports that involve high impact forces. Furthermore, walking as an exercise has not been shown to be detrimental following THA, but patients should be prepared for this activity with adequate muscle strengthening.

Outcomes of Total Hip Arthroplasty

Though incidence of hip prosthesis loosening is of importance to orthopaedic surgeons, this is generally not measured as an outcome of THA. The most commonly reported outcomes of hip replacement surgery that can be found in the literature relate to pain relief and restoration of mobility. Other outcomes of THA that may be of interest include functional outcomes, activity level, muscle strength, and postural stability.

Pain and Mobility Studies

Outcome studies following THA that address pain and mobility indicate an overall satisfaction with the results of THA by patients and physicians. In one of the earliest studies that investigated the effectiveness of total hip replacement as a method of treatment for degenerative joint disease, Murray, Brewer, and Zuege (1972) assessed pain and range of motion (ROM) in 30 subjects before and after THA with a McKee-Farrar prosthesis. In a form letter mailed 9 months after surgery, all but 1 of the 30 subjects who completed the form reported that relief of hip pain was the most significant benefit of the surgery. Hip ROM in the three planes of motion was assessed pre-operatively, then 3 and 6 months after surgery in 24 of the 30 subjects. The investigators did not include 6 of the subjects in their descriptive analysis because they either had serious complications after surgery or had the opposite hip replaced during the testing period. Of the remaining 24 subjects, 20 showed improvement in total excursion of hip motion in all three planes. Additionally, the investigators reported that most subjects showed the greatest gains during the first 3 months following surgery, with smaller improvements observed between 3 and 6 months after surgery.

Another early outcome study assessed pain and ROM in 25 patients before and 6 months after a Charnley total hip replacement (Stauffer, Smidt, & Wadsworth, 1974). Before surgery, all 25 patients had severe pain that limited their activities and 14 had pain at rest. Six months after the surgery, 18 reported no pain and 7 reported discomfort laterally over the greater trochanter. Only one subject considered the discomfort limiting. Pre and post-operative measurements of hip passive ROM were obtained in three planes of motion using an electrogoniometer. All subjects showed improvement after surgery with the largest ROM gains in adduction, abduction, and rotation. Adduction increased from a mean of 12 degrees to 21 degrees while abduction increased from 8 degrees to 38 degrees. Rotation increased from a mean of 2 degrees of external rotation contracture (no internal rotation) and 9 degrees of external rotation to 13 degrees of internal rotation and 28 degrees of external rotation after surgery. The authors concluded that the short-term results of the Charnley total hip replacement were encouraging, with the most consistent benefits being pain relief and restored mobility.

Overall pain and mobility are clearly improved after THA, and the greatest gains occur within the first 3 months following surgery. Improvements in pain and mobility continue between 3 and 6 months after surgery but the gains are smaller. Most studies of pain and mobility, however, compare the operated hip to the abnormal pre-operative status as the "standard" versus comparing the operated hip to the opposite side or to normative values. Additionally, although patients have improved pain and mobility post-operatively when compared to pre-operative status, their functional status does not always reflect this.

Functional Outcomes

Wilcock (1978) studied the outcome of THA in 49 patients over 55 years of age with an initial diagnosis of osteoarthritis of the hip. Outcome assessments were conducted via interview pre-operatively and 6-months post-operatively. The study by Wilcock is a descriptive study that assessed hip function using an Index of D'Aubigne as modified by Charnley. This modified index of activities of daily living was used to score six different activities. Wilcock reported that 40 of the 49 patients were pain-free 6 months after THA, but only 6 of the 49 patients were completely independent in ADL such as going outdoors, walking up stairs, or getting around in the house. He further reported that although 90% of his patients could walk long distances 6 months after surgery, only 12% could do so without external support. Wilcock did not, however, define what constituted "long distances" or whether patients in his study received any form of rehabilitation.

Gogia et al. (1994) performed a similar study with 22 patients who underwent THA as a result of osteoarthtritis but also received physical therapy after surgery. Gogia et al. used a self-rating questionnaire to assess pain and functional status pre-operatively, then 3 and 6 months after surgery. The investigators reported that the mean post-operative scores were higher on all items when compared to pre-operative scores, indicating improvement in pain and functional ability. However, tests of statistical significance were not performed or reported. Gogia et al. reported similar findings as in previous studies that the greatest improvements in pain and functional status occurred during the first 3 months after surgery.

Studies of functional outcomes following hip replacement are difficult to compare and interpret because of the wide variety of assessments used to report function. Although there is agreement that functional outcomes are important to assess, the lack of agreement about how to assess function makes comparisons between studies difficult. Because gait can be quantified, gait analysis is frequently used to quantify function following THA.

Analysis of Gait following THA

Gait parameters are measurable and can provide a good indicator of function and probable activity level (Perrin, Dorr, Perry, Gronley, & Hull, 1985). Gait analysis studies provided an assessment of THA outcome as early as the 1970s. Early studies compared walking speed, cadence, and stride length 3 and 6 months after THA to values obtained before surgery (Murray et al., 1972; Stauffer et al., 1974). Both of these early gait studies were descriptive and did not report statistical results. Both studies concluded that cadence, free walking speed, and stride length improved after THA. They also concluded that although cadence, walking speed, and stride length improved considerably for up to 6 months, the parameters did not improve to a level that would be considered within normal gait variability.

McBeath, Bahrke, and Balke (1980) studied walking speed and walking efficiency as determined by oxygen consumption in 77 patients who had unilateral or bilateral THA. Measurements were taken before surgery and up to 4 years after surgery. The results of this study are in agreement with earlier studies by Murray et al. (1972) and Stauffer et al. (1974) that showed that the most substantial improvements in walking speed occurred within 6 months after surgery. McBeath et al., however, demonstrated that walking speed continued to improve in smaller increments for up to 4 years. Walking efficiency also improved in a similar pattern.

Brown, Hislop, Waters, and Porell (1980) measured the same gait variables in 29 patients who had unilateral or bilateral THA. The results were similar to those of

McBeath et al. (1980) in that cadence, stride length, walking velocity, and oxygen consumption improved substantially after surgery. The study by Brown et al., however, showed the greatest improvement in gait parameters occurred between 3 months and 1 year. In addition, the results of the study by Brown et al. indicated that even with the substantial improvements in gait parameters, these values did not reach expected values when compared with healthy subjects of similar age. Velocity, cadence, stride length, and walking efficiency were all lower than normal even 4 years after surgery.

In a 5-10 year follow-up study of 47 patients with unilateral THA, Perrin et al. (1985) found similar post-operative gains in walking velocity as found in the previous study by McBeath et al. (1980). In a sub-group of 11 patients with unilateral hip involvement and without complications after surgery, Perrin et al. found that gait velocity improved from 38% of normal pre-operatively to 80% of normal over a 3- year period and was still 80% of normal at 5 years. In another sub-group of 18 patients with no complications after surgery, but multiple joint involvement, or systemic disease that affected ambulation, Perrin et al. found that initial walking velocity increased from 41% of normal to 68% of normal by 3 years, then declined to 63% of normal by 5 years. This previously unreported late decline in walking speed was observed in the multiple joint involvement sub-group as well as 3 of the 18 patients in the unilateral involvement sub-group. This late decline in walking speed was not associated with pain or radiographic evidence of component loosening. The investigators hypothesized that this decline may be a result of "acceleration of physiologic aging," or generalized deconditioning that could respond to a reconditioning program.

Long et al. (1993) investigated the outcome of noncemented THA in 18 patients with unilateral hip disease. Gait analysis performed pre-operatively, then at 3 months, 6 months, 12 months, and 2 years revealed that gait velocity that averaged 80% of normal pre-operatively improved to 94% of normal by 12 months post-surgery and 100% of normal by 2-years. Similar improvements were observed in cadence and single-limb stance. These investigators also obtained dynamic electromyograms (EMGs) and force plate data during the gait analysis. Pre-operative EMGs revealed that stance loss in 3 patients could be attributed to absence of activity in the gluteus medius and upper and lower gluteus maximus muscles. Abnormal EMGs were all resolved within 1-year after surgery. Force plate data showed decreased vertical loading during midstance and roll-off on the side of the replaced hip when compared to the uninvolved side at 1 and 2 years post-surgery in all 18 subjects. The investigators interpreted the decreased vertical loading as muscle weakness and concluded that although gait parameters return to normal by 2 years post-THA, force plate data confirms that muscle weakness persists for at least 2 years following uncemented THA. The authors further offered that this persistent muscle weakness can result in aching about the hip and provide reduced protection of the implant during endurance activities that could lead to prosthetic loosening.

Muscle Strength Outcomes

Studies of muscular recovery around the hip following THA consistently report significant improvements in muscle strength at the 6-month follow-up when compared to pre-surgical values (Murray et al., 1972; Shih et al., 1994; Vaz et al., 1993). This is not a useful comparison, however, because muscle strength of the surgical hip is being compared to reduced pre-surgical values as a result of pain and inactivity. A more useful assessment is the comparison of post-surgical muscle strength to normative values or to muscle strength values on the uninvolved side.

In the previously described study by Long et al. (1993), the investigators used force plate data to compare indirect measures of muscle strength on the involved side to the uninvolved side. Eighteen patients with unilateral, non-cemented THA had decreased vertical loading (12%), vertical midstance (9%), and vertical roll-off forces (5%) when compared to the uninvolved side 2 years after surgery. Long et al. did not employ statistical tests to compare strength on the surgical hip to that of the uninvolved side but presented the results as descriptive information. The investigators also did not provide rationale for using force plate data to indirectly assess muscle strength, but they concluded that the force plate data confirmed the persistence of muscle weakness 2 years following uncemented THA. Because muscle weakness potentially results in reduced protection of the prosthetic implant fixation, Long et al. recommended that a supervised exercise program be continued for a prolonged period of time in order to improve post-surgical muscle weakness.

Shih et al. (1994) studied muscle strength in 20 women who had cementless THA for unilateral osteoarthritis and 20 men who had cementless THA for unilateral osteonecrosis. The day after surgery, a physical therapist provided instructions in isometric exercises for muscles of the hip and knee. These exercises were continued during the hospital stay but patients were responsible for their own rehabilitation after hospital discharge. A Cybex 340 dynamometer was used to assess isometric muscle strength of hip flexors, extensors, and abductors on the surgical and non-surgical sides. Strength measurements were taken pre-operatively, 6 months post-operatively, and 1 year post-operatively. Although muscle strength improved by 166% in the flexors, 269% in the extensors, and 199% in the abductors when compared to pre-operative values 1 year after THA, the muscle strength remained lower when compared to the uninvolved side. At 1 year post-surgery, muscle torque measurements from the replaced hip were 84-89% of the uninvolved hip in the men, and 79-81% of the uninvolved hip in the women. Although the differences between involved and uninvolved strength reached statistical significance only for the hip flexors ($\underline{p}<0.05$), the authors warned that any muscular weakness around the hip joint changes hip joint forces and can lead to joint instability. These authors recommended that muscle strengthening exercises be continued for a minimum of a year after THA. The findings and recommendations by Shih et al. are consistent with those of Long et al. (1993).

In a study of 15 patients who underwent unilateral THA 1 year previously, Jackson et al. (2001) used a hand-held dynamometer (HHD) to compare strength of muscles on the surgical side to that of the uninvolved side. These investigators found that deficits in strength ranging from 10 to 18% are still present in the operated hip 1 year after surgery. Although a Hotelling's T-test conducted to assess differences between strength of muscle groups on the involved side to those on the uninvolved side failed to show significance ($p<0.05$), the results are consistent with other studies of muscle strength outcomes conducted 1 to 2 years following THA. The study by Jackson et al., however, provided new insights into postural stability outcomes following THA.

Postural Stability Outcomes

Postural stability outcomes in patients who had THA have rarely been reported in the literature In one study of postural stability following THA, Ellison, Miller, Hocate, Levitan, and Nandhini (2000) compared Berg Balance Scale ratings in a group of patients approximately 6 months post-THA to a group of age and gender matched healthy patients with no hip replacement. The Berg Balance Scale is a tool used to assess balance that requires a rater to observe subjects' performance during 14 different tasks, and to rate the performance on a scale of 0 to 4. Overall scores on the Berg Balance Scale were not significantly lower in the group of subjects with THA. However, scores on a subset of four more difficult tasks from the Berg Balance Scale were significantly lower in the group of subjects with THA. Although the results of the study by Ellison et al. are important, there are potential confounding factors to be considered. Four different raters were used in this study, and intra- or interrater reliability was not determined. Reliability of the raters could be important because the four raters were physical therapy students who presumably had minimal experience administering the Berg Balance Scale. Additionally, the raters were not blinded to group assignment (THA or healthy). Ellison et al. did, however, demonstrate a clear need to further investigate postural stability following THA.

In a recent 1-year outcome study of patients following THA, Jackson et al. (2001) investigated postural stability in single stance on the involved hip compared to the uninvolved hip. In their study of 15 subjects who had unilateral THA 1 year previously, Jackson et al. found statistically significant impairments ($\underline{p}<0.01$) in the ability to stand on the involved leg when compared with the ability to stand on the uninvolved leg. Mean impairments in postural stability on the involved side compared to the uninvolved side, as measured by a force plate, were 26% in medial to lateral stability, 27% in anterior to posterior stability, and 31% in total stability.

The finding that postural stability is reduced on the surgical side 1 year post THA (Jackson et al., 2001) is important when viewed in combination with the residual strength impairments found 1-2 years after surgery by several different investigators (Long et al., 1993; Shih et al., 1994). Muscle strength deficits and postural stability deficits have both been found to be risk factors for falling (Sattin, 1992; Tinetti, Speechley, & Ginter, 1988).

Although the number of falls following THA has not been studied, Jackson et al. (2001) found that 7 of the 15 subjects studied who were 1 year post-THA reported that they feared falling. Fear of falling has been shown to be correlated to participation in social and physical activity and independence in activities of daily living (Tinetti, Mendes de Leon et al., 1994). Tinetti et al. concluded that fear of falling often leads to loss of independence in ADL and an overall reduction in activity level.

Post-operative Activity Level

Many patients who elect to have THA have the common goal to become more active after their hip surgery. In a study of activity level following THA, however, Ritter and Meding (1987) found that subjects in their study showed a decrease in all forms of activity except bicycling. A questionnaire about activities before and after surgery was sent to 294 patients who had THA and were at least 3 years post-operative. One hundred sixty nine questionnaires were returned that consisted of data about 214 hips. Analysis of the questionnaire responses revealed that participation in walking, swimming, golfing, bowling, and "other" activities decreased significantly ($p<0.005$) after THA. Participation in bicycling increased slightly after hip surgery when compared to participation before surgery. The investigators concluded that there is a general shift away from activity after THA and that this shift is unfounded considering that subjects in their study who were very physically active were not more likely to experience THA complications such as mechanical loosening and joint dislocation.

In summary, the most commonly reported outcomes following THA relate to pain and mobility. The greatest gains in pain and mobility occur within the first 3 months following surgery. Between 3 and 6 months after surgery, improvements in pain and mobility continue, but at a slower rate. The greatest gains in functional outcomes also occur during the first 3 months after surgery but functional status is difficult to quantify. Gait parameters, muscle strength, activity level, and postural stability measurements have been used to assess long term outcomes of THA at 1 year to several years post-THA. Gait studies reveal that cadence, stride length, and walking velocity improve rapidly from 3 months to 6 months or a year, but these gait parameters are all lower than age-matched normative values even after 4 or 5 years following surgery. Studies of muscle strength outcomes reveal that impairments in muscle strength remain up to 2 years following THA. Of all the outcomes discussed, the least researched is that of postural stability following THA. Only one study was located that assessed postural stability following THA (Jackson et al., 2001). The study by Jackson et al. revealed impairments of postural stability in patients who were 1 year post-surgery. No studies were found that examined the effectiveness of an intervention such as a post-rehabilitative exercise program for the reduction of impairments in postural stability, muscle strength, and self-perceived function.

Components of Postural Stability

Postural control involves the sensory, motor, and central nervous systems. The sensory systems involved in postural control include vision, touch, proprioception, vibration sense, and vestibular sense. The motor systems involved in postural control include muscle strength and neuromuscular coordination. The central nervous system then provides integration of the sensory and motor components (Lord, Clark, & Webster, 1991).

Two different models of central nervous system (CNS) control have been proposed to describe the neural basis for postural stability in humans; the reflex-hierarchial model and the systems model (Woollacott & Shumway-Cook, 1990). In the reflex-hierarchial model, the CNS is hypothesized to be organized in an ascending hierarchy. In this vertical hierarchy, primitive reflexes such as stretch reflexes are controlled at the spinal cord level. Tonic neck reflexes are controlled at the brain stem level, righting reactions are controlled at the midbrain, and equilibrium reactions are controlled at the highest level of the CNS, the cerebral cortex (Chandler, Andrews, & Swanson, 1980; Milani-Comparetti & Gidoni, 1967). According to this model, the body's response to tilting of a support surface is elicited by stimulation of the labyrinth and contribution of visual and somatosensory components are ignored. Central to the reflex-hierarchial model is the hypothesis that in order for voluntary movement to occur, primitive reflexes must be inhibited.

The systems model is a more recent representation of postural control. In the systems theory, the body is modeled as a mechanical system that reacts to the changing forces of gravity and inertia. This model, evolved from the work of Bernstein (1967), views the human as being an active respondent in a continuously changing environment. Unlike the reflex-hierarchial model, the systems model recognizes that postural control involves a complex interaction of neural and biomechanical factors (Woollacott & Shumway-Cook, 1990). Central to the systems approach is the view that postural control is a skill that the nervous system "learns" by using multiple systems including the central nervous system, all available sensory systems, the vestibular system, and motor elements (Horak, Henry, & Shumway-Cook, 1997). Horak et al. state that an understanding of the systems approach theory has important implications for physical therapy practice. Rather than retraining balance by facilitating equilibrium reflexes, clinicians now recognize that motor learning concepts such as practice, feedback, experience, and education are critical to balance retraining.

It is well known that changes in the visual, vestibular, and somatosensory systems occur with aging (Lord et al., 1991). Literature investigating these sensory inputs on postural stability in the elderly is abundant and is presented next.

Postural Sway

Measurement of postural sway is frequently used to quantify postural stability. Because the upright posture is dependent on sensory input that includes vision, vestibular, and somatosensory information, the effect of age on these sensory modalities has been studied intensively. A number of studies have demonstrated that sway increases with age (Brocklehurst, Robertson, & James-Groom, 1982; Pyykko, Jantti, & Aalto, 1990), and that declines in the visual, vestibular, and somatosensory systems are also age-related (Kaplan, Nixon, Reitz, Rindfleish, & Tucker, 1985; Mulch & Petermann, 1979; Pitts, 1982). Lord et al. (1991) administered a battery of 13 visual, vestibular, sensorimotor, and balance tests to 95 elderly persons to determine whether declines in these sensory systems were related to declines in postural stability. Measures of postural sway were recorded in square millimeters for the four test conditions (eyes open, eyes closed, firm floor, and compliant floor). Partial correlations were then determined between individual sensory system measures and the four body sway measures. The results of this study demonstrated significant correlations ($p < .05$) between measures of sway on a firm surface with tactile sensation (r=.27) and joint position sense (r=.25). Significant correlations ($p < .05$) were also found between measures of sway on the compliant floor with reaction time (r= .25), ankle dorsiflexor and quadriceps strength (r=.25 and r=.23 respectively), visual acuity (r=.28), and tactile sensation (r=.25). That is, increased sway was found to be associated with poor tactile sensation, joint position sense, reaction time, muscle strength and visual acuity, but not with deficits in the vestibular system. The findings that vestibular function has little association with sway are consistent with the findings of Nashner (1971), who reported that the otoliths play no role in the initial detection of body sway.

Another important finding by Lord et al. (1991) was that when the subjects were placed in a position of decreased support (standing on a compliant surface), their reliance on vision and strength increased. Subjects with poor vision or reduced ankle dorsiflexor or quadriceps strength demonstrated increased body sway when placed on a compliant surface. The overall conclusion drawn by Lord et al. was that sensation in the lower limbs is the main sensorimotor factor contributing to balance under normal conditions (standing on a firm surface with eyes open or closed). When sensation was reduced (standing on foam), however, vision and strength played a major role.

Findings similar to those of Lord et al. (1991) were obtained in a study of 151 frail elderly (Brocklehurst et al., 1982). Brocklehurst et al. found postural sway to be age-related in subjects ranging from 65 to over 85 years of age. These investigators also found that visual acuity and vestibular sense were not associated with sway. Although Brocklehurst et al. did not find significant correlations between sway and 20 separate measurements of proprioception using both ankles and both great toes, the authors suggested that lack of correlation was probably owing to difficulty with the clinical tests used to measure proprioception. Proprioception was determined by recording the subject's interpretation of five movements performed by the investigators at each of the subjects' ankle and metatarsophalangeal joints. The investigators felt that about one third of their subjects had difficulty relaxing the muscles in contact with the investigator who was moving the joint and that this could have affected the subjects' ability to interpret the movements. Brocklehurst et al. did not describe the specific technique used to assess proprioception, but other investigators have reported clinical tests of proprioception in older subjects to be a problem as well (Kokemen, Bossemeyer, & Williams, 1978; Rymer & D'Almeida, 1977).

In another study of postural sway, subjects in four age groups were investigated and compared: 20-40, 40-60, 60-70 and over 70 years (Colledge et al., 1994). Postural sway in this study was measured using a force plate, and the length of the total path moved by the subject's center of mass was calculated. The results showed that postural sway increased linearly with age, and that it was not affected by gender at any age. T-tests performed on additional tests of balance with eyes open and eyes closed, on a firm surface and a compliant surface, revealed that sway increased significantly ($p < .0001$) in each age group with loss of vision (eyes closed) and reduced proprioception (foam surface). The investigators then determined dependence on vision and proprioception by calculating a visual and proprioception quotient respectively, from the raw data. Based on these calculated quotients, Colledge et al. concluded that all age groups are more dependent on proprioception than on vision for postural stability. Vision, however, becomes more important when proprioception is reduced by standing on a foam surface. Pyykko et al. (1990) reported a greater contribution of proprioception than visual input to postural stability, but found that the pattern reversed in subjects over 85 years of age. People over 85 years were more dependent on visual input than on proprioceptive input. This may be owing to a reduction in sensation and vestibular function that occurs with aging.

Somatosensory Contribution to Postural Control

Though somatosensory input is known to play an integral role in the control of posture, the components of somatosensory input and how each is affected by age and disease are less clear. Touch receptors, joint proprioceptors, pressure receptors, and muscle proprioceptors all contribute information useful to the control of posture (Pozzo, Berthoz, & Lefort, 1989). Because touch and pressure receptors in the skin are not variables of interest in the current study of postural control in patients who have had THA, these are not included in the following review.

Joint Proprioception

Measures of joint position sense are frequently used to assess joint proprioception. In order to study the decline of joint proprioception associated with aging, Skinner, Barrack, and Cook (1984) measured knee joint position sense in 29 subjects ranging in age from 20 to 82 years. In this investigation, the researchers measured joint position sense in two ways: (a) threshold to detect motion and (b) ability to reproduce passive knee positioning. A moderate correlation between age and threshold to motion detection (r=.570), and between age and ability to reproduce passive knee positioning (r=.555) was found. Because aging is also associated with degeneration of joint surfaces, Skinner et al. concluded that although joint proprioception declines with increasing age, it is not known whether the decline is the cause or result of pathological changes that occur in the aging joint.

Joint position sense was also found to be age-related in a study of 29 women ranging from 22 to 80 years (Kaplan et al., 1985). The group of 29 women was comprised of 15 women who were under 30 years of age and 14 women who were 60 years or older. Kaplan et al. used a universal goniometer to assess the ability of the subjects to reproduce the position of their contralateral knee when placed at 15, 30 and 70 degrees of flexion by the investigator. Student's t-tests were calculated to compare ability to reproduce joint position between the younger and older age groups. The results of this study revealed that the younger age group was significantly better than the older group at matching the resting position of the contralateral knee in all positions (p<.05).

The average difference in the matching test was 4 degrees for individuals in the younger age group and 7 degrees for individuals who were 60 years or older.

Barrett, Cobb, and Bentley (1991) studied joint position sense in subjects with healthy, osteoarthritic, and surgically replaced knees. Three groups of subjects ranging in age from 16 to 86 years were examined and compared: (a) 81 healthy knees from subjects of various ages, (b) 45 knees with radiologically confirmed osteoarthritis, and (c) 21 surgically replaced knees. Joint position sense was assessed by placing the limb in a Thomas splint with an affixed protractor at the knee joint. The investigator passively moved the limb to 10 different predetermined angles of knee flexion and the subject was asked to represent the perceived angle on a visual analogue model of the limb. Differences between the perceived angle and the actual angle were recorded as inaccuracies. Linear regression analysis revealed that in healthy subjects, increased age produced poorer average performance ($p<0.01$) in joint position sense. Additionally, subjects with osteoarthritic knees had significantly less accuracy in joint position sense ($p<0.001$) than subjects with healthy knees. Subjects with replaced knees had significantly better accuracy ($p<0.02$) than those with osteoarthritic knees. The investigators did not identify the statistical procedure used to compare accuracy between groups and did not provide the mean age of subjects for the groups. Because they determined that age was an important factor for joint position sense in normal subjects, the mean age for the three groups being compared should have been provided. Barrett et al. concluded that knee position sense deteriorates with age and joint position sense is impaired in osteoarthritic knees. The investigators discussed the possibility of impaired joint position sense as a primary cause of osteoarthritis but cautioned that it is not possible to conclude from this study, whether impaired joint position sense was a cause of osteoarthritis or a consequence of it.

The numerous studies where decreased joint position sense was found with aging are important, because there is a known correlation between increased incidence of falls in the elderly and decreased joint proprioception (Brocklehurst et al., 1982; Overstall et al., 1977). It should be noted, however, that other sensory systems decline with age as well (Brocklehurst et al).

In an early study of joint position sense after THA, Grigg, Finerman, and Riley (1973) found no significant difference between the subjects' uninvolved hip and the hip that had been surgically replaced. Grigg et al. studied ability to detect passive hip abduction and ability to assess magnitude of active and passive abduction in 10 subjects who were within 2 weeks of surgery and 6 subjects who were 4-8 months post surgery. Grigg et al. concluded that patients with THA retain an awareness of limb position in the hip at least in the movement of abduction. In addition, because all subjects had a full capsulectomy and replacement of articular surfaces, the authors concluded that there must be an extra-capsular component to joint position sense. The results and conclusions of this study, however, were based on a small sample of 16 subjects.

More recently, Stender and Drowatzky (1994) compared joint position sense in 10 subjects who had undergone THA (3 subjects had bilateral replacements, thus a total of 13 joints) with 14 subjects who had healthy hip joints. The subjects were assessed on four proprioceptive tasks consisting of joint position matching, joint repositioning, visual matching, and passive positioning. An ANOVA was used to compare the two groups on each of the four tests. Stender and Drowatzky reported no significant differences between the subjects with healthy joints and those with the replaced joints during any of the tasks when tested at an alpha level of 0.05. The investigators concluded that joint position sense during three active proprioceptive tasks and one passive proprioceptive task is preserved in subjects who lack joint receptors as a result of excision during THA surgery. The observed preservation of joint position sense after elimination of joint receptors in a surgically replaced joint was also observed in a study of finger joint replacements (Kelso & Wallace, 1978). Kelso and Wallace observed little difference in proprioception of finger movements between subjects with healthy finger joints and subjects with finger joint replacements.

Muscle Proprioception

As early as 1900, some believed that motor afferent nerves contribute to kinesthesia or "position sense." Though without apparent experimental support, this opinion gained widespread acceptance at that time (Goodwin, McCloskey, & Matthews, 1972). Not until 1972, did an experiment by Goodwin et al. provide evidence to support the view that muscle receptors, along with joint receptors, contribute to joint position sense. Goodwin et al. found that when they anaesthetized the afferent fibers to the interphalangeal joints of the index finger of 7 subjects, awareness of passive movement of the joints was retained. The investigators found that when they passively moved the anaesthetized interphalangeal joints, the subjects could correctly sense when the finger was moved, which direction the joint was moved, and whether the joint was being held in full flexion or full extension. Because the afferents to some of the muscles acting at these joints were spared because of their location in the forearm, the investigators concluded that the intact muscle afferents must be responsible for the retained joint position sense.

Similarly, the previously described study of joint position sense following THA lead Grigg et al. (1973) to conclude that an extra-capsular component to joint position sense exists. Because joint position sense was retained in the hip after complete capsulectomy and replacement of articular surfaces, the investigators concluded that their results were in accordance with the study by Goodwin et al. (1972). Neither of these early studies offered any specific suggestions, however, as to what the extra-capsular sensory components might be. On the other hand, Stender and Drowatzky (1994), in their study of joint position sense in subjects with THA, concluded that their results support the view that muscle spindle afferents provide information about joint kinesthesia and position sense.

Barrack, Skinner, Brunet, and Cook (1984) compared joint position sense in the knee joints of a group of 12 professional ballet dancers to an age-matched control group. Holding the point of view that muscle and tendon receptors have a dominant role in joint position sense, Barrack et al. studied whether extensive athletic training has an effect on joint position sense. Ballet dancers were chosen as subjects because their training emphasizes muscle development and acute awareness of joint position. The results of this study revealed that the dancers could detect slight changes in position significantly earlier and more consistently (p=.004) than non-dancers. Dancers could detect knee movements of 2.7° (SD=0.8°) while the control group detected movements of 3.9° (SD=0.9°). The investigators concluded that the results of their study support the dominant role of muscle and tendon receptors for joint position sense and that extensive athletic training can have a beneficial effect on joint position sense. However, because the study by Barrack et al. is descriptive rather than experimental, a cause and effect conclusion cannot be drawn.

Muscle Strength and Postural Stability

In addition to sensory input, motor response has also been shown to affect postural stability (Fiatarone et al., 1990; Lord et al., 1991). Assuming a healthy central nervous system, one's ability to respond to sensory input is dependent on muscle strength and neuromuscular coordination. Although the role of neuromuscular coordination in postural control is virtually unexplored, several studies have investigated the role of muscle strength in postural control.

In a study of a number of physiological factors believed to be associated with postural stability in the elderly, Lord et al., (1991) found that under normal conditions, the main contributing sensorimotor factor in postural stability is sensory input from the lower extremities. Multiple regression analyses also revealed that under adverse conditions (where sensation is reduced), vision and lower extremity muscle strength become major factors.

Gehlsen and Whaley (1990) compared balance, muscular strength, and flexibility between two groups of elderly subjects: one with a history of falls (HF), and one with no history of falls (NHF). Static balance was assessed by the number of seconds that subjects could maintain balance while standing on one foot with eyes open and eyes closed. The investigators also assessed dynamic balance by counting the number of times subjects stepped off a solid 8-foot line while walking backwards. A Cybex ™ Leg Press Isokinetic Dynamometer (Lumex, Ronkonkoma, NY) was used to measure the combined force produced by contraction of hip extensors, knee extensors, and plantarflexors when performing a leg press movement. A goniometer was used to measure ROM at the hip, knee, and ankle joints. ANOVA revealed significant differences between the HF and NHF groups in measures of single leg stance with eyes open ($p<.001$) and eyes closed ($p<.05$), demonstrating that fallers had impairments in static balance compared to non-fallers. There were no significant differences between the groups in measures of dynamic balance. Separate ANOVAs also revealed significantly lower values of muscle strength ($p<.01$), hip flexion ROM ($p<.05$), and ankle dorsiflexion ROM ($p<.01$) in the HF group compared to the NHF group. Gehlson and Whaley concluded that static balance, as measured by single leg stance, distinguishes fallers from non-fallers. Although there were significant group differences in muscle strength, the investigators did not feel that strength was an important factor in loss of balance because a correlation between the strength and balance data revealed a low relationship (r = .19). The investigators also concluded that decreased ankle dorsiflexion and hip flexion ROM are related to falls only when extreme joint excursion is required.

The findings by Gehlsen and Whaley (1990) agree with those of Whipple et al. (1987) that lower extremity muscle strength was significantly lower in fallers than nonfallers. Whipple et al. compared muscle function of knee and ankle extensors and flexors in a group of 17 nursing home residents with a history of falls to a group of 17 nursing home residents with no history of falls. A Cybex II isokinetic dynamometer (Lumex, Ronkonkoma, NY) was used to measure muscle strength in the dominant knee and ankle at two different angular velocities. A four-way ANOVA was used to analyze differences in peak torque (PT) and power (POW) in the two groups at different velocities (60 and 120 degrees/sec), different joints (knee and ankle), and different movements (flexion and extension). Results of this study revealed significant differences in overall lower extremity muscle function between the two groups. Main effects of PT (F=13.1, p< .0025) and POW (F=31.9, p<.001) indicated that fallers were generally weaker than non-fallers when velocity, joint, and movement were not specified. Mean PT and POW of fallers (10.2 nm and 11.2 nmrad/s, respectively) was about one half that of non-fallers (20.6 nm and 23.8 nmrad/s). Unlike Gehlsen and Whaley, however, Whipple et al. concluded that dynamic strength of knee and ankle flexors and extensors are important factors in the prevention of falls. Although the studies by Whipple et al. and Gehlsen and Whaley provide a good comparison of fallers to non-fallers, these studies are descriptive in nature and do not provide evidence of a cause and effect relationship between muscle strength and incidence of falls.

In summary, there is ample literature demonstrating that various components of sensorimotor function are related to incidence of falls. Reductions in joint position sense, static balance, and lower extremity muscle strength have been found to be related to incidence of falls. Studies demonstrating a cause and effect relationship between sensorimotor factors and incidence of falls, however, are lacking. The next section reviews measurement of function, muscle strength, and postural stability.

Measurement of Function, Muscle Strength, and Postural Stability

In order to evaluate the effect of an exercise program on the outcome of interest, methods of quantifying the outcome must be determined. In this section, methods of measuring function, muscle strength, and postural stability are discussed. Different methods of quantifying each of these outcomes are presented along with advantages and limitations of each method.

Measurement of Functional Outcomes

Studies of functional outcome following hip replacement are difficult to compare and interpret because of the wide variety of assessments used to report function. Bryant, Kernohan, Nixon, and Mollan (1993) studied methods of quantifying function following joint replacement. These authors reported that there are at least 19 different methods of calculating a score that assesses function following THA. Most functional assessments used following joint replacement focus mainly on level of pain and discomfort when performing various activities. Assessments used to rate pain and discomfort during various functional activities are examples of self-assessment of function and are designed to elicit the patient's perception of the outcome of surgery. Self-assessments of function usually measure pain on an ordinal scale by using descriptive terms such as 'severe,' 'moderate,' 'mild,' or 'none' (Keele, 1948). Other self-assessments of function use a visual analogue scale with a 10 cm line that represents the range of pain from no pain to severe pain (Huskisson, 1974).

In recent years, use of functional assessments that rely on the patient's perception of the outcome has increased. These self-assessments have ranged from broad, quality of life measures such as the SF-36 (Ware & Sherbourne, 1992) and the Nottingham Health Profile (Hunt et al., 1980) to shorter, more specific assessments such as the Harris Hip Score (Harris, 1994), the Charnley-Merle d'Aubigne score (Charnley, 1972), the Judet score (Judet & Judet, 1952), and the Questionnaire on the Perception of Patients About Total Hip Replacement (Dawson et al., 1996).

Bryant et al. (1993) obtained hip scores using 13 different methods of scoring for 41 patients who had undergone 47 hip arthroplasties 15 to 20 years previously. The authors reported wide discrepancy between scores obtained using different methods. They also reported more agreement among the scores that used numerical rating systems than scores that used descriptive terms. For example, Spearman correlation coefficients revealed a correlation of .73 between the Judet and Merle d'Aubigne assessments when scores were expressed in terms of excellent, good, or failure but a correlation of .93 when the scores were expressed as percentages of maximum function. Bryant et al. also used data collected from 226 patients who had THA 1 year previously to study individual variables rather than an overall score. Spearman correlation coefficients were calculated for 19 individual variables. The investigators found that pain correlated poorly with every other variable. Walking distance, use of walking aids, and return to work showed the highest correlations with the largest number of variables. A factor analysis identified three 'core' factors among the 19 variables studied. The three 'core' factors identified were functional activity, movement, and pain. Bryant et al. found that the best single measure of functional activity was walking distance, while the best single measure of movement was hip flexion ROM. Based on their examination of 19 variables in the 1-year follow-up, the authors concluded that the essential variables for assessing outcome of THA appear to be walking distance, hip flexion ROM, and pain. They further commented that measurement of additional variables is unnecessary because it adds little information about the outcome of THA.

Dawson et al. (1996) developed a 12-item questionnaire to assess functional outcome in patients who had THA. This questionnaire developed by Dawson et al. was named "Questionnaire on the Perception of Patients About Total Hip Replacement" and is frequently referred to as the "12-Item Hip Questionnaire." Dawson et al. obtained scores on the 12-Item Hip Questionnaire from 220 patients before THA and 6 months post-surgery. The investigators then compared the 12-Item Hip Questionnaire scores to scores on the SF-36, the Arthritis Impact Measurement Scales (AIMS), and the Charnley-

Merle d'Aubigne system. Pearson correlation coefficients were calculated between total score on the 12-Item Hip Questionnaire and related measures from the other three assessment systems, both pre-operatively and at the 6-month follow-up. Scores on the 12-Item Hip Questionnaire were found to correlate moderately with the Charnley-Merle d'Aubigne scores on pain and walking both pre- and post-operatively. Correlation coefficients ranging from $r=-.40$ to $r=-.58$ were statistically significant ($p<0.01$). Significant correlation ($p<0.01$) was also found between scores on the 12-Item Hip Questionnaire and scores on the SF-36 and AIMS in related areas such as physical function and pain. Correlation coefficients ranged from $r=.55$ to $r=-.70$ in the areas of physical function and pain. The authors concluded that the 12-Item Hip Questionnaire provided comparable information about function before and after THA as the Charnley-Merle d'Aubigne, SF-36, and AIMS assessment systems. The 12-Item Hip Questionnaire, however, was considered easier to administer and score.

Although there is agreement that the patient's perception of function is an important outcome to assess, there is lack of agreement about how this should be done. Health care professionals continue to use a wide variety of methods to assess functional outcomes and the patient's perception of function, making comparisons between studies difficult. For this reason, many studies of THA outcomes focus on assessments that can better quantify function.

Measurement of Muscle Strength

In the three studies of muscle strength following THA that are described previously, a different method of measuring strength was used in each study. In order to better understand these studies and make relevant comparisons among these and other studies, a discussion of issues relevant to testing strength of muscles follows.

Clarkson and Gilewich (1989) defined muscle strength as the maximal force or torque that a muscle or muscle group can produce in one maximal effort, when type of muscle contraction, velocity of movement, and joint angle(s) are specified. True measurement of tension developed in a muscle during maximal effort would require direct attachment of a measurement device to the muscle fibers (Smith, 2000). Instead, all clinical measurements of muscle strength use indirect methods that employ some form of sensing device applied externally to a specific body part.

Clinically, the most frequently used method of strength assessment is the manual muscle test (MMT). Manual muscle testing uses standardized test positions and procedures for applying and grading resistance. The "sensing device" used in this method of strength assessment is the tester's hand applied to the body part as the subject attempts to move the body part in a specified direction. The tester manually resists the movement with a force that is directed perpendicular to the subject's body segment. The examiner rates the amount of force exerted by the subject's muscle or muscle group against the manual resistance ("make test"), or the amount of force needed to cause the subject's body segment to give way and move in the direction of the force applied by the tester ("break test") (Bohannon, 1988). Although the MMT is simple to use and provides useful information to the clinician, it does not provide quantifiable units of force or torque produced by the muscle. Additionally, tester strength, subjectivity in rating the force exerted by a muscle, and lack of sensitivity present limitations.

The use of a hand-held dynamometer (HHD) provides the easiest adaptation of the MMT, while providing quantifiable units of force or torque. When using a HHD to measure strength, many of the same principles of strength measurement used for MMT are applied. Standardized test positions and procedures for load application are used, but the dynamometer held in the tester's hand is the sensing device. A "make test" or "break test" can be used, but the "make test" is generally preferred when using a HHD because of improved reliability (Wikhom & Bohannon, 1991). The force exerted by the subject pushing against the device is transmitted to a pressure sensor or strain gauge, and the output is displayed in units of peak force or calculated peak torque. The HHD is most useful for quantifying isometric muscle force or torque. The greatest limitation of the HHD is that it requires stabilization of the device and the subject's body part as the subject exerts a maximal contraction. Therefore, tester strength becomes a factor when testing large muscles that are capable of producing high forces or torques (Wikhom & Bohannon).

Isokinetic dynamomters are frequently used for dynamic testing of muscle strength. Dynamic testing involves measurement of concentric or eccentric muscle force as the muscle moves the body segment through a range of motion. Isokinetic dynamometers are also useful for measuring strength of very strong muscles than cannot be adequately stabilized for measurement with a HHD. Measurement of strength at different speeds of movement and through different ranges of movement can be performed. Output is provided in units of peak force/torque or sometimes as average force/torque through the range of movement. The primary limitation of muscle strength testing with isokinetic dynamometers is that these devices are very large, expensive, and require a lengthy set-up time. Because joints must be aligned with the mechanical axis of the device, testing of muscles at several different joints is not easily done.

Ideally, the method of strength testing selected is the easiest method that reveals to the clinician whether a patient has adequate strength to perform functional activities important to that patient. Because there are no strength measurements that can determine whether a patient has enough strength for a functional activity, the clinician or researcher should select the method capable of measuring strength under conditions similar to the task of interest (Smith, 2000).

Measurement of Postural Stability

Postural stability is defined as the ability to maintain or control the center of mass relative to the base of support in order to prevent falls (Horak, 1987). Balance is the process by which a subject uses equilibrium responses and movement strategies to maintain postural stability under conditions of perturbation (Westcott, Lowes, & Richardson, 1997). Although the terms postural stability and balance are often used interchangeably, the discussion that follows addresses only methods used to measure postural stability.

A number of clinical measures are used to assess postural stability. Common clinical measures include the Romberg test and one leg stance. The Romberg test assess whether a patient can stand heel-to-toe with eyes open and eyes closed. The one leg stance test times how long a patient can stand on one leg. Both the Romberg test and one leg stance test indirectly assess subjects' ability to maintain their center of mass over a reduced base of support. Although both tests are easy to administer, the information they provide is limited.

Force platforms are often used to obtain a variety of measures associated with postural stability, including ground reaction force and torque, center of pressure, and postural sway. In general, a force platform can be described as "a rigid plate supported by force transducers, usually placed at the corners" (Shimba, 1984). Thus, in it's simplest form, a force platform uses load cells usually made with strain gauges to measure ground reaction force and torque (Davis, DeLuca, & Ounpuu 1995). Beyond the direct measurement of ground reaction forces by the load cells on the platform, other values can be calculated. Some force platforms, for example, provide a measure of center of pressure. Center of pressure (COP) is the point of application of the resultant ground reaction force (Bizzo, Guillet, Patet, & Gagey, 1985), and is calculated by using vertical force measures at three or more points on the platform (Goldie, Bach, & Evans, 1989). A force platform measurement commonly reported in the literature is COP excursion. COP excursion is a distance measurement reported in centimeters or inches. The term "stabilometry" is used when force platform systems are used to take measurements of the movements of a subject's COP over time (Hasan, Lichenstein, & Shiavi, 1990). Some force platform systems attempt to define limits of sway or limits of COP movement by expressing COP excursion relative to base of support. When considering the stated definition of postural stability, expression of COP excursion relative to base of support empirically makes sense.

When considering the various measures of postural stability and the measurement systems used to obtain these measures, it is important to consider what type of information is needed. Clinical measures such as the single stance and Romberg tests are useful to screen patients who have impairments in postural stability. If more precise information is needed such as direction and magnitude of the instability, then a force platform should be used. A force platform that provides information about excursion of the COP relative to the base of support would be most useful.

Exercise Programs to Improve Strength and Postural Stability

Numerous studies assess the effects of exercise on muscle strength in a healthy population, but few studies that address the effect of exercise on strength in patients with THA. Similarly, several studies were found that investigated the effects of exercise on postural stability, but none that addressed postural stability in patients with THA. A review of the available studies follows.

Exercise Programs to Improve Muscle Strength

In one of the few studies that assessed the effects of a post-rehabilitation exercise program for patients with THA, Sashika et al. (1996) studied the effects of a home exercise program on 23 patients who had THA 6 to 48 months previously. The mean time period following THA was 26.4 months. Subjects were assigned to one of three groups by matching for age, gender, and length of time after surgery. Group A (n=8) performed hip flexion ROM exercises and "low resistance isometric exercises" for the hip extensors, hip abductors, and knee extensors that consisted of resisted straight leg raises in supine, prone, and sidelying as well as resisted knee extension in sitting. Group B (n=8) received the same exercises as Group A, plus eccentric abductor exercises in standing, and Group C (n=7) received no home exercise program. Although the authors indicated that the subjects in each group were matched for age, gender and time since surgery, they did not indicate whether they were randomly assigned to groups once they were matched. The two exercise groups exercised both hips 15-20 minutes twice a day for 6 weeks. Pre- and post-exercise measures of hip ROM, hip abductor torque, and gait speed and cadence were obtained. The results of a two-way ANOVA showed a significant improvement in hip abductor strength from 13.4 to 16.6 ft·lbs in Group A ($p < .01$), from 12.5 to 21.0 ft·lbs in Group B ($p < .01$), and from 9.1 to 13.6 ft·lbs in Group C ($p < .05$). The investigators hypothesized that subjects in the control group may have improved significantly because they became motivated to become more active when their initial test showed very weak hip abductors. Gait speed and cadence also improved significantly in Group A ($p<.05$) and Group B ($p<.01$) but not Group C. The researchers attributed this improvement in gait to improved hip abductor strength. ROM did not improve significantly in any of the groups. Sashika et al. concluded that the results of their study reveal residual muscle weakness in the hip abductors in subjects 6-48 months following THA. They further commented that their results refute an earlier study by Burton and Imrie (1973) that suggested that progressive ambulation is sufficient to improve hip abductor strength in patients with THA. Sashika et al. concluded that a 6-week home exercise program can be effective for improving hip abductor strength in patients who are 6-48 months post-THA.

The only other study located that investigated the effects of a post-rehabilitation exercise program following THA was a study performed in Sweden where the effects of an exercise program started 2 months after surgery were assessed (Johnsson, Melander, & Onnerfalt, 1988). Johnsson et al. studied 17 men and 13 women who had unilateral, cemented THA. After receiving the same physical therapy during their 7-12 day stay in the hospital, patients were randomly placed into one of two groups. Group A consisted of 14 patients with a mean age of 70 (58-76) years who were given organized physical therapy sessions. Group B consisted of 16 patients with a mean age of 66 (50-74) years who had no physical therapy following their hospital discharge. The physical therapy sessions started 2 months post-operatively and were administered two times per week for 1 month, followed by once a week for 1 month or once every other week for 2 months. Physical therapy exercise sessions consisted of various types of bridging, weight shifting, stepping, and sit to stand exercises for a duration of approximately 45 minutes. Measures of maximum isometric strength of hip flexors, extensors, abductors and adductors as well as knee flexors and extensors were obtained using a strain gauge dynamometer pre-operatively, 6-8 weeks post-operatively, and 6 months post-operatively. Measures of hip flexion, extension, abduction, and adduction were also obtained during the test sessions. Mean strength differences between the 2-month and 6-month post-operative assessments for hip abductors were 21 N (SD=18) and 14 N (SD=21) for Group A and Group B, respectively. Mean strength differences between the 2-month and 6-month post-operative assessments for knee extensors were 78 N (SD=54) and 47 N (SD=53) for Group A and Group B, respectively. Student's t-tests examining differences between Group A and Group B on measures of change from the 2 month to 6 month post-operative values of strength, however revealed that these differences were not statistically significant. Differences between groups in measures of hip ROM also were not statistically significant. The authors concluded that although they used a relatively small sample size, it appears that late organized physical therapy for THA using the exercises described, does not lead to significant improvement in muscle strength and ROM. It should be noted that the physical therapy group did obtain larger strength gains than the control group but differences were not statistically significant.

There are several problems with the above study that could have confounded the results. First, 2 months post-surgery is considered early for a post-rehabilitation program. Some investigators have found that the greatest improvements in pain, mobility, and functional status occur during the first 3 months after surgery, and that improvements continue between 3 and 6 months following surgery, but at a slower rate (Gogia et al., 1994; Murray et al., 1972). Therefore, differences in healing and pain levels could have been confounding factors in the study by Johnsson et al. It should also be noted that the 2-month strength values in the control group were considerably lower than the 2-month strength values in the exercise group. Lower starting values on a pre-test tend to show larger changes than higher starting values (regression toward the mean). Therefore, the control group would have more potential to increase strength than the exercise group. Although the investigators state that they obtained measures of muscle strength in both groups pre-operatively, they did not use these measures to test for equality between groups prior to the intervention. In summary, lower starting values of strength in the control group, and beginning the post-rehabilitation exercise program too soon could both have been confounding factors in this study. Both of these problems could have been avoided by using a mixed model ANOVA to look at differences within and between groups and possibly using initial strength as a covariate in ANCOVA.

Although no other studies investigating exercise as an intervention for muscle weakness in patients with THA could be found, a study by Fiatarone et al. (1990) is reviewed here because it is a landmark study that investigated the effects of high intensity resistance training in elderly subjects. Fiatarone et al. provided a high intensity resistance training program to a group of 10 frail subjects with a mean age of 90.2 (86-96) years. The subjects participated in a training program three times per week for 8 weeks. The program consisted of 3 sets of 8 repetitions at 50% of 1-RM during the first week and was increased to 3 sets of 8 repetitions at 80% of 1-RM for the remaining 7 weeks of training. All subjects completed the training sessions with the exception of one 86 year old male who stopped after 4 weeks because of complaints of a "straining sensation" in the general area of a previously repaired inguinal hernia. The average strength gains after 8 weeks of training were statistically significant ($p<.0001$) at 174% improvement on the right and 180% improvement on the left. The investigators concluded that high intensity weight-training is safe and can produce significant strength gains in frail, elderly men and women.

Exercise Programs to Improve Postural Stability

The effects of various types of exercise on postural stability are not well understood. In one of the earliest studies undertaken to assess whether an exercise program can improve postural stability, Lichtenstein, Shields, Shiavi, and Burger (1989) studied 50 elderly women over 65 years of age. Intact groups from two apartment buildings were randomized to serve as a control or exercise group. Baseline characteristics of subjects in the exercise and control groups were similar with the main difference being that the exercisers were better educated and had better vision. The exercise program consisted of 10 minutes of stretching exercises, 10 minutes of static balance exercises (standing on one leg), 15 minutes of "active balance" exercises (tandem heel-toe gait), 10 minutes of exercise maneuvers in response to color signals), and 10 minutes of walking. This exercise program was designed to improve balance, reaction time, and flexibility. The exercise group participated in this exercise program at the activity center in their apartment building three times a week for 16 weeks while the control group did nothing. Balance was assessed in both groups on a force platform at baseline and after 16 weeks. Although there were improvements in a number of sway measures in single stance with eyes open in the exercise group compared to the control group, none of the differences reached statistical significance at an alpha level of .05. In the more difficult task of single stance with eyes closed, the control group showed significantly larger improvements in sway than the exercise group (p=.02). Between group differences were assessed using ANOVA but perhaps should have been assessed using ANCOVA to adjust for differences in baseline characteristics between groups such as visual acuity. The researchers acknowledged that the use of intact groups within apartment buildings could have confounded the effects of exercise. Vision in particular, is known to affect balance and may have influenced response to the exercises used in this study.

In another early study, Roberts (1989) assessed the effects of a walking program on balance in elderly subjects. The experimental group consisted of 26 women and 5 men with a mean age of 71.8 years who walked for 30 minutes three times per week for 6 weeks. The control group consisted of 26 women and 4 men with a mean age of 71.8 years who maintained their regular activities for 6 weeks. The Roberts Balance Scale (Roberts & Fitzpatrick, 1983) was used to measure balance before and after the intervention. The Roberts Balance Scale consists of eight stances that challenge balance mechanisms by altering base of support (single or double stance) and visual cues (eyes open or eyes closed). Time in seconds up to a maximum of 30 seconds that a subject is able to maintain each of the eight stances is summed for a total score that can range from 0 to 240 seconds. In addition, the subjects' perception of balance was attained using the Balance Perception Questionnaire developed by the author of this study (Roberts). The experimental group was found to have a significantly better score on the Roberts Balance Scale than the control group (F=5.1, p=.03). The scores on the Balance Perception Questionnaire, however, were not significantly different between groups (p=.58). The investigator concluded that a 6-week walking program is effective for improving balance in elders but offered that perhaps the change was not large enough for detection by the participants.

In a study of the effect of low intensity aerobic exercise on muscle strength and balance in elderly sedentary subjects, Mills (1994) found no significant difference in strength and balance after 8 weeks of training when compared to a control group who did not exercise. A MANOVA was used to examine differences between groups on measures of muscle strength at the knee and ankle. Differences between groups were found to be non-significant at the knee (p=.55) and the ankle (p=.12). The experimental group did improve their balance by 22% as measured by the Roberts Balance Scale but a t-test used to compare differences between groups found this difference to be non-significant (p=.39). In reviewing the exercise program used in the study, it appears that the exercises consisted of a series of passive and active movements of the knees and ankles performed for about 20 minutes. The only exercises that used any resistance were standing toe raises and knee bends that used body weight as resistance. During these two exercises, subjects were asked to hold on to the back of a chair for support. Thus, it may be that the exercise intensity was not high enough to obtain significant increases in muscle strength. Improvements in balance should not have been anticipated because patients never exercised in an unsupported, weight bearing position. Improvements in balance owing to improvements in muscle strength alone may have been expected, but no changes in strength occurred.

In a retrospective study of balance in older women, Lord et al. (1993) compared measures of balance, reaction time, and muscle strength in elderly women who had been exercising regularly for 12 months to age-matched women who were inactive. The exercise group participated in two exercise classes per week, each consisting of 1 hour of gentle aerobic exercises that emphasized balance and flexibility. Student's t-tests were calculated to analyze differences in the means of a number of sensorimotor measures between the two groups. The results revealed that the group of exercising women performed significantly better in tests of quadriceps strength ($p < .01$), reaction time ($p < .05$), and postural sway on a compliant surface ($p < .05$) than women who did not exercise. The researchers concluded that the results of this study suggest that exercise may improve stability and thus help prevent falls by improving the function of a number of sensorimotor systems that contribute to stability. They caution, however, that because of the limitations of a retrospective study, causal directions should not be implied.

Judge et al. (1993) studied the effects of a vigorous program that included lower extremity strengthening, walking, and postural control exercises on single-stance balance in healthy, older women. These investigators hypothesized that a previous study that failed to show improvements in single-stance balance (Lichtenstein et al., 1989) did so because the exercise intervention did not include lower-extremity resistance exercises. Judge et al. hypothesized that adding resistance exercise to a postural control exercise program would improve single-stance balance more than an exercise program of only postural control exercises. The investigators based this hypothesis on the knowledge that single-stance balance requires appropriate lower extremity contractions in addition to vestibular, visual, and proprioceptive function. Judge et al. randomly assigned subjects to either a treatment group (n=12) that received combined training or a control group (n=9) that received flexibility training. Exercises in the combined training group consisted of lower extremity resistance training, brisk walking, flexibility, and postural control exercises. The resistance training consisted of exercises on variable resistance machines for hip and knee extensors, and sitting leg presses performed at 70% of 1-RM. Two sets of bilateral knee extensions and sitting leg presses were performed with 10-14 repetitions per set. Two sets of 20 repetitions each of unilateral standing hip extensions were also performed.

The walking program consisted of walking for 20 minutes at a brisk pace while flexibility and postural exercises consisted of stretching exercises, pelvic tilt and bridging exercises, and simplified Tai Chi exercises that involve slow, controlled movement in a weight bearing position. The flexibility training group served as the control and consisted of the same flexibility and postural exercise program as the combined group but did not include resistance training and walking. The combined training group exercised three times a week for 6 months while the flexibility training group performed no exercise for the first 12 weeks then exercised once a week the remainder of the time. Before training and at the end of training, postural sway measurements were obtained on a force platform and compared between and within groups. A repeated measures ANOVA revealed that the 18% improvement in single stance sway in the combined training group was statistically significant (p=.023) but the improvement in sway in the flexibility training group was not significant (p=.3). Judge et al. concluded that this was the first report of an effective intervention program that improved force plate measures of static balance without an intervention that trained single stance. Another interesting finding in this study was that correlation coefficients calculated between sitting leg press force and sway in single stance revealed no significant relationship (p>.5; r not reported). The investigators concluded that this lack of correlation suggests that control provided by postural muscles may be the critical factor in single-stance balance rather than muscle force development. They further offered that lower extremity strength appears to be a necessary factor but not sufficient by itself for improving single stance balance.

Although the results of studies investigating the role of exercise on postural stability are varied, it is clear that the type of exercise selected for the intervention are important. The exercises selected must be specific to the desired outcome. In order to improve postural stability in patients with THA, for example, exercises selected should be in a weight-bearing position and must necessitate a balance response. They must not, however, exert excessive or abnormal forces on the operated hip.

Summary

Over the last 10 years, improvements in the design of hip prosthetic components, fixation techniques, and surgical procedures have allowed THA to be performed successfully in a wider age range than ever before. The rehabilitation process for patients who have THA has received much less attention. Although a consensus on the standard of care for acute physical therapy practice following THA was reached in 1996, the effects of a more advanced physical therapy exercise program instituted later in the recovery process have not been investigated.

Many patients who undergo THA in order to resume an active lifestyle find that they are reluctant to participate in physical activity after surgery because of apprehension about the replaced hip. Although surgeons often counsel their patients to restrict activities that could lead to prosthetic component loosening, the appropriate activity level and type of activities allowed is still unclear. The literature supports avoidance of sports that involve high impact forces, but low impact activities such as walking, golf, swimming, biking, and bowling have not been shown to increase the incidence of component loosening.

The most commonly assessed outcomes of THA relate to pain and mobility. Other outcomes of interest to clinicians include functional outcomes, gait parameters, muscle strength, postural stability, and activity level. Although pain and mobility outcomes indicate an overall satisfaction with the results of THA, assessment of muscle strength outcomes reveals deficits in patients who had THA 1-2 years previously. Postural stability deficits have also been found in patients who are 1-year post-THA.

In spite of the deficits found in muscle strength and postural stability, few studies have assessed the effects of a post-rehabilitative exercise program on these deficits. One study showed that a 6-week home exercise program was effective for improving hip abductor strength in patients who were 6-48 months post-THA. Another study concluded that a physical therapy program instituted 2 months post-THA did not lead to significant improvement in muscle strength. There are no studies that assessed the effects of a post-rehabilitative exercise program on postural stability deficits in patients with THA. The effects of exercise on postural stability have been studied in healthy, older men and women. These studies indicate that postural stability can be improved in healthy older subjects, when the exercises are performed in a weight-bearing position and necessitate a balance response.

CHAPTER III

METHODS

The purpose of this study was to compare the effects of two different exercise programs on postural stability in patients who were 4 to 12 months post-surgery for THA. The effects of a control exercise program that emphasized mobility was compared to an experimental exercise program that emphasized balance and weight bearing. All subjects were tested for strength, postural stability, and function before and after their 8-week exercise intervention. This exercise investigation was an experimental study, utilizing a pretest-posttest control group design. The dependent variables consisted of a measure of postural stability, four measures of lower extremity muscle strength (hip flexors, hip extensors, hip abductors, and knee extensors), a score of self-perceived physical function, and answers to two questions about fear of falling. The independent variable was two levels of an exercise intervention. This chapter describes the subjects, instruments, procedures, and data analysis.

Subjects

Thirty subjects of any age, race, or gender who had undergone THA at least 4 months, but no more than 1 year prior, were recruited for this study. A sample of 30 subjects allowed random assignment of subjects into two groups of 15. This was determined to be an adequate sample size to achieve power of .80 for a large effect size at an alpha level of .05 for two repeated measures MANOVA. Although there is no conventional standard for acceptable power, many statisticians suggest that a beta of .20 with corresponding power of 80% provides acceptable protection against Type II error (Cohen, 1988; Young, Bresnitz, & Strom, 1983). The sample size estimation was based on an average correlation of .60 between pre- and posttest measures of strength and postural stability obtained on pilot data.

Subjects were recruited consecutively from the Texas Woman's University (TWU) Health Promotion and Research Center (HPRC) on the Presbyterian campus in Dallas, Texas. The HPRC was established in March 1999 to facilitate collaboration between neighboring Presbyterian Hospital physicians and TWU faculty and students. The HPRC currently provides musculoskeletal assessments free of charge to clients referred by physicians. In return, research efforts at the HPRC are supported and encouraged. Additionally, subjects were recruited consecutively from four orthopedic practices in the Dallas area. Each of the four orthopedic practices provided the investigator with telephone lists of patients who had undergone THA within the last 12 months.

Potential subjects who met the above inclusion criteria (i.e., THA between 4 months and 1 year previously) were screened for the following exclusion criteria: (a) pain with weight bearing on either extremity, (b) low back pain at the time of the study that was acute or chronic in nature, (c) hip revision surgery, (d) diagnosed vestibular problems, (e) central or peripheral nervous system involvement, and (f) dementia or decreased cognitive status that would affect ability to follow simple instructions.

Subjects who met the inclusion criteria and possessed none of the exclusion criteria were asked to volunteer for the study. A patient information sheet was used to assist in screening subjects for inclusion and exclusion criteria (see Appendix A). Those who elected to participate in the study read or were read to, an explanation of their rights as human subjects. They were then asked to sign an informed consent that is in accordance with Texas Woman's University's Institutional Review Board (see Appendix B). A random table of numbers was used to randomly assign subjects entered into the study to either the experimental or control group.

Instruments

The 12-Item Hip Questionnaire (Dawson et al., 1996) was used to assess physical function. This tool is also known as the Questionnaire on the Perception of Patients About Total Hip Replacement, but will be referred to by its shorter name in this paper. The 12-Item Hip Questionnaire was selected among several functional assessments because of its simplicity of administration and scoring. Additionally, this tool pertains specifically to functional ability of patients who have had THA. Thus, construct validity and test-retest reliability have been determined in reference to the target population of the present study (Dawson et al.). The 12-Item Hip Questionnaire is a self-administered paper and pencil exam whereby the patient rates pain and difficulty associated with performing a series of ADL. The score on the questionnaire is a total score obtained by summing the rating on each of the 12 items. The range of scores is from 12 to 60 with a low score indicating a high level of function. The 12-Item Hip Questionnaire can be found in Appendix C.

Measures of postural stability and lower extremity strength were assessed using the Human Performance Measurement (HPM) system (Human Performance Measurement, Inc., Arlington, TX). The HPM is a computer-automated system that integrates a battery of tests used to evaluate a broad range of sensorimotor functions. Each of the 14 modular test devices that comprise the HPM system can be used to assess one or more basic elements of performance (BEP). For this study, the BEP IIIa and BEP IV system components were used to measure muscle strength and postural stability, respectively. The BEP for Windows™ (Human Performance Measurement, Inc., Arlington, TX) software was used to operate the BEP modules, record, and store data on an IBM compatible notebook computer.

The BEP IIIa was used in this study to measure isometric strength of selected lower extremity muscles. The BEP IIIa is a hand-held transducer that measures the amount of force produced by a muscle (see Appendix D). The BEP for Windows™ software automatically calculates torque in Newton·meters using estimated moment arm lengths that are based on the subject's height. The standard error associated with estimated segment lengths based on stature has previously been shown to be approximately 1.0 cm when compared to measured segment lengths (Webb Associates, 1978).

The validity of hand-held dynamometers as a measurement of muscle strength has been previously determined (Jackson, Jackson, Frankowski, Long, & Meske, 1994; Surburg, Suomi, & Poppy, 1992). The reliability of the BEP IIIa for measurement of muscle strength in THA patients was assessed by Jackson et al. (2001) in a subset of subjects used in their study of 1-year outcomes following surgery for THA. Calculated intraclass correlation coefficients (ICC) used to estimate intrarater reliability ranged from .85 to .99. In the current study, a repeated measure of muscle strength for one randomly selected muscle (hip flexors, hip extensors, hip abductors, or knee extensors) was obtained for each subject. The resulting 30 repeated measures were used to estimate intrarater reliability of the strength measures taken with the BEP-IIIa.

The BEP IV system component was used in this study to measure postural stability. The BEP IV consists of a lightweight, portable force platform that provides measures of medial-lateral, anterior-posterior, and total stability (see Appendix D). Only measures of total stability were used for this study. The force platform measures postural stability by tracking changes in the center of pressure along two perpendicular axes (lateral and anterior-posterior) as the subject stands on either one leg or both legs. Steadiness, an aspect of postural stability defined as the ability to keep the body as motionless as possible, is stressed during tests of postural stability using the BEP IV. The BEP for Windows™ software first computes "percent instability" as the ratio of the average movement of the center of pressure to the base of support. This computed "percent instability" is then subtracted from 100% to provide a score of "percent stability." The validity of using force plate measures of center of pressure changes as an index of postural steadiness has previously been demonstrated (Goldie et al., 1989). The test-retest reliability of percent stability measurements using the HPM-BEP IV module was estimated using retest data from each subject. Two tests of postural stability were performed within the same test session. The two tests of postural stability were separated by 30 to 40 minutes

Procedures

After being randomly assigned to a treatment group, all subjects were pre-tested on measures of physical function, fear of falling, strength, and postural stability. They were then instructed in the appropriate exercises for their group assignment, and post-tested at the completion of the exercise intervention.

Pre- and Post-Intervention Measurements

Measures of physical function, fear of falling, postural stability, and muscle strength were obtained on all subjects before and after the 8-week exercise intervention. Subjects were first asked to complete the 12-Item Hip Questionnaire in order to obtain an assessment of their perception of function. Subjects read and responded to each of the 12 items by circling a response from 1 to 5 that best represented the amount of pain or difficulty they had experienced over the last 4 weeks, when performing the specified activity of daily living (ADL). A rating of "1" is indicative of little or no trouble or discomfort associated with performing an ADL, while a rating of "5" is indicative of great difficulty or discomfort. The scores on each item were then summed to obtain a total score. The 12-Item Hip Questionnaire can be found in Appendix C. After completing the questionnaire, fear of falling was assessed by asking each subject the following two questions. "Are you afraid of falling?" and "Since your surgery, are there any activities that you avoid doing because you are fearful of falling?" Each of the two questions had to be answered with a "yes" or "no" response.

Next, postural stability was assessed in single stance with eyes open using the BEP- IV force platform. Both legs were tested and the order of testing (involved or uninvolved) was determined by randomly selecting with replacement whether the involved or uninvolved limb first would be tested first. Stability was assessed as subjects attempted to stand steadily on one leg while holding the opposite leg in zero degrees of hip extension and 90 degrees of knee flexion. Subjects did not wear shoes during testing on the force platform but wore socks if they wished. Subjects were first instructed to stand on both feet and look straight ahead until an audible beep from the HPM system signified the beginning of the test. Upon hearing the beep, subjects raised one foot off the platform by flexing the knee to 90 degrees, and removed their hands from the table in front of them. They then attempted to maintain this single stance posture as steadily as possible until a second beep signified the end of the 10-second trial. The trial was terminated before the 10-second maximum when subjects lost their balance and had to touch down with a foot or hand. Three trials were measured with a 5 to 6-second rest taken in between each trial. The BEP for Windows™ software program calculated an average percent stability value based on center of pressure data gathered during the three

10-second (or less if a trial was terminated early) intervals. When subjects lost their balance and had to touch down with the hands or the non-supporting foot before the 10-second timed trial was completed, percent stability for that trial was based on a shorter period of time than 10 seconds. Although there were three trials, the BEP for Windows™ software calculates a mean based on the two trials with the most similar percent stability values. The calculated mean of the two trials of total stability for each subject was used for analysis.

Muscle strength of the hip flexors, hip extensors, hip abductors, and knee extensors was measured last using the BEP-IIIa force transducer. Again, both sides were tested and the order of testing was determined as previously described. Although involved to uninvolved side comparison was not the purpose of this study and was not examined statistically, the comparison may provide useful information about the patients' overall recovery. Additionally, this information was added to an existing database on THA outcomes. All muscle force measurements were taken in a gravity-lessened position, using a "make" test. To perform a "make" test, the examiner held the dynamometer steady, and instructed the subjects to push against it. Instructions to the subjects were to gradually start pushing, and then to increase their force until they were pushing as hard as they could. The force applied to stabilize the transducer was directed perpendicular to the transducer head at all times.

Muscle tests were performed in the following order: hip flexors, hip extensors, hip abductors, and knee extensors. Hip flexors and extensors were tested in the sidelying position with the test leg on top. To test the hip flexors, the test leg was positioned in 90° of hip and knee flexion. The tester faced the subject and positioned the force transducer over the distal aspect of the anterior femur. To test hip extensors, the test leg was positioned in 0° of hip flexion and 90° of knee flexion. The tester was positioned behind the subject and placed the force transducer over the distal aspect of the posterior femur. Hip abductors were tested in the supine position with the hip and knee in neutral flexion/extension and the hip abducted slightly. The tester stood on the side of the leg to be tested and placed the force transducer over the distal aspect of the lateral femur. Knee extensors were tested with the subject in the seated position with the hip and knee flexed 90°. The tester aligned herself at the level of the distal tibia and placed the transducer against the anterior surface of the distal tibia as the subject attempted to extend the knee. Two trials were performed for each muscle tested. Attention was paid to stabilizing unwanted motion during testing of each muscle group.

As with the tests for postural stability, the beginning of each trial was indicated with an audible beep. For each trial, subjects were instructed to gradually start pushing against the dynamometer when the beep was heard, and then to push as hard as possible until an audible beep signified the end of the trial (5 seconds). A second trial was then performed in the same manner after a brief (2-3 s) pause. The BEP for Windows™ software automatically calculated mean muscle torque values using the average of the two trials for each muscle tested. For this study, muscle torque was calculated using estimated limb segment lengths that were based on the subject's height rather than using actual measured limb segment lengths.

Exercise Interventions

Subjects were given a different set of exercises depending on whether they were in the control exercise group or the experimental group. Both exercise programs were designed to provide benefits to patients while adhering to usual total hip precautions. The exercise protocol given to the control exercise group consisted of seven basic isometric and active ROM exercises commonly used during the acute phase of recovery from THA. The exercises given to the control group were as follows: (a) gluteal muscle sets (b) quadriceps sets, (c) hamstring sets, (d) ankle pumps, (e) heel slides, (f) hip abduction in supine, and (g) hip internal and external rotation in supine. Subjects in the experimental exercise group received a set of seven weight bearing exercises that consisted of the following: (a) sit-to-stand exercise, (b) unilateral toe raises, (c) partial knee bends with progression, (d) one-legged standing balance with progression, (e) knee raises with alternating arm raises (marching), (f) side and back leg raises in standing, and (g) unilateral pelvic raising and lowering in standing. Exercises for both groups can be found in Appendix E.

Subjects in both groups were instructed to perform their exercise programs at home three to four times per week for 8 weeks. Once subjects were instructed in their exercises, subjects in both groups had one follow-up visit within the next 2 weeks to assure that they were performing exercises correctly and to progress the exercises appropriately. A second follow-up visit was scheduled within the next 2 weeks. All subjects began by performing one set of 15 repetitions of each exercise and were instructed to increase to 20 repetitions after the first follow-up visit. On the second follow-up visit, the exercises were progressed to 2 sets of 15 and subjects were instructed to increase the repetitions in each set to 20 in the next 2 weeks as tolerated. No resistance was added to any of the exercises, but changes in form were made to increase the degree of difficulty of the exercises. Subjects continued to exercise on their own for the remainder of the 8-week period. All subjects maintained an exercise log (see Appendix F) during the 8-week intervention period and were asked to turn in their log at the end of the 8 weeks. The exercise logs were used to check compliance to the exercise program. A minimum of 50% compliance was required to remain in the study. Each subject who completed the study was remunerated $50 for participating. Subject remuneration was available from a grant awarded by the Texas Physical Therapy Education and Research Foundation (TPTERF).

Data Analysis

Data were analyzed using the 9.0 version of SPSS for Windows (SPSS Inc., Chicago, IL). Descriptive statistics were calculated for the subjects' age, height, weight, and time since surgery, as well as for pre- and post-exercise measures of function, fear of falling, postural stability, and strength. The median and minimum/maximum values for pre- and post-exercise scores on the hip questionnaire for each group were determined, and number of "yes" and "no" responses to the fear of falling questions were counted.

The mean, standard deviation, and minimum/maximum values for strength and postural stability were determined for each exercise group of subjects before and after the exercise intervention.

An analysis of variance (ANOVA) was conducted using repeated measures of muscle strength in randomly selected muscles in order to calculate an intraclass correlation coefficient (ICC) that provides a combined estimate of reliability for the strength measurements of the four muscles tested. ICC(3,2) values for muscle strength measurements were used to assess intra-tester reliability. Test-retest reliability of postural stability measurements was determined by performing an ANOVA between measures of percent total stability obtained during each of the two tests within the same session, and an ICC(3,2) was calculated.

The Mann-Whitney U test was used to test for differences between the groups on hip questionnaire scores. Within group differences between the pre- and post-intervention measures on the 12-Item Hip Questionnaire scores for the control group and the experimental group were analyzed using the Wilcoxon Signed Ranks test. An alpha level of .05 was used to determine significance of findings for both of these tests.

A Chi Square test was used to analyze differences between the groups on responses to the two fear of falling questions. Significance of within group differences in pre- and post-intervention responses to the two questions about fear of falling was analyzed using the McNemar change test. An alpha level of .05 was used for both tests in the analysis of each question.

In order to test for equivalence of groups prior to intervention, a multivariate independent t-test (Hotelling's T) was used to test differences between groups on pre-intervention measures of muscle strength and postural stability. A multivariate analysis of variance (MANOVA) was used to test differences between and within groups on the five scaled dependent variables (four strength variables and one postural stability variable). The MANOVA was a 2X2 mixed design with repetition over one factor, namely, the pre- and post-exercise scores of strength and postural stability. A significant interaction of group by pre-post intervention measures found with the MANOVA was further analyzed to investigate the nature of the interaction. A multivariate related samples t-test (Hotelling's T) was performed to analyze differences between pre- and post-intervention measures for each group. Significant multivariate t-tests were followed with univariate paired t-tests for each muscle strength and postural stability variable. An alpha level of .05 was used for all statistical tests used in analysis of muscle strength and postural stability variables.

CHAPTER IV

RESULTS

Current standard physical therapy programs used during the acute phase of recovery from THA are effective for reducing pain and improving function, but residual muscle strength and postural stability deficits persist 1 to 2 years following THA. An exercise program designed to address muscle strength and postural stability deficits that is implemented several months after surgery when post-operative precautions are relaxed, might reduce the deficits. The effectiveness of such an exercise program has not been demonstrated. The purpose of this study was to investigate the efficacy of a post-rehabilitation exercise program initiated 4 to 12 months following THA. Efficacy of the proposed program was assessed by comparing muscle strength, postural stability, fear of falling, and self-perceived function in a group of subjects who received the proposed exercise program to a control group of subjects who received basic isometric and active ROM exercises that were similar to those given immediately post-operatively. This chapter provides a description of the subjects who participated in the study. Next, descriptive data are presented for each of the two exercise groups before and after participating in the exercise program. Descriptive data are provided for measures of self-perceived function, fear of falling, postural stability, and muscle strength. The descriptive data for the dependent variables are followed with inferential statistics comparing measures in the two groups before and after the exercise intervention.

Subjects

Thirty-five subjects who underwent THA 4 to 12 months previously participated in this study. Subjects were recruited consecutively from the Texas Woman's University Health Health Promotion and Research Center (HPRC) and from four orthopedic practices in the Dallas area. Twenty-eight subjects completed the 8-week training program and post-intervention assessment. Fourteen of the subjects who completed the study were in the experimental exercise group and 14 were in the control exercise group. Seven of the 35 subjects initially recruited were dropped from the study for a variety of reasons. A summary of subjects who dropped from each exercise group is presented in Table 1.

Table 1

Summary by Group of Reasons Subjects Failed to Complete the Study

Exercise Group	Reason for Dropping Out
Control (n=2)	1. Pain in uninvolved buttock and thigh
	2. Did not show for re-checks or post-test
Experimental (n=5)	1. Unrelated medical problems
	2. Never started the exercise due to exacerbation of herniated disc
	3. Unable to continue exercise due to severe OA on non-surgical side
	4. Did not show for re-checks or post-test
	5. Had to leave town indefinitely to tend to sick relative
Total lost (n=7)	

The 7 subjects who dropped out of the study represent a 20% drop-out rate. Six percent of the subjects who dropped out of the study were in the control group, and the remaining 14% were in the experimental group.

The 28 subjects who completed the study consisted of 15 women and 13 men with a mean age of 59.5 years. A summary of characteristics of subjects who completed the study can be found in Table 2.

Table 2

Description of Subjects

Characteristic	M	SD	SE	Min	Max
Age (yrs)					
All	59.5	11.2	2.1	36.0	77.0
Experimental Group	59.4	10.8	2.8	36.0	76.0
Control Group	95.6	12.1	3.2	37.0	77.0
Body Weight (kg)					
All	81.7	17.8	3.3	46.8	113.2
Experimental Group	83.0	17.2	4.6	46.8	113.2
Control Group	80.4	18.9	5.0	50.0	111.4
Height (cm)					
All	169.8	8.9	1.6	153.5	188.0
Experimental Group	169.1	7.6	2.0	157.6	186.7
Control Group	170.5	10.2	2.7	153.5	188.0
Time Post-surgery (mo)					
All	7.4	2.0	0.4	4.5	12.0
Experimental Group	7.6	2.1	0.5	4.5	12.0
Control Group	7.2	1.9	0.5	4.5	11.0

Note. All (n=28), Experimental Group (n=14), Control Group (n=14)

As indicated in Table 2, all subjects underwent surgery for THA at least 4 months prior to entry into the study but no more than 12 months prior to entry. Although surgical approach was not a criteria used for inclusion into the study, all participants underwent an anterolateral approach for their THA. All of the orthopedic surgeons whose patients participated in this study routinely perform THA using an anterolateral approach and a hybrid type of component fixation. In a hybrid type of fixation, one of the prosthetic components is press fit (usually the acetabular component), while the other is cemented.

Of the 28 study participants, 24 had a primary diagnosis of osteoarthritis (OA). The remaining four subjects had primary diagnoses of avascular necrosis (1), congenital dysplasia (1), rheumatoid arthritis (1), and status post an old fracture that was originally fixed with pins (1). Twelve of the study participants had a right THA, 15 had a left THA, and one participant had a bilateral procedure. Four of the study participants had undergone a THA on the opposite side prior to this surgery.

All of the study participants had received physical therapy after their hip surgery. All received in-patient physical therapy during their hospital stay followed by continuation of some type of supervised exercise program. Nineteen of the study participants had home health physical therapy following their hospital discharge that ranged from 1 week to 2 months. Three subjects had in-patient rehabilitation following their hospital discharge, 3 subjects went to out-patient physical therapy sessions, and 3 started a water aerobics program. Three of the study participants did not respond to the question about physical therapy following their THA. None of the study participants were receiving physical therapy at the time of this study.

Compliance with the exercise intervention was determined by examination of each subject's exercise log. Subjects were considered to be 100% compliant if they exercised 3 times per week for 8 weeks. In the experimental group, 11 subjects turned in a completed exercise log that indicated 100% compliance. One subject was 92% compliant and 2 subjects failed to turn in an exercise log but verbally acknowledged that they exercised regularly at least three times per week. The mean compliance rate for the experimental group was based on the 12 completed exercise logs, and was calculated to be 99.3% compliance. In the control group, 10 subjects turned in a completed exercise log that indicated 100% compliance. Three subjects turned in exercise logs that indicated less than 100% compliance (92%, 83%, and 63%). One subject failed to turn in an exercise log but verbally acknowledged that she had been exercising regularly 3-4 times per week. The mean compliance rate of 95.2% for the control group was based on information from the 13 exercise logs that were turned in. The overall mean compliance rate for both groups combined was 97.2%.

Reliability of Test Instruments

Repeated measures of postural stability using the BEP-IV and measures of strength using the BEP-IIIa were obtained to assess intrarater reliability of these test instruments and procedures used within this study. Intratester reliability of the BEP-IV was estimated by performing a repeated measures ANOVA-based intraclass correlation coefficient ICC. Each of the repeated test values of percent total stability used in the analysis was a mean value of two trials. Repeated test values for 26 subjects (n=26) were used in the calculation of the ICC (3,2). The investigator intended to obtain repeated measures for all subjects who completed the study, but 2 subjects could not perform the additional reliability testing because of time constraints. The calculated ICC (3,2) of .95 for postural stability measures obtained using the BEP-IV is considered excellent.

An ANOVA was also conducted between the 26 (n=26) repeated measures obtained from randomly selected muscles. Each of the repeated test values of muscle strength used in the analysis was a mean value of two trials. An ICC (3,2) was then calculated to provide a combined estimate of reliability for the strength measurements of the four muscles tested. The calculated ICC (3,2) of .94 for muscle strength measurements obtained using the BEP-IV is considered excellent.

Self-Perceived Function

Descriptive Statistics

Self-perception of function was assessed using the 12-Item Hip Questionnaire. The median and maximum/minimum values for pre- and post-exercise scores on the hip questionnaire for the entire sample (n=28) and for each group (n=14) are shown in Table 3.

Table 3

Median Scores on the Hip Questionnaire (HQ) Pre- and Post Exercise

	Pre-Exercise			Post-Exercise		
	Mdn	Min	Max	Mdn	Min	Max
All (n=28)	19.5	13	33	16.5	12	38
Experimental (n=14)	21.0	15	33	16.0	12	38
Control (n=14)	19.0	13	32	17.5	12	33

A low score on the 12-Item Hip Questionnaire signifies high function. Note that in Table 3, the lower scores observed after the 8-week intervention suggest higher function post-exercise than pre-exercise. The significance of the changes in hip questionnaire scores for each group after exercise was tested statistically.

Statistical Tests of Significance for Differences in Self-Perceived Function

The results of the 12-Item Hip Questionnaire on function, and fear and avoidance questions were analyzed using non-parametric tests. To analyze differences within and between groups on the hip questionnaire, two different nonparametric tests were used. The Mann-Whitney U was used to test for significance of differences between groups. The test was performed on the pre-exercise scores of self-perceived function in order to test for equivalence between the two groups before the intervention. The calculated

Mann-Whitney U statistic of 77.5 revealed that differences between groups on hip questionnaire scores were not significantly significant (p=.34). That is, the control and experimental groups were similar in their perception of function before they started their exercise programs.

The Wilcoxon Signed Ranks test was used to analyze whether differences in scores on the questionnaire before and after the 8-week intervention were significant for the experimental group and for the control group. The Wilcoxon T-values obtained were used to calculate z-values that were compared to a z table of critical values. The calculated z-values (–2.55 for the experimental group, –1.10 for the control group) indicate that differences before and after the exercise were significant at an alpha level of .05 for the experimental group (p=.01) but not for the control group (p=.26). That is, subjects in the experimental exercise group perceived that their function was improved after the 8-week exercise program. Subjects in the control exercise group, however, did not feel that their function had improved.

Fear of Falling

Descriptive Statistics for Fear of Falling Questions

In addition to the 12-Item Hip Questionnaire, subjects were asked to respond "yes" or "no" to each of the following questions: "Are you afraid of falling?" and "Since your surgery, are there any activities that you avoid doing because you are fearful of falling?" The responses to these two questions are summarized in Table 4.

Table 4

Responses to Fear of Falling (Fear) and Avoidance of Activities (Avoidance) Questions Pre- and Post-Exercise

	Pre-Exercise		Post-Exercise	
	Yes	No	Yes	No
		Fear Question		
All (n=28)	16	12	12	16
Experimental (n=14)	7	7	5	9
Control (n=14)	9	5	7	7
		Avoidance Question		
All (n=28)	10	18	4	24
Experimental (n=14)	7	7	3	11
Control (n=14)	3	11	1	13

As noted in Table 4, little apparent change was observed before and after exercise in response to the question about being afraid of falling. More change was observed in response to the question about avoidance of activity because of fear of falling. The observed change, however, was mainly in the experimental group. The significance of the changes noted before and after the exercise intervention was analyzed statistically.

Statistical Tests of Significance for Differences in Responses to Fear of Falling Questions

A Chi Square (X^2) analysis was used to test for significance of differences between groups on their responses to each of the fear of falling questions. The test was performed on the pre-exercise responses in order to test for equivalence between the two groups prior to the exercise intervention. The calculated X^2 of .58 for the fear question and 2.48 for the avoidance question indicated that the groups were not significantly different in their responses to the question "Are you afraid of falling?" ($p=.70$), or to the question "Since your surgery, are there any activities that you avoid doing because you are fearful of falling?" ($p=.24$). That is, both groups were similar in their responses to fear of falling questions before they started their exercise program.

Significance of differences in pre- and post-intervention responses to the questions about fear of falling and avoidance of activities was analyzed using the McNemar change test. The McNemar test was used to determine the probability that the observed changes in response to the questions after participating in an exercise intervention came from a binomial population where half of the total number of cases that changed would have changed in a positive direction (changed from "yes" to "no"). The calculated probability of .50 for the fear of falling question and .62 for the avoidance of activities question indicated that the changes observed following the 8-week intervention were not significant in the control group. Similarly, the calculated probability of .50 and .12 for the fear and avoidance questions respectively, indicated that the changes that occurred following the exercise intervention in the experimental group were not significant. That is, neither of the exercise programs appeared to affect the subjects' fear of falling or avoidance of activities.

Postural Stability and Muscle Strength Variables

Descriptive Statistics for Postural Stability and Strength Variables

Postural stability and muscle strength were measured using the BEP-IV force platform and the BEP-IIIa hand-held dynamometer, respectively. Means, standard deviations, minimum, and maximum values for each variable before and after the exercise intervention were calculated and are presented for each group in Table 5.

Table 5

Descriptive Statistics for Postural Stability and Strength Variables by Group Before and After the 8-Week Exercise Intervention

Variable	Pre-Exercise M	SD	Min	Max	Post-Exercise M	SD	Min	Max
				Experimental Group[a]				
Postural Stability (%)								
Total Stability	66.10	35.57	1.70	97.40	90.44	5.20	74.80	97.20
Muscle Strength (N-m)								
Hip Flexors	40.45	15.32	17.10	65.70	50.37	17.60	17.80	85.70
Hip Extensors	53.03	24.57	18.80	103.60	78.39	26.98	26.30	124.90
Hip Abductors	53.94	17.20	14.50	86.30	76.14	21.31	31.80	124.50
Knee Extensors	76.60	25.24	26.50	113.30	94.50	28.43	34.90	135.90
				Control Group[b]				
Postural Stability (%)								
Total Stability	76.34	27.24	.90	97.90	76.95	31.11	6.70	97.30
Muscle Strength (N-m)								
Hip Flexors	41.72	19.84	18.40	89.00	44.71	13.26	17.80	85.70

(Table continues)

Table 5 (continued)

Variable	Pre-Exercise				Post-Exercise			
	M	SD	Min	Max	M	SD	Min	Max
Hip Extensors	52.06	21.47	27.60	104.20	53.99	23.66	29.00	93.20
Hip Abductors	51.56	20.84	14.50	86.30	53.33	21.23	17.80	95.10
Knee Extensors	68.79	34.42	26.70	144.00	69.50	26.15	34.80	114.50

Note. [a]n=14. [b]n=14.

Note that the pre-exercise values for postural stability and muscle strength appear similar between the two groups. After the exercise intervention, measures of postural stability and muscle strength increased in the experimental group, but did not appear to change in the control group. The significance of the differences observed for the experimental group and the control group before and after the exercise intervention were tested statistically.

Statistical Tests of Significance for Differences in Postural Stability and Muscle Strength

A 2X2 repeated measures MANOVA was used to test for significance of differences between and within groups on the four strength variables and one postural stability variable. The MANOVA revealed a significant group by pre-post value interaction, $F(5,22) = 5.72$, $p = .002$ (see Appendix G for MANOVA table). That is, different combinations of group and pre-post levels had differential effects on measurements of muscle strength and postural stability.

In order to determine the nature of the interaction, the simple main effects of group and pre-post differences were analyzed using multivariate t-tests. Differences between groups on pre-intervention measures of muscle strength and postural stability were analyzed using a multivariate independent t-test (Hotelling's T). Differences between groups on measures of muscle strength and postural stability before the exercise intervention were not statistically significant, $F(5,22)=.61$, $p=.69$. That is, the experimental and control groups were equivalent on measures of muscle strength and postural stability before they started their exercise programs. A separate multivariate related samples t-test (Hotelling's T) was then performed to analyze differences between pre-and post-intervention measures for each group (simple main effects of group). The multivariate analyses revealed that pre- and post-intervention differences were significant for the experimental group, $F(5,9) = 10.83$, $p=.001$. The pre- and post-intervention differences were not significant, however, for the control group, $F(5,9) =.14$, $p=.98$ (See Appendix G for table). That is, the experimental group performed better on collective measures of strength and postural stability after exercising for 8 weeks, but the control group did not perform better.

Univariate paired samples t-tests were then performed for each muscle strength and postural stability variable in the experimental group to determine which variables demonstrated significant differences between pre-and post-intervention measures. The results of the paired t-tests are shown in Table 6.

Table 6

Summary of Paired Samples t-Tests to Assess Differences in Postural Stability and Muscle Strength Before and After the 8-Week Intervention in the Experimental Group

	Paired Differences		
Variable	M	SE	t
Postural Stability			
Total Stability (%)	24.33	8.60	2.82*
Muscle Strength			
Hip Flexors (Nm)	9.91	2.08	4.76**
Hip Extensors (Nm)	25.35	5.46	4.64**
Hip Abductors (Nm)	22.20	4.25	5.22**
Knee Extensors (Nm)	17.89	4.30	4.15**

Note: n=14. *$p < .05$. **$p < .01$.

Significant differences between pre- and post- exercise values were found for each of the muscle strength and postural stability variables. That is, after 8 weeks of exercise, subjects in the experimental exercise group improved in all of the muscle strength and postural stability measurements.

Summary

Twenty-eight subjects who underwent THA 4 to 12 months previously, completed the study. Fourteen of the subjects (n=14) were in the experimental group, and 14 of the subjects (n=14) were in the control group. Seven of the original 35 subjects (20%) recruited for the study dropped out of the study for a variety of reasons. The reasons for dropping out were summarized by group. Six percent of the subjects who dropped out of the study were in the control group, and 14% were in the experimental group. Demographic data for the 28 subjects who completed the study were summarized. Additionally, study participants were described by primary diagnosis and type of physical therapy received following their surgery for THA. Finally, compliance to the intervention program for each group was discussed. All study subjects were more than 50% compliant. A minimum of 50% compliance was required to remain in the study.

Intra-tester reliability of postural stability measures using the BEP-IV was excellent with a calculated ICC (3,2) of .95. Intra-tester reliability of muscle strength measures using the BEP-IIIa was also excellent, with a calculated ICC (3,2) of .94.

Descriptive data on median scores for the 12-Item questionnaire revealed that the experimental group's median score improved from a pre-exercise score of 21.0 to a post-exercise score of 16.0 while the control group's median score improved from 19.0 to 17.5. The Wilcoxon Signed Ranks test used to test for significance of differences before and after the intervention revealed that the differences were significant for the experimental group, but not for the control group. That is, subjects in the experimental group, but not the control group, felt that their function had improved after the 8-week exercise program.

Responses to the questions about fear of falling and avoidance of activities due to fear of falling were summarized. For both groups, differences in pre- and post-intervention responses analyzed using the McNemar change test revealed no significant differences for either question. The results of this analysis indicate that neither of the exercise programs had any effect on the subjects' fear of falling.

Means, standard deviations, minimum and maximum values for measures of postural stability and muscle strength of hip flexors, extensors, abductors, and knee extensors were provided. The 2X2 repeated measures MANOVA used to analyze differences between and within groups revealed a statistically significant group by pre-post-test interaction effect. The significant interaction suggested that each of the exercise interventions had a different effect on measurements of postural stability and muscle strength.

The subsequent multivariate related samples t-test (Hotelling's T) performed on each group separately revealed that pre-post intervention measures were significant for the experimental group but not for the control group. That is, overall the experimental group performed better on measures of strength and postural stability after exercising for 8 weeks, but the control group did not. In order to determine which of the strength and postural stability variables demonstrated significant differences between pre- and post-intervention measures, univariate related samples t-tests were conducted.

The univariate paired samples t-test performed on each muscle strength and postural stability variable revealed that pre-post differences in the experimental group were significant for all postural stability and muscle strength variables. This finding suggested that the exercise program used for the experimental group was effective for improving muscle strength and postural stability when initiated in patients 4 to 12 months post-THA.

CHAPTER V

DISCUSSION

Patients with THA typically receive physical therapy only during the acute phase of recovery. The physical therapy programs used during this early rehabilitative phase are effective for reducing pain and improving function, but residual muscle strength and postural stability deficits persist 1 to 2 years following surgery. An exercise program that emphasizes postural control and weight bearing might reduce muscle strength and postural stability deficits, but the effectiveness of such a program had not been demonstrated. The purpose of this study was to investigate the effectiveness of a post-rehabilitative exercise program initiated 4 to 12 months post THA.

The proposed exercise program was assessed by comparing muscle strength, postural stability, fear of falling, and self-perceived function in a group of subjects who received the experimental exercise program to a control group of subjects who received basic isometric and active ROM exercises. Twenty-eight subjects who underwent THA 4 to 12 months previously were randomly placed into the experimental ($\underline{n}$=14) or control ($\underline{n}$=14) exercise group. Both groups were instructed in their respective exercise programs and asked to perform their exercises 3 times per week at home for 8 weeks. Measures of muscle strength, postural stability, fear of falling, and self-perceived function were obtained before and after participation in the 8-week exercise program.

This chapter presents a summary of findings, followed by a discussion of the findings related to each dependent variable. The conclusion is presented next followed by limitations, and recommendations for future study.

Summary of Findings

Research Question 1

The first research question posed in this study was the following: Would an experimental post-rehabilitative exercise program be effective for improving hip muscle strength, postural stability, self-perceived function, and fear of falling in patients with THA? In order to answer this question, three hypotheses were formulated. Each of the three null hypotheses is stated and the results of the study that support rejection or failure to support rejection of the hypotheses are presented.

Null Hypotheses

1. There would be no significant difference in muscle strength and postural stability before and after an experimental post-rehabilitative exercise program in patients with THA.

Results: Reject the null hypothesis. A MANOVA revealed that there was a significant interaction effect between the two factors (group by pre-post). An investigation of the interaction was performed using multivariate t-tests for each group. The Hotelling's T revealed that there were significant differences between the pre- and post-intervention measures of muscle strength and postural stability in the experimental group. Univariate t-tests revealed that these differences were significant for all of the muscle strength and postural stability variables measured. That is, after 8 weeks of exercise, subjects in the experimental exercise group improved in measures of hip flexor strength, hip extensor strength, hip abductor strength, and postural stability.

2. There would be no significant difference in scores of self-perceived function before and after an experimental post-rehabilitative exercise program in patients with THA.

Results: Reject the null hypothesis. A Wilcoxon Signed Ranks test demonstrated that pre- and post-exercise intervention scores on the 12-Item Hip Questionnaire were significantly improved in the experimental group of subjects.

3. There would be no significant difference in fear of falling before and after an experimental post-rehabilitative exercise program in patients with THA.

Results: Fail to reject the null hypothesis. A McNemar change test demonstrated that the responses to questions about fear of falling did not significantly change after 8 weeks of exercise in the experimental group.

The results of this study support rejection of null hypotheses 1 and 2 but fail to support rejection of null hypothesis 3. Based on these findings, the first research question can be answered as follows: An experimental post-rehabilitative exercise program is effective for improving muscle strength, postural stability, and self-perceived function in patients with THA. The exercise program is not, however, effective in reducing fear of falling in patients with THA.

Research Question 2

The second research question posed in this study was the following: Would a control post-rehabilitative exercise program be effective for improving hip muscle strength, postural stability, self-perceived function, and fear of falling in patients with THA? In order to answer this question, three additional hypotheses were formulated (null hypotheses 4, 5, and 6). Each of these hypotheses is stated and the results of the study that support rejection or failure to support rejection of the hypotheses are presented.

Null Hypotheses

4. There would be no significant difference in muscle strength and postural stability before and after a control post-rehabilitative exercise program in patients with THA.

Results: Fail to reject the null hypothesis. A MANOVA revealed that there was a significant interaction effect between the two factors (group by pre-post). The Hotelling's T test performed to investigate the nature of the interaction revealed that the differences between the pre- and post-intervention measures of muscle strength and postural stability were not statistically significant in the control group. That is, after 8 weeks of exercise, subjects in the control exercise group did not improve in measures of muscle strength and postural stability.

5. There would be no significant difference in scores of self-perceived function before and after a control post-rehabilitative exercise program in patients with THA.

Results: Fail to reject the null hypothesis. A Wilcoxon Signed Ranks test demonstrated that pre- and post-exercise intervention scores on the 12-Item Hip Questionnaire were not significantly improved in the control group of subjects.

6. There would be no significant difference in fear of falling before and after a control post-rehabilitative exercise program in patients with THA.

Results: Fail to reject the null hypothesis. A McNemar change test demonstrated that the responses to questions about fear of falling did not significantly change in the control group after 8 weeks of exercise.

The results of this study do not support rejection of null hypotheses 4, 5, and 6. Based on these findings, the second research question can be answered as follows: A control post-rehabilitative exercise program is not effective for improving muscle strength, postural stability, and self-perceived function in patients with THA. The control exercise program also is not effective for reducing fear of falling in patients with THA.

Discussion of Sample Characteristics

Twenty-eight subjects (n=28) completed this study. Subjects were recruited from Texas Woman's University Health Promotion and Research Center and from four different orthopedic practices. Although all subjects were recruited from the Dallas area, it is assumed that these subjects do not differ from patients who have THA in other regions of the country. That is, it is assumed that the sample of subjects in the current study is representative of the population of patients who have THA.

The 28 subjects in this study were randomly placed into the control (n=14) or experimental (n=14) exercise group. Each of the groups was then compared before and after the exercise intervention to determine the effectiveness of each exercise program. In order for the results of this study to be valid, it is important that the subjects in each of the exercise groups are examined and compared on characteristics that could affect their performance on measures of function, fear of falling, muscle strength, and postural stability. The section on sample characteristics that follows will examine and discuss drop out rates, physical characteristics, primary diagnoses, and compliance rates in the study sample as a whole as well as in each of the exercise groups individually.

Drop Out Rate

Thirty-five subjects were recruited for the current study, and 28 subjects completed the study. The 7 subjects who dropped out of the study represent an overall drop out rate of 20%. Although 20% seems high, it is important to look at the reasons for dropping out that are outlined in Table 1. Only 2 subjects dropped out due to reasons that could be related to the exercise used in the study (exacerbation of herniated disc and unable to perform exercises due to severe osteoarthritis on the uninvolved side). One of the exclusion criteria for this study was the presence of back pain at the time of the pre-test. Although the subject who dropped out due to exacerbation of a herniated disc did not have back pain at the time of the pre-test, she did have back pain due to a herniated disc that was confirmed by MRI approximately 4 weeks prior to the pre-test. Although it is not known whether the exercise program used in this study caused an exacerbation of her back symptoms, it is a possibility. For future studies, it may be advisable to amend the exclusion criteria so that subjects who have a confirmed herniated disc within the last 2-3 months would be excluded.

Drop out rates in each exercise group individually were 6% in the control group and 14% in the experimental group. The higher drop out rate observed in the experimental group could be viewed as problematic; however 3 out of the 5 subjects who dropped from the experimental group were for reasons that were seemingly unrelated to the exercise program. The experimental exercise program, however, was designed to be more challenging in the areas of postural control and muscle strength than the control exercise program. Drop out rates due to reasons such as inability to perform the exercises because of osteoarthritis on the uninvolved side or in a joint other than the replaced hip, are potentially higher in an exercise program that stresses weight bearing.

Physical Characteristics of Subjects

The mean age for the overall sample of subjects ($\underline{n}$=28) was 59.5 years. Although most subjects were 60 years or older, there were several younger subjects who brought the overall mean age to below 60 years. Two subjects were under 40, and 3 subjects were under 50 years of age. This represents a somewhat younger sample of subjects than the typical patient with THA. The National Institutes of Health report that two-thirds of all THA procedures are performed in individuals who are 65 years of age or older (National Institutes of Health Consensus Development Panel on Total Hip Replacement [NIH], 1994). However, the mean age for each exercise group in this study was almost identical at 59.4 years and 59.6 years for the experimental and control groups, respectively. Lemmer et al. (2000) reported that strength gains in young subjects (20-30 years) are different from strength gains in older subjects (65-75 years) in response to the same strengthening program. This should not have been a factor in the current study, however, because 59 years of age is still considered to be "older."

Of the 28 subjects who completed the study, 13 were men and 15 were women. It should be noted that 8 of the men were in the experimental group and 5 were in the control group. The literature suggests that there are sex issues related to muscle strength training. A review of the literature, however, revealed that although older men achieve greater increases in muscle volume than older women in response to strength training (Ivey et al., 2000), no significant differences in strength gains between older men and women were found after 9 weeks of strength training (Lemmer et al., 2000). It should also be noted that although the experimental group in the current study participated in an exercise program that was designed to increase muscle strength, the exercise program did not utilize progressive resistive exercise (PRE) or any form of external resistance. The exercise program used by the experimental group involved only the use of body weight. No literature could be found that investigated the effect of sex on the type of strengthening program used in the current study.

Primary Diagnosis

Of the 28 participants, 24 had a primary diagnosis of osteoarthritis. Two subjects had primary diagnoses that eventually may have lead to osteoarthritis (congenital dysplasia and status post old fracture that was fixed with pins). Consequently, the experimental and control groups both consisted primarily of subjects who had THA secondary to osteoarthritis. Of the 2 remaining subjects, 1 had a primary diagnosis of avascular necrosis and the other had a primary diagnosis of rheumatoid arthritis. Both of these subjects were in the experimental group. The subject with rheumatoid arthritis had bilateral THA and TKA but met all inclusion criteria and did not have any of the exclusion criteria. Although there was concern that this subject may have difficulty with the exercise program and that she may not experience any improvement due to multiple joint replacements, she did well with the exercise and made dramatic improvements in both muscle strength and postural stability.

Compliance

The overall compliance rate to the prescribed exercise programs in this study was 97.2% as calculated from subjects' completed exercise logs. Although the mean compliance rate in the control group (95.2%) was good, it was lower than the mean compliance rate for the experimental group (99.3%). The difference in compliance rates between the two groups may be attributed to the nature of the two exercise programs. That is, the control group exercise program consisted mainly of isometric contractions performed in the supine position, and several of the subjects commented that the exercises were very "boring." This is a frequent criticism of isometric exercises in general, and complaints of boredom are not unusual. The exercises in the experimental group were more varied and more challenging. Although the difference in compliance rate between the groups was considered to be small and not potentially confounding, there could have been a slight Hawthorne effect. Subjects in the experimental group may have perceived that their exercises were different from what they previously had during their acute stage of rehabilitation. Therefore, subjects in the experimental group may have perceived that their exercises were potentially more helpful.

Discussion of Self-Perceived Function

Correlation studies between measures of physical impairments and functional performance have often demonstrated a weak association between the two (Finch, Walsh, Thomas, & Woodhouse, 1998; Lankhorst, Van de Stadt, & Van der Korst, 1985; Liang & Jette, 1981). In the current study, correlations between impairments and functional status were not calculated but it was observed that significant improvements in muscle strength and postural stability measures in the experimental group were accompanied by significant improvements in measures of self-perceived function. Conversely, lack of improvements in muscle strength and postural stability in the control group was accompanied by non-significant improvements in measures of self-perceived function. Although the current study did not statistically assess the correlation of impairments in muscle strength and postural stability with measures of self-perceived function, the observed concurrent improvement in impairments and function is important. It could be argued that observation of concurrent improvement in impairments and function as a result of an intervention is clinically more meaningful than a high calculated correlation coefficient. Nonetheless, the potential use of the 12-Item Hip Questionnaire to assess progress in patients with THA warrants further study.

Discussion of Fear of Falling

The results of the current study revealed no significant changes in fear of falling after participation in the control or experimental exercise programs. Because the experimental group demonstrated significant improvements in function, muscle strength, and postural stability after the 8-week exercise program, non-significant improvements in fear of falling in this group was somewhat unexpected. A discussion of possible explanations for the non-significant findings in the experimental group follows.

One explanation could be that the two questions used to assess fear of falling did not adequately measure the characteristic of interest, or the questions may not have been sensitive enough to measure actual change. The two questions used in the current study about fear of falling and avoidance of activities because of fear were chosen both for their simplicity and their documented use in the measurement of fear in previous studies (Jackson et al., 2001; Tinetti et al., 1988). Tinetti et al. (1990) argued that use of the two questions about fear of falling may be oversimplified and can lead to inaccuracies in reporting because people use different standards to make judgments about fear. In the current study, the subjects seemed uncertain about standards that should be used to answer the questions. Many subjects, for example, were not sure about how to answer the questions and requested further qualification from the investigator. The investigator, however, did not offer any qualifications in order to avoid biasing their response to the questions. Tinetti et al. has developed a Falls Efficacy Scale (FES) that is used to rate a person's self-confidence in avoiding a fall during each of 10 specific activities of daily living. The FES uses a continuous scale rather than a dichotomous scale (being fearful or not) and has the advantage of assessing the extent to which fear of falling affects willingness to perform specific activities of daily living. Use of the FES may be more effective in assessing fear of falling as well as assessing change in fear of falling as a result of an intervention such as the experimental exercise program used in the present study. The FES should be used in further studies of the efficacy of post-rehabilitative exercise programs to assess fear of falling.

Another explanation for the lack of significant changes in fear of falling could be that not many of the subjects indicated that they were afraid of falling before the exercise intervention. In the experimental group, for example, only 7 of 14 indicated they were afraid of falling or avoided activities because they were afraid of falling. Of those 7 subjects, 2 were no longer fearful after exercise and 4 no longer avoided activities. Because of the small numbers to begin with, however, the changes were not statistically significant. The fact that only 7 of 14 indicated that they were afraid of falling or avoided activities because they were afraid of falling could have been due to two reasons: (a) the two questions may not have accurately assessed fear of falling as discussed above or (b) the subjects in this study truly did not fear falling.

Discussion of Postural Stability and Muscle Strength

Significant improvements in muscle strength and postural stability were demonstrated in the experimental group after 8 weeks of exercise. Postural stability improved 36.8% while muscle strength improved 24.5% for hip flexors, 47.8% for hip abductors, 41.2% for hip abductors, and 23.4% for knee extensors. The magnitude of improvements in postural stability and muscle strength in the experimental group demonstrate statistical significance as well as clinical significance.

Only one study could be found in the literature that assessed the effects of a post-rehabilitative exercise program for patients with THA. Sashika et al. (1996) studied the effects of a home exercise program on strength, ROM, and gait in 23 patients (mean age 63.4 years) who had THA 6 to 48 months previously. Postural stability and function were not studied. The patients were placed into 1 of 3 exercise groups that were matched for age, gender, and length of time after surgery. Group A (*n*=8) received an exercise program consisting of ROM and "low resistance" isometric exercises. The exercises described as "low resistance" isometric exercises, however, consisted of straight leg raises in supine, sidelying, and prone as well as long arc knee extensions all performed with a leg weight that was calculated to be 20 to 30% of their maximum isometric torque. Group B (*n*=8) received the same exercise program as Group A plus a pelvic raising/lowering exercise while standing on the operated leg to strengthen the hip abductors on the stance leg. The pelvic raising/lowering exercise was one of the exercises performed in the experimental group in the current study. See Appendix E for description and picture of pelvic raising/lowering exercise in "Experimental Group Exercise Protocol." Group C (n=7) received no home exercise program. At the end of a 6-week training program, maximum isometric torque of the hip abductors was measured using a Cybex II isokinetic dynamomter (Lumex, Inc., Ronkonkoma, NY 11779) and compared to pre-exercise values. Hip abductor strength improved by 3.2 ft-lb (4.3 N-m) in Group A, 8.5 ft-lb (11.5 N-m) in Group B, and 4.5 ft-lbs (6.1) in Group C. Because the mean hip abductor strength was very low in each of the groups to start with however, these small improvements represented improvements of 24% in Group A, 68% in Group B, and 49% in Group C. Within group improvements were statistically significant in all exercise groups including Group C, which received no exercise, but the clinical significance of such small improvements should be questioned. In the current study, hip abductor strength increased by 22.2 N-m in the experimental group, and 1.8 N-m in the control group. Although the magnitude of the improvements in muscle strength were much greater in the current study, percent improvement was larger in the Sashika et al. study due to low pre-exercise values. Pre-exercise hip abductor strength mean values reported by Sashika et al. were 13.4 ft-lb (18.2 N-m) in Group A, 12.5 ft-lb (16.9 N-m) in Group B, and 9.1ft-lb (12.3 N-m) in the control group. Although subjects in the current study were a mean of 7.4 months post-surgery compared to 26.4 months post-surgery in the Sashika et al. study, mean pre-exercise hip abductor strength values were higher in the current study. Mean hip abductor strength values before exercise were 53.9 N-m in the experimental group and 51.6 N-m in the control group. The low hip abductor strength values before exercise in the Sashika et al. study may signify that (a) the subjects in this study had substantial strength impairments at 26.4 months post-surgery, or (b) the subjects in the Sashika et al. study did not understand or feel confident with the test procedures used to obtain isometric strength measurements using the Cybex II dynamometer. The second explanation for low pre-exercise hip abductor strength values would explain why the control group's strength values significantly improved even though they performed no exercise. That is, all groups may have improved significantly on the post-test because they learned how to perform the test better. Although Sashika et al. concluded that the proposed home exercise program (Group B exercise protocol) was effective as a post-rehabilitative exercise program for THA, this conclusion should be questioned because Group A and the control group also significantly improved. The authors did not statistically compare each of the 3 groups to each other. That is, between group comparisons were not performed.

Limitations

In reviewing the postural stability data in the current study, it was observed that 9 of the 28 subjects had postural stability that was 90% or more. Because measurements of postural stability cannot be any better than 100%, subjects who had 90% stability or better had little room for improvement regardless of which exercise program they participated in. A better study design would have been to recruit only subjects who had less than 90% stability but this was not possible in the current study. Fortunately, the subjects with a high level of postural stability to begin with, were evenly divided among the two exercise groups in the randomization process. Four of the subjects with an initially high level of stability were in the control group and 5 were in the experimental group.

The current study was a single blind study. That is, the subjects were blinded as to whether they were in the experimental or control group, but the investigator who performed all test measurements also performed all exercise instructions. Therefore, the investigator was not blinded as to which subjects were in the experimental group or control group. A double blind study would have been the preferred design but would have required personnel other than the investigator to perform the exercise instructions. Because data were collected at several sites, personnel to provide exercise instruction would have been needed at each of the sites for the convenience of the subjects. Although the double blind design was considered for the current study, time and money constraints made it infeasible.

Conclusion

Differences in scores of self-perceived function before and after a post-rehabilitative exercise program were found to be statistically significant in the experimental exercise program but not the control exercise program. Differences in measures of postural stability and muscle strength before and after a post-rehabilitative exercise program were also found to be statistically significant in the experimental exercise program but not the control exercise program. Muscle strength was assessed for the hip flexors, extensors, abductors, and knee extensors. Differences in all four strength measurements were found to be significantly different before and after the experimental exercise program but not the control exercise program. Fear of falling, however, did not change significantly before and after the experimental or control exercise program. In conclusion, the experimental post-rehabilitative exercise program used in this study is effective for improving self-perceived function, selected muscle strength, and postural stability in patients who underwent THA 4 to 12 months previously. Furthermore, the control group post-rehabilitative exercise program is not effective for improving self-perceived function, muscle strength, and postural stability in patients who had THA 4 to 12 months previously. Neither of the exercise programs were found to be effective for improving fear of falling in patients who underwent THA 4 to 12 months previously.

Clinical Significance

Current physical therapy programs used during the early phase of rehabilitation are effective for reducing pain and improving basic functional skills, but residual muscle strength and postural stability deficits persist 1 to 2 years after surgery. The results of the current study support the use of a post-rehabilitative exercise program that can be initiated as early as 4 months after surgery. The experimental exercise program used in the current study has been shown to be effective as a home exercise program with only three physical therapy visits. The initial instruction in the home exercise program would occur on the first visit and the last two visits would be used to check for correct form and to progress as needed. Each of the three physical therapy visits should be separated by approximately 2 weeks. The exercise program in the current study started with 1 set of

15 repetitions as tolerated and gradually progressed to 2 sets of 15 to 20 over the 8-week program. Most subjects in the current study had progressed to at least 2 sets of 15 by the end of the study.

In the current study, a hand-held dynamometer effectively measured change in muscle strength that occurred following the 8-week exercise program. Being able to demonstrate change in strength as a result of a physical therapy intervention is important. Strength of the muscles tested in the current study could not have been effectively assessed using manual muscle testing techniques because of lack of sensitivity. A hand-held dynamometer is relatively inexpensive and should be considered a necessary tool in physical therapy clinics that provide post-rehabilitative exercise programs for patients with THA.

Unlike the isometric exercises used in the acute phase of rehabilitation following THA, the experimental exercise protocol used in this study was varied and challenging. Once subjects had completed the 8-week program, most of them indicated that they enjoyed the exercises and would continue to do them. When patients perceive that an exercise program is helpful and they enjoy doing the exercises, they are more likely to continue with their program even after they have been discharged from physical therapy. Currently, when patients complete their acute rehabilitation, they are instructed to continue to perform their initial exercise program indefinitely. Of the 28 subjects who participated in the current study, none were still doing their program that was instructed by their physical therapist post-operatively.

Recommendations for Future Study

Recommendations for future study include repeating the current study using a double blind design. The study should use a larger sample size that excludes subjects with initial postural stability measurements of 90% or more in single stance. Additionally, the falls efficacy scale (FES) should be used to assess fear of falling rather than the two questions used in the current study. A follow-up visit at 12-months post-THA should be added to this future study to assess continued compliance to the exercise program and to determine whether improvements in function, muscle strength, and postural stability are maintained or enhanced.

The previous recommendation for future study includes excluding subjects with initial postural stability measurements of 90% or more. The cut-off measurement of 90% however, is arbitrary and was chosen only because these subjects have limited potential for large improvements (cannot improve beyond 100%). Ninety percent or more as a cut-off was not based on a known functional relationship. That is, there is no literature showing that improving postural stability beyond 90% would have no benefit in terms of added function. In the current study, postural stability improved in the experimental group and self-perceived function also improved. It would be interesting to know if improvements in self-perceived function would have occurred if all subjects had postural stability measurements of 90% or more to begin with. Studies investigating postural stability and functional improvements are needed.

Another recommendation would be to investigate the use of a post-rehabilitative exercise program that could be initiated at 3 months rather than 4 months. The experimental exercise program used in the current study could be used but would need to start at a lower level in terms of repetitions and level of difficulty. Starting the post-rehabilitative exercise program at 3 months post-surgery would have the added advantage that many patients have post-op visits with their orthopedic surgeon up to 3 months. After the 3-month visit, many patients have no further follow-up visits until 1-year post-surgery. For this reason, the physician referral to physical therapy for a post-rehabilitation program would be facilitated if the program could start at 3 months rather than 4 months.

Due to improvements is prosthetic materials and fixation methods, THA surgeries are being performed on younger patients than ever before. A previous study by Jackson et al. (2001) showed that a group of 15 patients ranging in age from 51 to 76 years (M = 62 years, SD = 8 years) who were 12 months post-surgery for THA demonstrated significant impairments in postural stability on the involved side compared to the uninvolved side. It is not known whether similar impairments exist in younger subjects who have THA. A study should be performed that assesses whether postural stability deficits exist in patients who are under 50 years of age and who have undergone THA 12 months previously. If postural stability deficits do exist, the experimental group exercise protocol used in the current study should be tested in this younger population. It is possible that younger patients would respond differently to the experimental exercise protocol than the current experimental group of subjects.

Finally, since most physical therapy clinics do not own a force platform, it would be useful to identify a clinical test of postural stability that is sensitive enough to measure progress.

REFERENCES

Barber, T. C., Roger, D. J., Goodman, S. B., & Schurman, D. J. (1996). Early outcome of total hip arthroplasty using the direct lateral vs. the posterior surgical approach. Orthopedics, 19, 873-875.

Barrack, R. L., Skinner, H. B., Brunet, M. E., & Cook, S. D. (1984). Joint kinesthesia in the highly trained knee. Journal of Sports Medicine, 24, 18-20.

Barrett, D. S., Cobb, A. G., & Bentley, G. (1991). Joint proprioception in normal, osteoarthritic and replaced knees. Journal of Bone and Joint Surgery, 73-B, 53-56.

Beckenbaugh, R. D., & Illstrop, D. M. (1978). Total hip arthroplasty. A review of 335 cases with long follow-up. Journal of Bone and Joint Surgery, 60A, 306.

Bernstein, N. (1967). Coordination and regulation of movements. New York, NY: Pergamon Press, Inc.

Bizzo, G., Guillet, N., Patet, A., & Gagey, P. M. (1985). Specifications for building a vertical force platform designed for clinical stabilometry. Medical Biological Engineering in Computers, 23, 474-476.

Bohannon, R. W. (1988). Make tests and break tests of elbow flexor muscle strength. Physical Therapy, 68, 193-194.

Brocklehurst, J. C., Robertson, D., & James-Groom, P. (1982) Clinical correlates of sway in old age sensory modalities. Age and Ageing, 11, 1-10.

Brown, M. B., Hislop, H. J., Waters, R. L., & Porell, D. (1980). Walking efficiency before and after total hip replacement. Physical Therapy, 60, 1259-1263.

Bryant, M. J., Kernohan, W. G., Nixon, J. R., & Mollan, R. A. (1993). Statistical analysis of hip scores. The Journal of Bone and Joint Surgery, 75-B, 705-709.

Burton, D. S., & Imrie, S. H. (1973). Total hip arthroplasty and postoperative rehabilitation. Physical Therapy, 53, 132-140.

Chandler, H. P., Reineck, F. T., Wixson, R. L., & McCarthy, J. C. (1981). Total hip replacement in patients younger than thirty years old. The Journal of Bone and Joint Surgery, 63A, 1426-1434.

Chandler, L. S., Andrews, M. S., & Swanson, M. W. (1980). Movement assessment of infants: A manual. Rolling Bay, WA: Rolling Bay Press.

Charnley, J. (1970). Total hip replacement by low friction arthroplasty. Clinical Orthopaedics and Relataed Research, 72, 7-21.

Charnley, J. (1972). The long-term results of low-friction arthroplasty of the hip performed as a primary intervention. The Journal of Bone and Joint Surgery, 54-B, 61-76.

Charnley, J., & Pusso, R. (1968). The recording and the analysis of gait in relation to the surgery of the hip joint. Clinical Orthopaedics and Relatated Research, 58, 153.

Clarkson, H. M., & Gilewich, G. B. (1989). Musculoskeletal assessment: Joint range of motion and manual muscle strength. Baltimore: Williams & Wilkins.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (3rd ed.). New York: Academic Press.

Colledge, N. R., Cantley, P., Peaston, I., Brash, H., Lewis, S., & Wilson, J. A. (1994). Ageing and balance: The measurement of spontaneous sway by posturography. Gerontology, 40, 273-278.

Crowninshield, R. D., Brand, R. A., Johnston, R. C., & Milroy, J. C. (1980). The effect of femoral stem cross-sectional geometry on cement stresses in total hip reconstruction. Clinic Orthopaedics and Related Research, 146, 71-77.

Davis, R. B., DeLuca, P. A., & Ounpuu, S. (1995). Analysis of gait. In J. D. Bronzino (Ed.), The biomedical engineering handbook (pp. 381-390). Boca Raton: CRC Press.

Dawson, J., Fitzpatrick, R., Carr, A., & Murray, D. (1996). Questionnaire on the perception of patients about total hip replacement. The Journal of Bone and Joint Surgery, 78, 185-190.

Department of Health and Human Services. (1990). Healthy people 2000: National health promotion and disease prevention objectives (DHHS Publication No. (PHS) 91-50213). Washington , DC.

Dubs, L., Gschwend, N., & Munzinger, U. (1983). Sports after total hip arthroplasty. Archives of Orthopaedic and Traumatic Surgery, 101, 161-169.

Duncan, P. W., Chandler, J. M., Studenski, S. A., Hughes, M., & Prescott, B. (1993) How do physiologic components of balance affect mobility in elderly men? Archives of Physical Medicine and Rehabilitation, 75, 1343-1349.

Eftekar, N. (1971). Charnley "low friction torque" arthroplasty. A study of long-term results. Clinical Orthopaedics and Related Research, 81, 93-104.

Ellison, J., Miller J., Hocate, M. F., Levitan, S., & Nandhini, M. (2000). Comparison of Berg Balance Scale scores between rehabilitated patients with total hip arthroplasty and matched healthy subjects. Journal of Rehabilitation Outcomes Measurements, 4, 49-54.

Enloe, L. J., Shields, R. K., Smith, K., Leo, K., & Miller, B. (1996). Total hip and knee replacement treatment programs: A report using consensus. Journal of Orthopaedic and Sports Physical Therapy, 23, 3-11.

Fernie, G. R., Gryfe, C. I., Holliday, P. J., & Llewellyn, A. (1982). The relationship of postural sway in standing to the incidence of falls in geriatric subjects. Age and Ageing, 11, 11-16.

Fiatarone, M. A., Marks, E. C., Ryan, N. D., Meredith, C. N., Lipsitz, L. A., & Evans, W. J. (1990). High-intensity strength training in nonagenarians. Journal of the American Medical Association, 263, 3029-3034.

Finch, E., Walsh, A., Thomas, S. G., & Woodhouse, L. J. (1998). Functional ability perceived by individuals following total knee arthroplasty compared to age-matched individuals without knee disability. Journal of Orthopaedic and Sports Physical Therapy, 27, 255-263.

Gehlsen, G. M., & Whaley, M. S. (1990). Falls in the elderly: Part II, balance, strength and flexibility. Archives of Physical Medicine and Rehabilitation, 71, 739-741.

Gogia, P. P., Christensen, C. M., & Schmidt, C. (1994). Total hip replacements in patients with osteoarthritis of the hip: Improvement in pain and functional status. Orthopedics, 17, 145-150.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: Reliability and validity. Archives of Physical Medicine and Rehabilitation, 70, 510-517.

Goodwin, G. M., McCloskey, D. I., & Matthews, P. B. C. (1972) The persistance of appreciable kinesthesia after paralysing joint afferents but preserving muscle afferents. Brain Research, 37, 326-329.

Gore, D. R., Murray, M.P. Sepic, S. B., & Gardner, G. M. (1982). Anterolateral compared to posterior approach in total hip arthroplasty: Differences in component positioning, hip strength, and hip motion. Clinical Orthopaedics and Related Research, 165, 180-187.

Griffith, M. J., Seidenstein, M. K., Williams, D., & Charnley J. (1978). Eight year results of Charnley arthroplasties of the hip with reference to the behavior of cement. Clinical Orthopaedics and Related Research, 137, 24-36.

Grigg, P., Finerman, G. A., & Riley, L. H. (1973) Joint position sense after total hip replacement. The Journal of Bone and Joint Surgery, 55A, 1016-1025.

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower extremity function in persons over the age of 70 years as a predictor of subsequent disability. New England Journal of Medicine, 332, 556-561.

Harris, W. H. (1994). Traumatic arthritis of the hip after dislocation and acetabular fractures: Treatment by mold arthroplasty. The Journal of Bone and Joint Surgery, 51A, 737-755.

Hasan, S. S., Lichtenstein, M. J., & Shiavi, R. G. (1990). Effect of loss of balance on biomechanics platform measures of sway: Influence of stance and a method for adjustment, Journal of Biomechanics, 23, 783-789.

Hoppenfeld, S., & deBoer, P. (1994). Surgical exposures in orthopaedics. The anatomic approach (2nd ed.). Philadelphia: J.B. Lippincott.

Horak, F. B. (1987). Clinical measurement of postural control in adults. Physical Therapy, 67, 1881-1884.

Horak, F. B., Henry, S. M., & Shumway-Cook, A. (1997). Postural perturbations: New insights for treatment of balance disorders. Physical Therapy, 77, 517-533.

Hunt, S. M., McKenna, S. P., McEwen, J., Backett, E. M., Williams, J., & Papp, E. (1980). A quantitative approach to perceived health status: A validation study. Journal of Epidemiology and Community Health, 34, 281-286.

Huskisson, E. C. (1974). Measurement of pain. Lancet, ii, 1127-1131.

Ivey, F. M., Roth, S. M., Ferrell, R. E., Tracy, B. L., Lemmer, J. T., Hurlbut, D. E., Martel, G. F., Siegel, E. L., Fozard, J. L., Metter, E., Fleg, J. L., & Hurley, B. F. (2000). Effects of age, gender, and myostatin genotype on the hypertrophic response to heavy resistance strength training. Journal of Gerontology, 55, M641-648.

Jackson, E. T., Jackson, A. W., Frankowski, C. M., Long, K. M., & Meske, N. B. (1994). Interdevice reliability and validity assessment of the Nicholas hand-held dynamometer. Journal of Orthopaedic and Sports Physical Therapy, 20, 302-306.

Jackson, E. T., Emerson, R., & Smith, S. (2001). Outcomes of total hip arthroplasty: A study of patients 1-year post-surgery. Manuscript submitted for publication.

Johnsson, R., Melander, A., & Onnerfalt, R. (1988). Physiotherapy after total hip replacement for primary arthrosis. Scandinavian Journal of Rehabilitative Medicine, 20, 43-45.

Judet, R. & Judet, J. (1952). Technique and results with acrylic femoral head prosthesis. Journal of Bone and Joint Surgery (Br), 34-B, 173-180.

Judge, J. O., Lindsey, C., Underwood, M., & Winsemius, D. (1993). Balance improvements in older women: Effects of exercise training. Physical Therapy, 73, 254-262.

Kampa, K. (1993). Hip injuries: A rehabilitation perspective. In C. B. Lewis & K. A. Knortz (Eds.), Orthopaedic assessment and treatment of the geriatric patient (pp. 243-262). St. Louis: Mosby-Year Book.

Kaplan, S. F., Nixon, J. E., Reitz, M., Rindfleish, L., & Tucker, J. (1985). Age-related changes in proprioception and sensation of joint position. Acta Orthopedica Scandinavia, 56, 72-74.

Kaye, G. (1982). The cementless total hip arthroplasty. Physiotherapy, 68, 394-398.

Keele, K. D. (1948). The pain chart. Lancet, 2, 6-8.

Kellogg International Work Group on the Prevention of Falls by the Elderly. (1987). The prevention of falls in later life. Danish Medical Bulletin, 34, (4, Supplement), 1-24.

Kelso, J. A. & Wallace, S. A. (1978). Conscious mechanisms in movement. In: Information processing in motor control and learning, New York: Academic Press, Inc.

Kilgus, D. J., Dorey, F. J., Finerman, G. A. M., & Amstutz, H. C. (1991). Patient activity, sports participation, and impact loading on the durability of cemented total hip replacements. Clinical Orthopaedics and Related Research, 269, 25-31.

Kokemen, E., Bossemeyer, R. W., & Williams, W. J. (1978). Quantitative evaluation of joint motion sensation in an aging population. Journal of Gerontology, 33, 62-67.

Lankhorst, G. J., Van de Stadt, R. J., & Van der Korst, J. K. (1985). The relationship of functional capacity, pain, and isometric and isokinetic torque in osteoarthritis of the knee. Scandinavian Journal of Rehabilitation, 17, 167-172.

Lemmer, J. T., Hurlbut, D. E., Martel, G. F., Tracy, B. L., Ivey, F. M., Metter, E. J., Fozard, J. L., Fleg, J. L., & Hurley, B. F. (2000). Age and gender responses to strength training and detraining. Medicine and Science in Sports and Exercise, 32, 1505-1512.

Liang, M. H., Cullen, K. E., & Poss, R. (1982). Primary total hip or knee replacement: Evaluation of patients. Annals of Internal Medicine, 97, 735-739.

Liang, M. H., & Jette A. M. (1981). Measuring functional ability in chronic arthritis: A critical review. Arthritis and Rheumatology, 24, 80-86.

Lichtenstein, M. J., Shields, S. L., Shiavi, R. G., & Burger, C. (1989). Exercise and balance in aged women: A pilot controlled clinical trial. Archives of Physical Medicine and Rehabilitation, 70, 138-143.

Long, W. T., Dorr, L. D., Healy, B., & Perry, J. (1993). Functional recovery of noncemented total hip arthroplasty. Clinical Orthopaedics and Related Research, 288, 73-77.

Lord, S. R., Caplan, G. A., & Ward, J. A. (1993). Balance, reaction time, and muscle strength in exercising and nonexercising older women: A pilot study. Archives of Physical Medicine and Rehabilitation, 74, 837-839.

Lord, S. R., Clark, R. D., & Webster, I. W. (1991). Postural stability and associated physiological factors in a population of aged persons. Journal of Gerontology, 46, M69-76.

Maki, B. E., Holliday, P. J., & Topper, A. K. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. Journal of Gerontology, 49, M72-M84.

McBeath, A. A., Bahrke, M. S., & Balke, B. (1980). Walking efficiency before and after total hip replacement as determined by oxygen consumption. The Journal of Bone and Joint Surgery, 62-A, 807-810.

McKee, G. K., & Watson-Farrar J. (1966). Replacement of the arthritic hips by the McKee-Farrar prosthesis. Journal of Bone and Joint Surgery (Br.), 48, 245-259.

Milani-Comparetti, A., & Gidoni, E. A. (1967). Routine developmental examination in normal and retarded children. Development and Medicine in Children's Neurology, 9, 631-638.

Mills, E. M. (1994). The effect of low-intensity aerobic exercise on muscle strength, flexibility, and balance among sedentary elderly persons. Nursing Research, 43, 207-211.

Mulch, G., & Petermann, W. (1979). Influence of age on results of vestibular motion tests. Annual of Otology Rhinology Laryngology, 88, Supplement 56.

Munin, M. C., Kwoh, C. K., Glynn, N., Crossett, L., & Rubash, H. E. (1995). Predicting discharge outcome after elective hip and knee arthroplasty. American Journal of Physical Medicine and Rehabilitation, 74, 294-301.

Murray, M. P., Brewer, B. J., & Zuege, R. C. (1972). Kinesiologic measurements of functional performance before and after McKee-Farrar total hip replacement. Journal of Bone and Joint Surgery, 54-A, 237-255.

Nashner, L. M. (1971). A model describing vestibular detection of body motion. Acta Otololaryngology, 72, 429-436.

National Institutes of Health Consensus Development Panel on Total Hip Replacement. (1994). Total hip replacement. Journal of the American Medical Association, 273, 1950-1956.

National Safety Council. (1987). Accident facts and figures. Chicago, IL.

Overstall, P. W., Exton-Smith, A. N., Imms, F. J., & Johnson, A. L. (1977). Falls in the elderly related to postural imbalance. British Medical Journal, 1, 261-264.

Perrin, T., Dorr, L. D., Perry, J., Gronley, J., & Hull, D. B. (1985). Functional evaluation with five- to ten-year follow-up evaluation. Clinical Orthopaedics and Related Research, 195, 252-260.

Pitts, D. G. (1982). The effects of aging on selected visual functions. In D. W. Kline, & K. Dismukes (Eds.). Aging in human visual function. New York, NY: Alan R. Liss.

Pozzo, T., Berthoz, A., & Lefort, L. (1989). Head kinematics during various motor tasks in humans. Progressive Brain Research, 80, 377-383.

Pyykko, I., Jantti, P., & Aalto, H. (1990). Postural control in elderly subjects. Age and Ageing, 19, 215-221.

Ritter, M. A., & Meding, J. B. (1987). Total hip arthroplasty: Can the patient play sports again? Orthopedics, 10, 1447-1452.

Roberts, B. L. (1989). Effects of walking on balance among elders. Nursing Research, 38, 180-182.

Roberts, B. L., & Fitzpatrick, J. J. (1983). Improving balance: Therapy of movement. Journal of Gerontological Nursing, 9, 151-156.

Rouben, D. P. (1994). Surgical treatment of the hip. In R. A. Donatelli & M. J. Wooden (Eds.), Orthopaedic physical therapy (pp. 565-577). New York: Churchill Livingstone.

Rymer, W. Z., & D'Almeida, A. (1977). Joint position sense: The effects of muscle contraction. Brain, 103, 1-22.

Sashika, H., Matsuba, Y., & Watanabe, Y. (1996). Home program of physical therapy: Effect on disabilities of patients with total hip arthroplasty. Archives of Physical Medicine and Rehabilitation, 77, 273-277.

Sattin, R. W. (1992). Falls among older persons: A public health perspective. Annual Review of Public Health, 13, 489-508.

Sattin, R. W., Huber, D. A. L., DeVito, C. A., Rodriguez, J. G., Ros, A., Bacchelli, S., Stevens, J. A., & Waxweiler, R. J. (1990). The incidence of fall injury events among the elderly in a defined population. American Journal of Epidemiology, 131, 1028-1037.

Shands, A. R. (1976). Historical milestones in the development of modern surgery of the hip joint. Proceedings of the Fourth Open Scientific Meeting of the Hip Society (p. 6). St. Louis: C. V. Mosby.

Shih, C. H., Du, Y. K., Lin, Y. H., & Wu, C. C. (1994). Muscular recovery around the hip joint after total hip arhroplasty. Clinical Orthopaedics and Related Research, 302, 115-120.

Shimba, T. (1984). An estimation of center of gravity from force platform data. Journal of Biomechanics, 17, 53-60.

Shumway-Cook, A., Gruber, W., Baldwin, M., & Liao, S. (1997). The effect of multidimensional exercise on balance, mobility, and fall risk in community-dwelling older adults. Physical Therapy, 77, 46-57.

Siopack, J. S., & Jergesen, H. E. (1995). Total hip arthroplasty. Western Journal of Medicine, 162, 243-249.

Skinner, H. B., Barrack, R. L., & Cook, S. D., (1984). Age-related decline in proprioception. Clinical Orthopaedics and Related Research, 184, 208-211.

Smith, S. (2000). Measurement of neuromuscular performance capacities. In J. D. Bronzino (Ed.), The biomedical engineering handbook (2nd ed.) (pp. 148.1-148.21). Boca Raton: CRC Press.

Stauffer, R. N., Smidt, G. L., & Wadsworth, J. B. (1974). Clinical and biomechancal analysis of gait following Charnley total hip replacement. Clinical Orthopaedics and Related Research, 99, 70-77.

Stender, B. L., & Drowatzky, J. N. (1994). Joint position sense in subjects with total hip replacements: The possible role of muscle afferents. Journal of the American Kinesiotherapy Association, 48, 10- 24.

Surburg, P. R., Suomi, R., & Poppy, W. K. (1992). Validity and reliability of a hand-held dynamometer with two populations. Journal of Orthopaedic and Sports Physical Therapy, 16, 229-234.

Tinetti, M. E., Baker D. I., McAvay, G., Claus, E. B., Garrett, P., Gottschalk, M., Koch, M. L., Trainor, K., & Horwitz, R. I. (1994). A multifactorial intervention to reduce the risk of falling among elderly people living in the community. New England Journal of Medicine, 331, 821-827.

Tinetti, M. E., Mendes de Leon, C. F., Doucette, J. T., & Baker, D. I. (1994) Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. Journal of Gerontology, 49, M140-147.

Tinetti, M. E., Richman, D., & Powell, L. (1990). Falls efficacy as a measure of fear of falling. Journal of Gerontology, 45, P239-243.

Tinetti, M. E., Speechley M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. New England Journal of Medicine, 319, 1701-1707.

Vaz, M. D., Kramer, J. F., Rorabeck, D. H., & Bourne, R. B. (1993). Isometric hip abductor strength following total hip replacement and its relationship to functional assessments. Journal of Orthopaedic and Sports Physical Therapy, 18, 526-531.

Ware, J. E., & Sherbourne, C. D. (1992). The MOS 36-item short-form health survey (SF36). I. Conceptual framework and item selection. Medical Care, 30, 473-483.

Webb Associates. (1978). Anthropometric Source Book, Vol. 1 (NASA Publication No.1024, pp. IV.6-IV.14). Washington, DC: National Aeronautics and Space Administration.

Welch, R. B., McGann, W. A., & Picetti, G. D. (1988). Charnley low-friction arthroplasty. A 15-17 year follow-up study. Orthopaedic Clinics of North America, 9, 551-555.

Westcott, S. L., Lowes, L. P., & Richardson, P. K. (1997). Evaluation of postural stability in children: Current throries and assessment tools. Physical Therapy, 77, 629-644.

Whipple, R. H., Wolfson, L. I., & Amerman, P. M. (1987). The relationship of knee and ankle weakness to falls in nursing home residents: An isokinetic study. Journal of the American Geriatric Society, 35, 13-20.

Wikhom, J. B., & Bohannon, R. W. (1991). Hand-held dynamometer measurements: Tester strength makes a difference. Journal of Orthpaedic and Sports Physical Therapy, 13, 191-198.

Wilcock, G. K. (1978). Benefits of total hip replacement to older patients and the community. British Medical Journal, 2, 37-39.

Woollacott, M. J., & Shumway-Cook, A. (1990). Changes in posture control across the life span – A systems approach. Physical Therapy, 70, 799-807.

Young, M. J., Bresnitz, E. A., & Strom, B. L. (1983). Sample size nomograms for interpreting negative clinical studies. Annals of Internal Medicine, 99, 248.

APPENDIXES

APPENDIX A

Patient Information Sheet

Patient Information Sheet

Name______________________________________ Date of Surgery ____________

Gender: Female ☐ Male ☐ Age _______ Number of months post op _______

Primary diagnosis______________________________ R on opposite side? Y ☐ N ☐

Surgery Information

Surgeon ________________________Surgical approach __________Side R ☐ L ☐

Fixation type: (Acetabular component) Cemented ☐ Cementless ☐

(Femoral component) Cemented ☐ Cementless ☐

After care

Which of the following describes the type of physical therapy received after surgery?

- ☐ Exercises and self-care instructions at the hospital
- ☐ In-patient rehabilitation. How long? _____
- ☐ Home health physical therapy. How long? _____
- ☐ No physical therapy was received.
- ☐ Other. Explain. ____

Exclusion Criteria

1. Is there pain when standing on either leg by itself? Yes ☐ No ☐
2. Does the subject have low back pain at this time? Yes ☐ No ☐
3. Is this a revision surgery? Yes ☐ No ☐
4. Are there any diagnosed vestibular problems? Yes ☐ No ☐
5. Is there central or peripheral nerve involvement in either leg? Yes ☐ No ☐
6. Dementia or decreased cognitive status? Yes ☐ No ☐
7. Are there any known contraindications to exercising? Yes ☐ No ☐

APPENDIX B

Human Subjects Informed Consent Form

YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM TO KEEP.

TITLE OF STUDY:
Effect of Post-Rehabilitation Exercise on Strength and Postural Stability Following Total Hip Arthroplasty

PURPOSE:
The purpose of this project is to study the effectiveness of an exercise program for patients who have had a total hip replacement when the exercise is given 4 to 12 months after surgery. Subjects of any age, race, or gender who have had a hip replacement at least 4 months but no more than 12 months ago are being asked to participate in this study.

WHAT YOU WILL BE ASKED TO DO IF YOU PARTICIPATE:
You will be checked by a physical therapist before and after being asked to perform a home exercise program for 8 weeks. I will a) ask you to answer 2 questions about fear of falling that can be answered with a "yes" or "no," b) ask you to fill out a short questionnaire, c) measure the muscle strength in both of your hips, and d) measure your balance on each leg. Strength measurements of the muscles surrounding each hip will be measured by asking you to push as hard as you can against a device I hold in my hand that measures the amount of force you push with. Balance will be measured using a device that you stand on and try to hold yourself as steady as possible on one leg. Measurements will be performed at the TWU Health Promotion & Research Center (HPRC) at the Presbyterian Campus and each session should take about 40-45 min. You will also be asked to come to the Center two other times to be taught an exercise program. You will be given one of two exercise programs selected by chance. The exercises in both groups were designed to be helpful to patients who have had a total hip replacement. Each of the two sessions in which you are taught the exercises should take about 30 mins. You will be asked to perform 7 exercises 4 times per week for 8 weeks, and to keep a record of how often you exercise. You have the right to withdraw from the study at any time and your withdrawal will not affect the quality of care you receive. You may receive a copy of the results once the study is finished by contacting:

Elaine Trudelle-Jackson
TWU School of Physical Therapy
8194 Walnut Hill Lane
Dallas, TX 75231
(214)706-2300

POTENTIAL RISKS AND INCONVENIENCES AND MEASURES TO REDUCE THEM:

- *Potential inconveniences* include time spent at the Center for measurements and exercise instructions. Sessions at the HPRC will be by appointment, so as to keep unnecessary waiting to a minimum. Additionally, you will spend about 30 minutes, 4 times per week, for 8 weeks performing your exercise program at home.

- *Potential risks* include minor discomfort that may be experienced during the muscle strength tests from pressure against the measuring device or from your muscles feeling tired during the test. You may also experience delayed onset muscle soreness that begins the day after you perform physical activity that you are not used to. This type of muscle soreness gradually goes away over the next 3 or 4 days. Finally, although injuries are not expected to occur during this study, there is a small risk of falling during the tests for balance. To reduce this risk, a table will be placed in front of you that can be used to steady yourself should you need to. Also, you will be within reach of the tester who can assist you in regaining your balance should you need assistance.

- *Confidentiality risks* will be minimized by assigning you an identification number. Your name will not be used during data entry. Only the investigators who are involved in this study will have access to information that would allow you to be identified by name. This information will be kept in a locked file and will not be available to others. Copies of signed consent forms will also be kept in the locked file. Once data has been entered and analyzed, it will be stored only on a floppy disk. Only the investigators will have access to the data stored on the disk. Data will be kept for 5 years before erasing it from the disk. Findings of the study will be presented at professional meetings for physical therapists or other medical professionals. Findings may also be published in a physical therapy or other medical professional journal.

POTENTIAL BENEFITS:
You will receive free musculoskeletal testing by a licensed physical therapist. If you complete the study, you will receive a $50 payment for participating. The payment is available from a grant awarded by the Texas Physical Therapy Education and Research Foundation. In addition, the information gained from this study will be used to improve treatment given to other patients who receive total hip replacements.

APPROPRIATE ALTERNATIVES, IF ANY: None

TITLE OF STUDY: Effect of Post-Rehabilitative Exercise on Strength and Postural Stability Following Total Hip Arthroplasty

PARTICIPATION IS VOLUNTARY: Participation in this study is completely voluntary. If you give your consent, you are free to withdraw your consent and to discontinue participation in this study at any time. Your refusal to participate or your withdrawal from this study will not affect treatment in any way.

YOU ARE MAKING A DECISION ABOUT WHETHER OR NOT TO PARTICIPATE IN THIS STUDY. YOU SHOULD NOT SIGN THIS FORM UNTIL YOU UNDERSTAND ALL OF THE INFORMATION PRESENTED ABOVE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE AFTER HAVING READ (OR BEEN READ) THE INFORMATION PROVIDED ABOVE.

Having read the above information, I voluntarily agree that I will participate in this study. I understand that there will be no effect on my status with Texas Woman's University if I decide to withdraw from this study.

____________________________________ __________________

Participant's Signature Date

____

Participant's Age

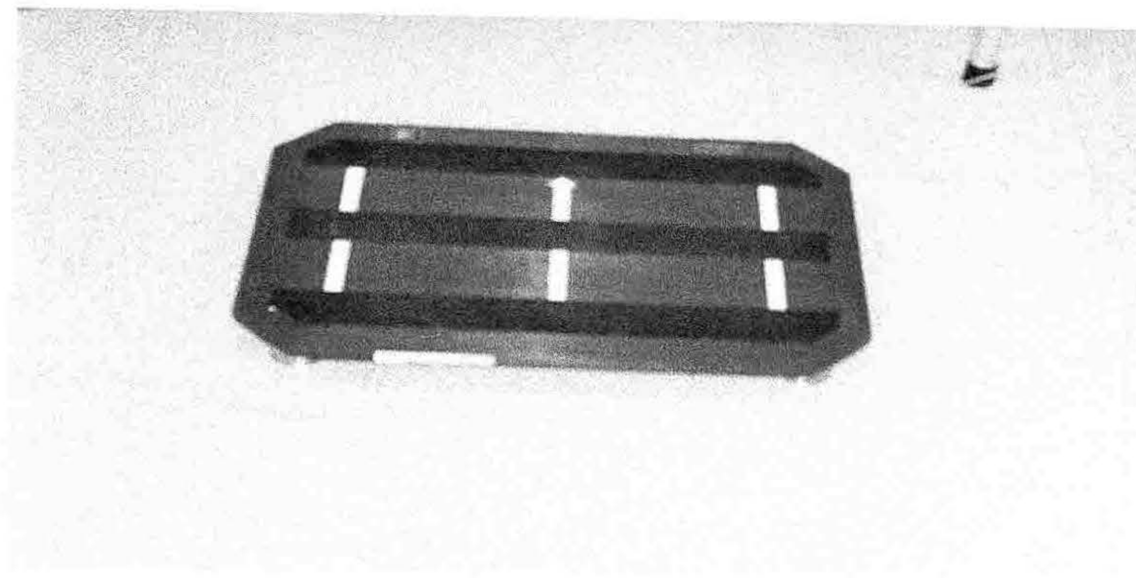
____________________________________ __________________

Signature of Investigator

APPENDIX C

Photographs of Test Instruments

Photographs of Test Instruments



BEP IV – Force Platform

BEP IIIa – Hand Held Dynamometer

APPENDIX D

12-Item Hip Questionnaire

12-Item Hip Questionnaire

During the last four weeks:

1.) How would you describe the pain you usually had in your hip?	1) None 2) Very mild 3) Mild 4) Moderate 5) Severe
2.) Have you had any trouble with washing and drying yourself (all over) because of your hip?	1) No trouble at all 2) Very little trouble 3) Moderate trouble 4) Extreme difficulty 5) Impossible to do
3.) Have you had any trouble getting in and out off a car or using public transport because of your hip? (whichever you tend to use)	1) No trouble at all 2) Very little trouble 3) Moderate trouble 4) Extreme difficulty 5) Impossible to do
4.) Have you been able to put on a pair of socks, stockings or tights?	1) Yes, easily 2) With little difficulty 3) With moderate difficulty 4) With extreme difficulty 5) No, impossible
5.) Could you do household shopping on your own?	1) Yes, easily 2) With little difficulty 3) With moderate difficulty 4) With extreme difficulty 5) No, impossible
6.) For how long have you been able to walk before the pain from your hip became severe? (with or without stick)	1) No pain/>30 minutes 2) 16-30 minutes 3) 3 to 15 minutes 4) Around the house only 5) Not at all
7.) Have you been able to climb a flight of stairs?	1) Yes, easily 2) With little difficulty 3) With moderate difficulty 4) With extreme difficulty 5) No, impossible
8.) After a meal (sat at a table), how painful has it been for you to stand up from a chair because of your hip?	1) Not at all painful 2) Slightly painful 3) Moderately painful 4) Very painful 5) No, impossible

9.) Have you been limping when walking because of your hip?	1) Rarely/never 2) Sometimes or just at first 3) Often, not just at first 4) Most of the time 5) All the time
10.) Have you had any sudden severe pain – 'shooting', 'stabbing' or 'spasms' – from the affected hip?	1) No days 2) Only 1 or 2 days 3) Some days 4) Most days 5) Every day
11.) How much has pain from your hip interfered with your usual work (including housework)?	1) Not at all 2) A little bit 3) Moderately 4) Greatly 5) Totally
12.) Have you been troubled by pain from your hip in bed at night?	1) No nights 2) Only 1 or 2 nights 3) Some nights 4) Most nights 5) Every night

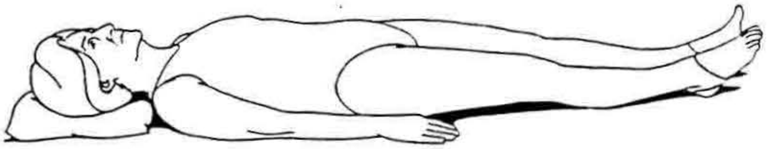
---

Dawson, J., Fitzpatrick, R., Carr, A., & Murray, D. (1996). Questionnaire on the perception of patients about total hip replacement. The Journal of Bone and Joint Surgery, 78, 185-190.

APPENDIX E

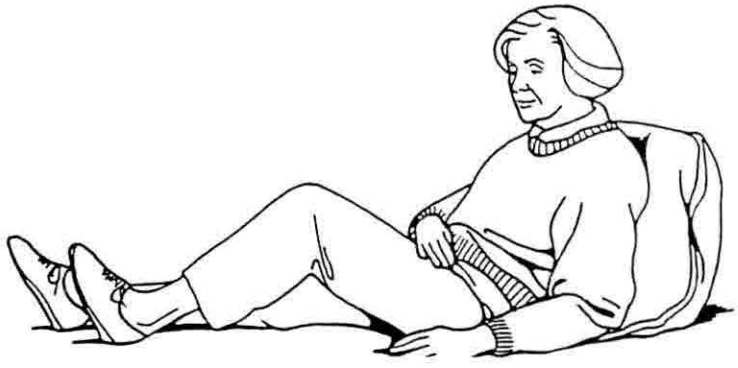
Exercise Programs

Control Group Exercise Protocol

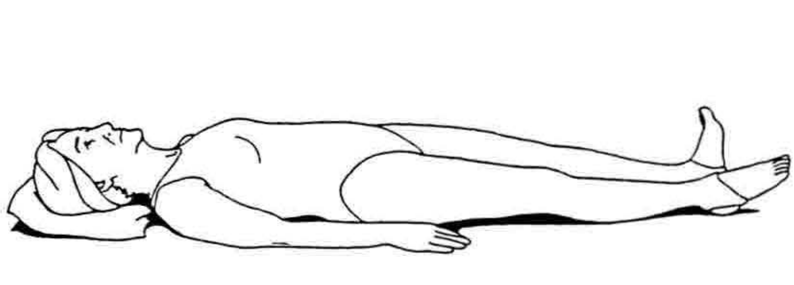


Gluteal Sets.
Lie on your back with both legs supported on the bed. Squeeze buttocks muscles as tightly as possible and hold for 6 secs.

Quad Sets.
Lying on your back or sitting with your leg(s) straight in front of you, slowly tighten the front thigh muscle until it is as tight possible and hold for 6 sec.

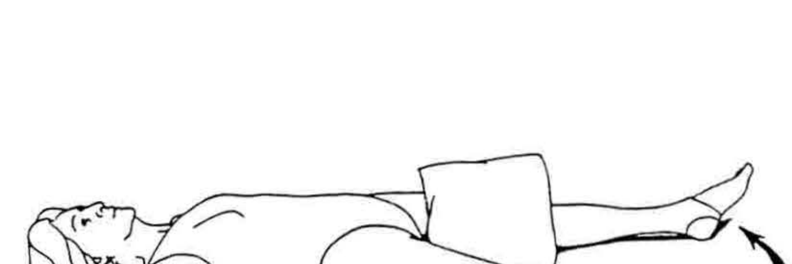


Hamstring Sets.
With your leg bent slightly, push the heel into the bed or floor without bending the knee any further. Hold for 6 secs.

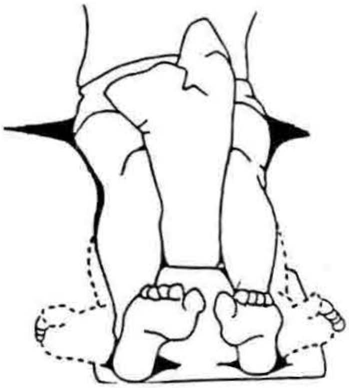


Ankle Pumps.
Bend your ankle up toward you as far as you can, then point your toes by bending your ankle away from you as far as you can.

Heel Slides.
Lying on your back, bend your knee by sliding your heel toward your buttocks as far as you can. Return to the starting position and repeat.

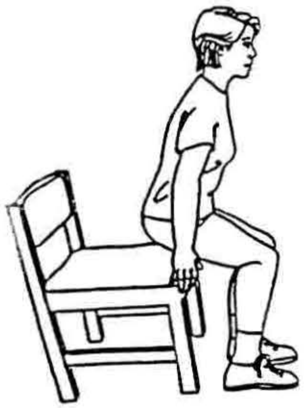


Hip Abduction.
Lying on your back, slide your leg out to the side while keeping the kneecap pointing toward the ceiling. Return to the starting position and repeat.

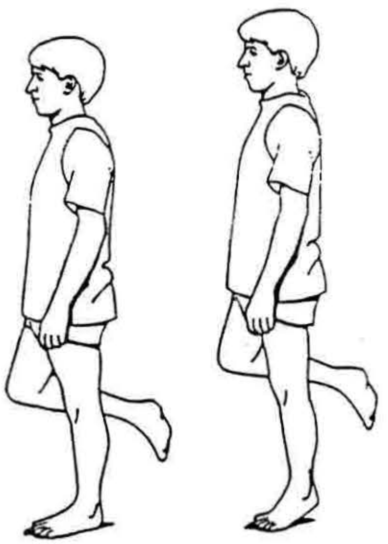


Internal/External Rotation.
Lying on your back, roll legs in and out.

Experimental Group Exercise Protocol

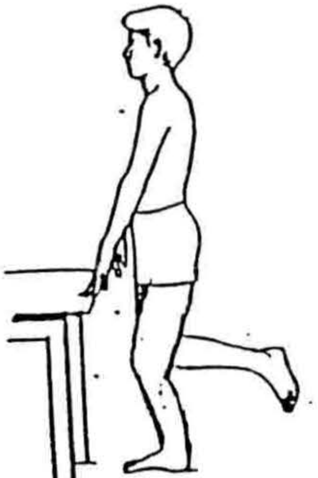


Sit to Stand.
Keeping back straight and feet wide apart, reach back for chair while squatting until buttocks almost touch the seat, then return to the starting position. (Hands are used only to guide the movement. Do not use hands to push.)

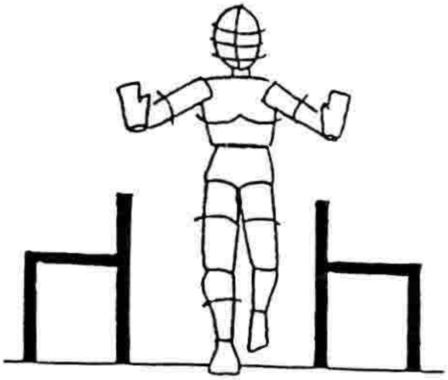


Toe Raises.
Stand straight, feet flat on the floor. With abdomen tight and shoulders back, hold one leg up as you raise up on toes as high as you can.

Partial Knee Bends.
Stand on both legs. With abdomen tight, back straight, and shoulders back, lower yourself by bending knees to about 30°. Straighten knees and repeat.



Progression.
Assume position above but stand on one leg. Grip floor with toes and slowly lower your weight by bending the knee to about 30° then return to the start position. You may progress to doing these while holding dumbbells.



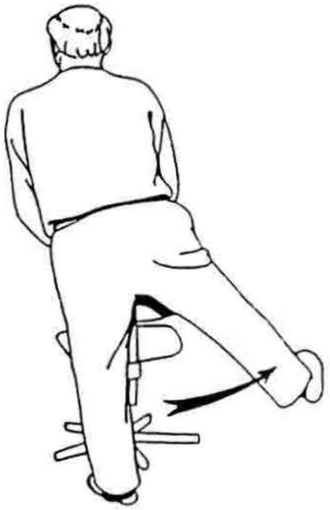
One Legged Standing Balance.

Using two chairs to support your hands, transfer your weight onto your operated leg and pick the other leg up. Remove your hands from the chairs and maintain your balance for up to 20 secs.

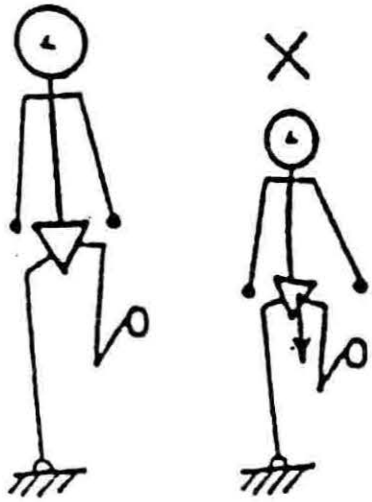
Progression.

Assume the same position as above. While standing on your operated leg, move your head from side to side. When this becomes easy, perform the exercise while turning your head from side to side as if looking over one shoulder then the other.

Knee Raises.
Stand straight with abdomen tight and shoulders back. Slowly lift one knee as high as you can, then lower back to the floor. Alternate legs. Raise opposite arm at same time as the knee is raised.



Side and Back Leg Raises.
Standing straight with abdomen tight and shoulders back, slowly raise leg out to the side then return to start position. Do the same for the other leg. Repeat this exercise but this time raise leg back behind you.



Pelvic Raising/Lowering.

Standing on the operated leg, bend other knee up. Stand unsupported while not allowing the pelvis on the side of the bent knee to drop. Progress by slowly raising and lowering the pelvis on the side of the bent knee.

APPENDIX F

Exercise Log

Month ________________

Exercise Log (Group I)

	Gluteal Sets	Quad Sets	Hamstring Sets	Ankle Pumps	Heel Slides	Hip Abduction	Int/Ext Rotation
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							

Month________________

Exercise Log (Group II)

	Sit to Stand	Toe Raises	Knee Bends	Standing Balance	Knee Raises	Side & Back Leg Raises	Pelvic Raise/Lower
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							

APPENDIX G

MANOVA Tables

Summary of MANOVA of the Effect of the 8-Week Intervention on Postural Stability and Muscle Strength

Source of Variance	df	F-ratio
Between Subjects (Group)		2.70*
Hypothesis	5	
Error	22	
Within Subjects (Pre-Post)		7.74**
Hypothesis	5	
Error	22	
Interaction (Group X Pre-Post)		5.72**
Hypothesis	5	
Error	22	

Note: n=28. *$p < .05$. **$p < .01$

Multivariate Analysis of Pre-Post Intervention Differences for Each Treatment Group

Variable	*df*	*F*-ratio
	Experimental Group (*n*=14)	
Within Subjects (Pre-Post)		10.83*
Hypothesis	5	
Error	9	
	Control Group (*n*=14)	
Within Subjects (Pre-Post)		0.14*
Hypothesis	5	
Error	9	

Note: *$p < .01$