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WHOLE-BODY VIBRATION COMPARED TO TRADITIONAL PHYSICAL  
THERAPY IN INDIVIDUALS WITH TOTAL KNEE ARTHROPLASTY

by

A. Wayne Johnson

A dissertation submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Exercise Sciences

Brigham Young University

April 2007

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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

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This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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## ABSTRACT

### WHOLE-BODY VIBRATION COMPARED TO TRADITIONAL PHYSICAL THERAPY IN INDIVIDUALS WITH TOTAL KNEE ARTHROPLASTY

A. Wayne Johnson

Department of Exercise Sciences

Doctor of Philosophy

**Background and Purpose.** The purpose of the present study was to compare total knee arthroplasty (TKA) rehabilitation with and without whole body vibration (WBV) to 1) understand if WBV is a useful treatment during TKA rehabilitation to increase quadriceps strength and function, and 2) to investigate the effect of WBV on quadriceps voluntary muscle activation. **Subject and Methods.** Individuals post TKA (WBV n=8, control n=8) received physical therapy with and without WBV for four weeks. Quadriceps strength and muscle activation, function, perceived pain, and knee range of motion were measured. **Results.** No adverse side effects were reported in either group. There was a significant increase in strength and function for both groups ( $P < 0.01$ ). There was no difference pre to posttest between groups for strength, muscle activation, or pain (Hotelling's  $T^2 = 0.42$ ,  $P = .80$ ) or for function ( $F = 0.54$ ,  $P = 0.66$ ). **Discussion and Conclusion.** In individuals with TKA, WBV showed equal strength and function

improvement to physical therapy directed progressive resistive exercise. Influence of WBV on muscle activation remains unclear, as initial muscle activation was near established normal quadriceps levels and remained so post treatment.

**Key Words:** *Muscle strength, Muscle activation, Central activation ratio, Knee rehabilitation*

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WHOLE-BODY VIBRATION COMPARED TO TRADITIONAL PHYSICAL  
THERAPY IN INDIVIDUALS WITH TOTAL KNEE ARTHROPLASTY

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**ABSTRACT**

**Background and Purpose.** The purpose of the present study was to compare total knee arthroplasty (TKA) rehabilitation with and without whole body vibration (WBV) to 1) understand if WBV is a useful treatment during TKA rehabilitation to increase quadriceps strength and function, and 2) to investigate the effect of WBV on quadriceps voluntary muscle activation. **Subject and Methods.** Individuals post TKA (WBV n=8, control n=8) received physical therapy with and without WBV for four weeks. Quadriceps strength and muscle activation, function, perceived pain, and knee range of motion were measured. **Results.** No adverse side effects were reported in either group. There was a significant increase in strength and function for both groups ( $P<0.01$ ). There was no difference pre to posttest between groups for strength, muscle activation, or pain (Hotelling's  $T^2=0.42$ ,  $P=.80$ ) or for function ( $F=0.54$ ,  $P=0.66$ ). **Discussion and Conclusion.** In individuals with TKA, WBV showed equal strength and function improvement to physical therapy directed progressive resistive exercise. Influence of WBV on muscle activation remains unclear, as initial muscle activation was near Established normal quadriceps levels and remained so post treatment.

**Key Words:** *Muscle strength, muscle activation, central activation ratio, knee rehabilitation*

## INTRODUCTION

Osteoarthritis (OA) affects over 21 million Americans and is projected to increase in prevalence.<sup>1</sup> Osteoarthritis affects 70% of adults over 65 years old and is a major cause of joint pain and disability.<sup>2,3</sup> No cure exists at the current time for OA. Treatments for OA have focused on limiting the symptoms and restoring or improving mobility and function.<sup>4</sup> Knee OA presents with pain, loss of mobility and function which impact a person's quality of life.<sup>5,6</sup> When conservative treatments no longer provide relief, end-stage knee OA is commonly treated with total knee arthroplasty (TKA).<sup>4</sup> In 2003, there were 418,000 total knee replacements performed in the U.S.A., primarily for arthritis.<sup>7</sup>

Rehabilitation after TKA has shown benefits and improved outcome, but residual deficits to strength and function exist. A systematic review of randomized clinical trials of patients with TKA, found that exercise therapy is beneficial for patients.<sup>4,8-11</sup> Physical therapy facilitates increased range of motion (ROM), knee strength, mobility, and function.<sup>4</sup> Despite the improvement made during TKA rehabilitation, often, strength and functional deficits persist.<sup>8-10</sup> Recovery of quadriceps strength to normal levels following TKA is rare.<sup>12</sup> A loss of quadriceps strength has been associated with increased fall risk<sup>13-15</sup> and detrimentally affected walking.<sup>9,11</sup> Deficits in stair climbing<sup>9</sup> and over all function also persist.<sup>12,16</sup>

Whole-body vibration (WBV) is a new exercise mode that has been suggested as a means to rehabilitate patients with lower extremity weakness.<sup>17-19</sup> Cardinale and Bosco<sup>18</sup> propose that WBV has a great potential in therapeutic application, where it may increase muscular performance in patients and older adults. Whole-body vibration has

been shown to increase muscle performance<sup>14, 19, 20</sup> and postural control,<sup>21</sup> in the elderly. No adverse side effects were noted in these studies.<sup>14, 19-21</sup>

Strength impairment following TKA is reported to be a result of failure of voluntary muscle activation and to a lesser extent, muscle atrophy.<sup>12</sup> Failure of voluntary muscle activation is the inability to produce all available muscle force despite maximal conscious effort.<sup>22-25</sup> Voluntary muscle activation, as measured by the central activation ratio (CAR), has been found to be decreased (CAR = 0.72-0.74) in individuals with TKA.<sup>12, 22, 26</sup> The CAR is found by performing a maximal voluntary isometric contraction (MVIC), then applying an electrical stimulation to the contracting muscle.<sup>27</sup> Augmentation of the voluntary force produced indicates a deficit in muscle activation. The CAR is a ratio between the maximal voluntary isometric contraction and the maximal voluntary isometric contraction with the superimposed electrical stimulation. A ratio of 1 indicates a fully activated muscle, less than 1 indicates a deficit in voluntary activation, and thus, a deficit in strength.<sup>27</sup>

Currently, no studies have been found that investigated WBV as a treatment to physical therapy rehabilitation of individuals with TKA. Neither has the CAR been used to study the effect of WBV on individuals with a known quadriceps femoris voluntary muscle activation deficit such as those with TKA. The purpose of the present study was to compare traditional TKA rehabilitation with and without WBV to understand if WBV is a useful treatment during TKA rehabilitation to increase strength and function and to investigate the effect of WBV on voluntary muscle activation in individuals with recent TKA.



## Methods

### *Subjects*

Twenty-one subjects (male= 10 and female= 11), signed an institutional review board approved informed consent form, and volunteered for participation in the study. Sixteen subjects finished the study (males= 10 and females= 6). In the vibration group three subjects stopped participation. One subject had manipulation under anesthesia, another subject had complication with the TKA unrelated to the study, and the third subject had no complications, but decided to stop participation. Two subjects were dropped from the control group after not returning to physical therapy. Subjects had undergone total knee arthroplasty by orthopedic surgeons 3 to 6 weeks before beginning the study. Subjects were randomly assigned to the WBV group (n=8; males= 6, females= 2) or control group (n=8; males= 4, females= 4). Control subjects' average age was  $68.5 \pm 6$  years, height was  $1.68 \pm 0.1$  m, body mass was  $97 \pm 21$  kg, and BMI was  $34.2 \pm 8.7$  kg/m<sup>2</sup>. Subjects, in the WBV group, average age was  $67 \pm 10$  years, height was  $1.77 \pm .08$  m, body mass was  $104.8 \pm 17.9$  kg, and BMI was  $33.3 \pm 4.7$  kg/m<sup>2</sup>. Subjects with musculoskeletal involvement other than TKA that limited their function, uncontrolled blood pressure, diabetes mellitus, neoplasm, neurological disorders, fibromyalgia, or a cardiac pacemaker were excluded. Subjects were required to complete at least 10 of 12 scheduled therapy sessions. Subjects were allowed to miss up to two sessions, but not in the same week, before being discharged from the study.

The minimal number of subjects proposed to be used in the study was 8 subjects per group for a total of 16 subjects. Hart et al,<sup>28</sup> from previous data, determined a priori

that 16 subjects is necessary to find differences in quadriceps activation at an  $\alpha=.05$  while maintaining statistical power greater than  $1-\beta=.8$ , based on the observed group effect comparing quadriceps activation in subjects with low back pain.

### *Experimental Design*

A 2 x 2 (time and treatment) factorial design was used in the study. The first factor was time (two levels –pretest and posttest separated by 4 weeks of treatment), the second factor was the treatment program (two levels- traditional physical therapy rehabilitation only and traditional rehabilitation + whole-body vibration). The dependent variables were 1) strength (MVIC) at 75° of knee flexion<sup>12, 29</sup> during a maximal knee extension isometric contraction, 2) function with the Timed-up-and-go test (TUG), 3) voluntary activation of the quadriceps at 75° of knee flexion during a maximal isometric knee extension contraction (CAR), and 4) perceived pain levels at rest and with movement via visual analog pain scale (VAS) was done pretest to posttest. Knee joint ROM was gathered as descriptive data.

### *Testing Protocol*

Subjects participated in a baseline pretest (3 to 6 weeks post surgery) and in a 4-week posttest of quadriceps femoris isometric strength, voluntary muscle activation, TUG, ROM, and perceived pain levels.

*Pretest.* Data were gathered in the order listed: 1) VAS, 2) active knee joint ROM, 3) TUG test, 4) MVIC and voluntary muscle activation testing. 1) Subjects completed a 100 mm horizontal line VAS with anchor points of “no pain” and “worst imaginable pain” for average pain over the last 24 hours at rest and average pain over the last 24 hours with

movement. 2) Active knee joint ROM was measured using a universal goniometer, and gathered following previously published methods.<sup>12</sup> 3) TUG test: Subjects were asked to rise from an armchair (seat height 46 cm), walk 3 meters, turn and return to sitting in the same chair.<sup>30</sup> Subjects were asked to walk as quickly as they felt safe and comfortable. Subjects were allowed to use the chair arm rest to stand and sit down, as well as any assistive device needed. The TUG has a high inter-tester (ICC = 0.99) and intra-tester reliability (ICC = 0.99).<sup>30</sup> 4) Quadriceps femoris strength and voluntary muscle activation of the quadriceps femoris muscle were tested on both the operated knee and non-operated knee. The non-operated lower extremity was tested first, in order to decrease possible anxiety about the test. The order of the testing remained the same for the postintervention testing. Subjects warmed up for 5 minutes on a bicycle ergometer or NuStep (NuStep, Inc., Ann Arbor, MI 48108), before strength and muscle activation testing. Intensity was determined by the patient's comfort level and the patient's ability to complete full revolutions.

*Quadriceps Strength and Activation Testing.* Subjects used the same seat for both pre and posttest. Subjects were positioned in the chair so that the hips were flexed to approximately 85° and their knee flexed to 75°. <sup>29</sup> An ankle cuff attached to the strain gauge (Omegadyne, Inc., Stanford, CT, model: LC101-250) was placed on the subjects' ankle approximately 4 cm proximal to the lateral malleolus of the leg being tested. The strain gauge was positioned so that a 90° angle existed between the strain gauge and the subject's lower leg. The strain gauge was anchored to the seat frame. The thigh, pelvis, and trunk were stabilized to the chair with inelastic straps. Two self-adhering electrodes

(3"x5," ACP High conductivity electrodes, Accelerated Care Plus, Reno, NV) were attached to the thigh as done in previous research.<sup>22</sup> The anode was placed over the motor point of the rectus femoris and the cathode was placed over the motor point of the vastus medialis. (Fig. 1)

Strength testing followed the method established by Stevens, Mizner, and Snyder-Mackler.<sup>29</sup> Subjects were instructed to perform two 3 to 5-second voluntary isometric contractions at an intensity that they perceived as 50% to 75% of their maximal effort. These contractions functioned as a warm-up and to familiarize the subjects with the testing procedure. Subjects' quadriceps was stimulated at 135 V to familiarize the subject with the sensation of electrical stimulation. Subjects then rested 3 minutes before commencement of data collection. Prior to each data collection, subjects were told to maximally, isometrically contract their quadriceps for 4 seconds and not to volitionally lessen their contraction after the stimulus was felt. Subjects received verbal encouragement from the tester during the contraction. Approximately 2 seconds into the contraction, a 135 V, 10-pulse, 100 pps train (1000 microsecond pulse duration) (S88 stimulator with an SIU8T stimulus isolation unit (Grass Instruments, Inc., Quincy, MA) was delivered to the muscle to assess whether the subject was maximally activating the quadriceps femoris muscle (burst superimposition technique).<sup>27, 29, 31-33</sup> The data was digitized at 1500 Hz and analyzed by customized software. An example of the CAR curve is found in Fig. 2. With full activation, no increase in force was seen and a CAR of 1.0 was achieved. The subject performed three trials. Each trial was separated by 3 minutes, in order to minimize the effects of muscle fatigue.

Subjects participated in physical therapy as ordered by the orthopedic surgeon from immediate postoperation until the beginning of the study. After baseline measurements and random assignment to groups subjects participated in traditional or traditional and whole-body vibration rehabilitation for 4 weeks at a rate of three visits per week for a total of 12 visits. At the end of the four weeks subjects were retested at approximately the same time of day.

#### *Traditional rehabilitation*

A protocol was followed similar to that established by Stevens, Mizner, and Snyder-Mackler.<sup>29</sup> Rehabilitation occurred at physical therapy clinics.

**Range of Motion.** Bicycle ergometer or NuStep (10 to 15 minutes), started with forward and backward pedaling with no resistance until enough ROM for full revolution; progression: lower seat height to produce stretch with each revolution. Active-assistive ROM was done for knee flexion, sitting or supine, using other leg to assist. Knee extension stretch was done with manual pressure (in clinic) or weights (at home). Patellar mobilizations: 3x30 superior/inferior; medial/lateral, as needed.

**Strength.** Quad sets, straight leg raises (without quad lag), hip abduction (side lying or theraband or machine), standing hamstring curls (theraband, chair scoots, or machine), seated knee extension, standing terminal knee extensions from 45° to 0°, step ups (5.08-15.24 cm), step downs and side steps, wall squats (squats) to 45° NuStep, total gym, shuttle, 1 to 3 sets of 10 repetitions for all strengthening exercises. Criteria for progression: exercises are to be progressed (eg, weights, step height, etc.) once the patient can complete the exercise correctly and feels maximally fatigued at the end of each set.

Progression: (0.454-0.907 kg) weights added to exercises, step ups and step downs (5.08-15.24 cm). Weight bearing exercises performed on the shuttle, total gym or in standing equivalent to the WBV exercises.

*Pain and Swelling, Incision Mobility, Functional Activities.* Ice and compression as needed (duration of 10 to 20 minutes as directed by attending physical therapist). Soft tissue mobilization until incision moves freely over subcutaneous tissue. Ambulation training with assistive device as appropriate with emphasis on heel strike, push-off at toe-off and normal knee joint excursions. Emphasis on heel strike, push-off at toe-off and normal knee joint excursion when able to walk without assistive device. Stair ascending and descending step-over-step when patient has sufficient concentric/eccentric strength.

#### *Whole-Body Vibration and Traditional Rehabilitation*

Subjects assigned to the WBV group participated in traditional TKA rehabilitation exercises designed to increase ROM and reduce pain. Strengthening exercises were performed during WBV similar to the protocol used by Roelants, Delecluse, and Verschueren.<sup>19</sup> Whole-body vibration occurred on the vibrating platform (Power Plate, Badhoevendorp, The Netherlands) using unweighted static and dynamic exercise. Subjects were asked to wear the same footwear during the duration of the study. Subjects were asked to report any adverse reactions or negative side-effects to the training. Subjects started at 2 mm (low) vibration and progressed to 5 mm (high) as tolerated and in accordance with exercise progression. Vibration was maintained at 35 Hz. Subjects started with basic exercises and then progressed to more advanced exercises. They began with 1 repetition and progressed to 3 repetitions. They started with

30 seconds and progress to 60 seconds per repetition. The total vibration duration the subject received began at 3 minutes and progressed to 18 minutes.

*Warm-up.* Subjects rode a bike ergometer or NuStep for 5 to 15 minutes at a self-selected pace.

*Whole-body Vibration Exercises.* Subjects were instructed in proper exercise technique for all of the following exercises, including to keep their back straight, head up, and to maintain balance by holding onto the handles. In the lunge and squatting exercises subjects were instructed not to let their knees move forward beyond their toes.

- 1) Lunge step (step-up). The non-operated leg was vibrated first, by placing the forward foot on the center of the platform and the rear foot on the floor. Subjects flexed 60° to 90° at the knees. Subjects rocked forward and back on vibrated foot.
- 2) ¼ squat or high squat (<50° to 60°). Subjects stood with both feet on the platform, their feet slightly apart. They bent the knees to 50° to 60° of flexion. Subjects maintained this position for the duration of the vibration.
- 3) Calves. Subjects stood with both feet on the platform, their feet slightly apart. They flexed slightly at the knees. Subjects rose up and down on their toes throughout the duration of the vibration.
- 4) Wide stance, Dynamic squats. Subjects did squats with 3 seconds down and 3 seconds up cadence alternating for the duration of the vibration. Subjects stood with their feet shoulder width apart.
- 5) Squats with ball squeezes. Subjects stood with both feet on the platform, their feet slightly apart. They flexed 60° to 70° at the knees. A weighted ball (5 kg) was placed

between their knees. Subjects squeezed the ball in the squat position for the duration of the vibration.

### *DATA ANALYSIS*

Data were analyzed to determine if differences existed between the groups and within groups. Statistical analysis was done with the SAS program. Hotelling's  $T^2$  test was conducted to find differences in change of CAR, MVIC, and pain between the groups. The difference in TUG and the within groups differences were analyzed with a general linear model ANOVA.

### **Results**

Both groups completed the assigned protocols. No adverse side effects were reported in the WBV group or control group. No increased pain was reported in the WBV group during or after vibration.

There was no difference in the change from pre to posttest for strength, muscle activation (CAR), or pain between groups (Hotelling's  $T^2 = 0.42$ ,  $P = .80$ ). There was also no difference in the change of function (TUG) between the groups ( $F = 0.54$ ,  $P = 0.66$ ). There was no effect for gender or operated leg side. There were significant within group changes over the treatment in strength, function, flexion ROM for both groups, and voluntary muscle activation change in the WBV group was significant pre to posttest. Perceived pain with movement pre to posttest was significant for the WBV, while perceived pain at rest pre to posttest was significant in the control group. (Tabs. 1- 6)



## Discussion

The current study investigated the use of WBV as a treatment in TKA rehabilitation. Whole-body vibration appeared to produce equally beneficial results as traditional therapy in TKA rehabilitation. The WBV group and traditional therapy group had equal strength gains (Tab. 1). Strength normalized to BMI was the same (Tab. 2). Strength gains in both groups were considered clinically significant as each group showed just less than a 100% increase. The traditional therapy group used weighted progressive resistance exercises. The WBV group performed unweighted static and dynamic exercises on the Power Plate vibration platform comparable to that of other studies.<sup>19, 34, 35</sup> These prior studies, using older and younger untrained women, reported results of equal strength gains between WBV on the Power Plate vibration platform and a progressive resistive exercise protocol.<sup>19, 34, 35</sup> They used the same parameters as the current study of 35 Hz vibration and progression of exercises by increasing; number of repetitions (1 to 3 reps), vibration displacement (2 mm to 5 mm), and duration of the vibration during repetitions (30 to 60 seconds). The three previous studies lasted 6 weeks and the current study was conducted over 4 weeks. Thus, a training protocol with WBV on the Power Plate System ranging from 4 weeks to 6 months appears to produce equal strength gains to a traditional progressive resistance exercise program.

Whole-body vibration may have application in treatment of TKA, although it did not result in greater improvements over traditional progressive resistance exercises. A proposed benefit of WBV is the reduced stress of resistance training on older individuals. Kallinen and Markku et al<sup>36</sup> suggest that older adults are more likely to overload the

musculoskeletal and cardiovascular system because of their diminished ability to adapt to high levels of loading, which may increase risk of injury or complications. Studies involving elderly and special patient populations, such as those with multiple sclerosis and Parkinson's, exposed to WBV have not produced adverse effects.<sup>19,37-41</sup> In the current study no side effects or discomfort were reported by the subjects. Subjects anecdotally reported liking the WBV exercises; this is consistent with other studies of WBV.<sup>19, 34, 35, 37</sup> Thus, while not directly measured, it appears that WBV with physical therapist supervision is a safe means of strengthening, while producing similar effects to a progressive resistance exercise program.

Function, as indicated by a statically and clinically significant decrease in time during the TUG, improved for both groups (Tab. 3). Similar improvement in the TUG has been noted in other studies of individuals with TKA rehabilitation.<sup>42-44</sup> Traditional TKA rehabilitation shows benefit in function, but levels of function following TKA continue to be less than age matched controls.<sup>4, 8-11, 13-15</sup> Whether or not residual functional loss would be improved after prolonged WBV rehabilitation has not been investigated.

Decreased pain levels have been a desired primary outcome measure for TKA. A general decrease in perceived pain levels during rest and with movement was noted in both groups. Subjects indicated no difference on the VAS at rest and during movement pre to post test that WBV group did not have than the traditional therapy group, Thus, WBV appears not to hinder pain relief or cause increased pain.

The question of the effect of WBV rehabilitation on voluntary muscle activation continues to be unclear. There was no difference between groups in CAR values throughout the study. There was however a significant increase in the WBV group for the involved limb. However, CAR values were near the normal range at both pre and posttesting. Other researchers report the normal range of knee extensor activation to be about 95% (91-100%).<sup>22, 25, 26, 32, 43, 45-49</sup> The only other study which examined the effect of WBV on quadriceps muscle activation used healthy untrained subjects.<sup>17</sup> Their pretreatment CAR values were 0.95 ( $\pm 0.02$ ), and after 6 WBV treatments over 2 weeks no change in the CAR values were observed. Attempting to make conclusions about the effect of WBV on voluntary muscle activation when comparing values in the normal range and near 1.0 limits the ability to detect muscle activation change. Thus both studies fail to elucidate the effect of repeated WBV sessions on voluntary muscle activation.

The initial CAR levels of the current study were higher than expected based on previously published results.<sup>12, 22, 26, 29</sup> The range of CAR values in the current study is included in the upper range of previously reported studies, except lower CAR values were not found that would lower the average CAR (Tab. 7). Two other studies of CAR in individuals with knee OA found average CAR levels similar to the current study.<sup>50, 51</sup> Additional studies are needed to understand the variability of muscle activation in individuals with TKA and knee OA.

The post CAR levels in the current study were also higher than expected. For example, in a case report of an individual with bilateral TKA 12 months postoperation, he had a CAR of 0.83.<sup>43</sup> After 6 weeks of electrical muscle stimulation his CAR value

increased to 0.97. This individual only reached a high level of activation after a year and then only after 6 weeks of electrical muscular stimulation. Another case series study of eight bilateral TKA subjects after 6 weeks of electrical muscle stimulation reported improved CAR values from 0.68 to 0.83 for the weaker leg and 0.82 to 0.84 for the stronger leg.<sup>29</sup> In the current study the subjects reached CAR values of 0.98 in WBV group and 0.97 in the control after 4 weeks of rehabilitation. Improvement in CAR values were seen in all of these studies, but interpretation of the CAR values between these studies as a reflection of improved outcome is difficult. Additional studies are needed to understand how the CAR can be used to investigate treatment outcomes between various treatments and protocols.

## **Conclusion**

Whole body vibration as a treatment in TKA rehabilitation showed equal strength and function improvement compared to traditional physical therapy. Whether WBV is worth the set up costs to treat patients with TKA will need to be evaluated by rehabilitation providers. Benefits proposed with WBV are that the unweighted exercises may reduce stresses on older individuals, while exhibiting equal strength gains to progressive resistive exercises. Individuals have reported liking WBV. This may increase adherence to rehabilitation protocols. Function and ROM also improved in those individuals with TKA using WBV. Negatives to using WBV in TKA rehabilitation are the cost of the equipment, while not producing greater strength, function, and ROM changes than potentially less expensive and readily available equipment in the clinic. The influence of WBV on muscle activation levels remains unclear, as baseline values of the

current study were near established normal knee extensor muscle activation levels.

Whole body vibration needs further investigation to understand its influence on muscle strength and function in the treatment of other neurologic and orthopedic impairments.

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Table 1. Maximal voluntary isometric contraction (MVIC) of quadriceps femoris of involved and uninvolved limbs in individuals 3 to 6 weeks post total knee arthroplasty and after 4 weeks of whole body vibration and traditional physical therapy (WBV) or traditional physical therapy (control).

	WBV Group (N)		Control Group (N)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Involved MVIC				
pre	105.9 $\pm$ 57.4	57.4-218.4	110.6 $\pm$ 42.0	55.2-171.4
post	195.2 $\pm$ 64.4*	79.1-268.1	196.1 $\pm$ 62.5*	128.0-316.7
Uninvolved MVIC				
pre	291.6 $\pm$ 131.0	30.7-448.1	242.1 $\pm$ 59.8	142.2-329.1
post	375.3 $\pm$ 208.1	27.9-759.2	272.5 $\pm$ 65.1	175.6-372.1

\* Significant difference from pretest ( $P < 0.01$ )

Table 2. Normalized force to BMI (N/BMI) of quadriceps femoris of involved and uninvolved limbs in individuals 3 to 6 weeks post total knee arthroplasty and after 4 weeks of whole body vibration and traditional physical therapy (WBV) or traditional physical therapy (control).

	WBV Group (N/BMI)		Control Group (N/BMI)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Involved pre	3.1 $\pm$ 1.5	1.8-6.1	3.3 $\pm$ 1.2	2.2-5.7
Involved post	5.7 $\pm$ 1.4*	3.5-7.2	6.1 $\pm$ 2.7*	3.3-10.6
Uninvolved pre	8.4 $\pm$ 3.6	1.4-12.5	7.3 $\pm$ 1.9	4.5-9.8
Uninvolved post	10.8 $\pm$ 5.9	1.2-21.9	8.4 $\pm$ 2.8	4.0-11.2

\* Significant difference from pretest ( $P < 0.01$ )

Table 3. Timed up and go test (TUG) of individuals with total knee arthroplasty 3 to 6 weeks post surgery and after 4 weeks of whole body vibration and traditional physical therapy (WBV) or traditional physical therapy (control).

	WBV Group (s)		Control Group (s)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
TUG pre (s)	11.3 $\pm$ 4.2	6.8-19.0	13.0 $\pm$ 3.9	8.9-19.0
TUG post (s)	7.8 $\pm$ 1.8*	6.0-10.0	8.8 $\pm$ 1.4*	6.9-11.0

\* Significant difference from pretest ( $P < 0.01$ )



Table 4. Muscle activation (CAR) of the quadriceps femoris of the involved and uninvolved limbs in individuals 3 to 6 weeks post total knee arthroplasty and after 4 weeks of whole body vibration and traditional physical therapy (WBV) or traditional physical therapy (control).

	WBV Group		Control Group	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Involved CAR				
pre	0.90 $\pm$ 0.10	0.77-1.00	0.95 $\pm$ 0.03	0.90-0.99
post	0.98 $\pm$ 0.03*	0.91-1.00	0.97 $\pm$ 0.03	0.92-1.00
Uninvolved CAR				
pre	0.95 $\pm$ 0.08	0.80-1.00	0.97 $\pm$ 0.03	0.91-1.00
post	0.98 $\pm$ 0.03	0.94-1.00	0.96 $\pm$ 0.05	0.85-1.00

\* Significant difference from pretest ( $P < 0.01$ )

Table 5. Perceived average 24 hour pain levels via 100 mm visual analog scale at rest and with movement at pre and posttest.

	WBV Group (mm)		Control Group (mm)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Rest VAS pre	26.9 $\pm$ 19.9	8.0-64.0	22.5 $\pm$ 21.0	0.0-62.0
Rest VAS post	14.9 $\pm$ 10.8	2.0-31.0	5.4 $\pm$ 5.4*	0-15.0
Movement VAS pre	35.0 $\pm$ 15.5	18.0-53.0	27.9 $\pm$ 11.5	8.0-45.0
Movement VAS post	18.5 $\pm$ 18.2*	4.0-62.0	17.1 $\pm$ 19.6	3.0-64.0

\* Significant difference from pretest ( $P < 0.05$ )

Table 6. Knee range of motion of involved and uninvolved limbs of individuals 3 to 6 weeks post total knee arthroplasty and after 4 weeks of whole body vibration and traditional physical therapy (WBV) or traditional physical therapy (control).

	WBV Group (°)		Control Group (°)	
	Mean ± SD	Range	Mean ± SD	Range
Involved ROM				
Pre (total ROM)	100 ± 11	86-118	89 ± 9	76-104
Post (total ROM)	116 ± 8	101-127	106 ± 10	92-118
Flexion change	12 ± 6*	0-19	14 ± 8*	1-21
Extension change	4 ± 3 <sup>†</sup>	0-9	2 ± 4	-4-8
Uninvolved ROM				
Pre (total ROM)	128 ± 12	102-145	119 ± 8	107-132
Post (total ROM)	130 ± 7	123-145	122 ± 8	104-131
Flexion change	0.9 ± 9	-10-20	2 ± 4	-5-8
Extension change	1 ± 1	0-3	2 ± 3	-2-7

\* Significantly different from pretest ( $P < 0.001$ )

<sup>†</sup> Significantly different from pretest ( $P < 0.02$ )

Table 7. Comparison of central activation ratio (CAR) values in other studies of subjects with total knee arthroplasty and knee osteoarthritis and the CAR for the current study. Current study values are contained within the other studies ranges, but did not find lower CAR values that would decrease the average. Current study findings are similar to those of knee OA studies.

	CAR		
	Mean	Range	Number of Subjects
Mizner 2005	0.72		20
Mizner 2003	0.74	0.34-1.00	52
Stevens 2004			
TKA*	0.68	0.34-1.00	8
TKA†	0.82	0.60-0.95	8
Stevens 2003	0.69		28
Current study			16
TKA control	0.95	0.90-0.99	8
TKA WBV	0.90	0.80-1.00	8
Comparison of other studies with knee OA and not TKA			
Fitzgerald 2004	0.96		105
Lewek 2004	0.93		12

\* Initially weaker leg after bilateral TKA

† Initially stronger leg after bilateral TKA



FIGURE 1. Quadriceps strength and activation testing. Strain gauge is attached to seat frame and to subject's ankle at  $90^\circ$  to leg. Knee flexed to  $75^\circ$ . Two electrodes were placed over the vastus medialis and proximal rectus femoris of the quadriceps.

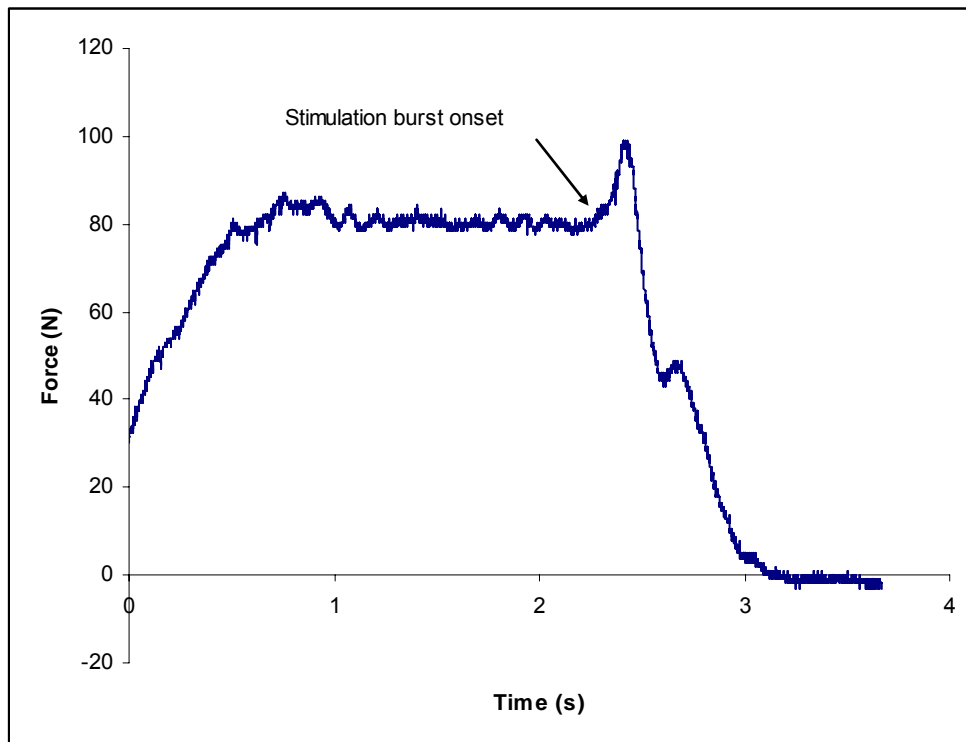


FIGURE 2: A sample of quadriceps force production during a stimulation burst-superimposition of a subject 3 weeks after total knee arthroplasty with a central activation ratio of 0.81.

Appendix A  
Prospectus

## Chapter 1

### Introduction

Osteoarthritis (OA) affects 20 million Americans, or approximately 12.1% of U.S. adults, and is projected to increase in prevalence.<sup>1</sup> Osteoarthritis affects 70% of adults over 65 years old and is a major cause of disability.<sup>2</sup> Knee OA presents with pain, loss of mobility and function which impact a person's quality of life.<sup>3,4</sup> No cure exists at the current time for osteoarthritis. Treatments for OA have focused on limiting the symptoms and restoring or improving function.<sup>5</sup> Conservative interventions include non-invasive treatments such as strengthening and range of motion (ROM) exercises,<sup>5-7</sup> modalities, pharmaceuticals including non-steroidal anti-inflammatory medication,<sup>8</sup> and weight loss.<sup>4</sup> Invasive treatments such as total joint arthroplasty are used as a final treatment approach. Total joint arthroplasty is indicated for patients with pain and substantial functional disability. These patients do not have acceptable pain decrease and function restoration with conservative treatment and are not candidates for other reconstructive procedures such as arthroscopy.<sup>9-13</sup> End-stage OA in the knee is treated with total knee arthroplasty (TKA).<sup>5</sup>

Physical therapy is indicated after TKA to facilitate increased ROM, strength of knee extensors, mobility, function, and quality of life. Van Baar,<sup>5</sup> in a systematic review of randomized clinical trials of patients with TKA, found that exercise therapy is beneficial for patients. The noted improvements are decreased pain, decreased self-reported and observed disability, improved ambulation, and improved patient's global



assessment of effect.<sup>5</sup> Despite the improvement that is made, often, deficits remain that limit strength and function.

Recovery of quadriceps strength to normal levels following TKA is rare.<sup>14</sup>

Voluntary muscle activation as measured by the central activation ratio (CAR) has been found to be decreased (CAR = 0.72-0.74) in individuals with TKA.<sup>14-16</sup> The CAR is found by performing a maximal voluntary isometric contraction (MVC),<sup>5</sup> and during the maximal contraction applying a superimposed burst stimulation to the contracting muscle. Augmentation of the voluntary force produced indicates a deficit in muscle activation. The CAR is a ratio between the maximal voluntary isometric contraction and the voluntary isometric with the superimposed burst. A ratio of 1 indicates a fully activated muscle, less than 1 indicates a deficit in voluntary activation and thus strength. A loss of strength of the quadriceps has been associated with increased fall risk,<sup>8, 17, 18</sup> detrimentally affected walking,<sup>19, 20</sup> stair climbing,<sup>19</sup> and function.<sup>14, 21</sup> Adjunct or new means of strengthening may be beneficial in overcoming the strength and functional deficits.

Whole-body vibration (WBV) is a new exercise mode that has been suggested as a means to rehabilitate patients with lower extremity weakness.<sup>22-24</sup> Cardinale and Bosco<sup>23</sup> suggest that WBV has a great potential in therapeutic application, where it may increase muscular performance in patients and older adults. Whole-body vibration has been shown in the elderly to increase muscle performance,<sup>18, 24, 25</sup> and postural control.<sup>26</sup> No adverse side effects were noted in these studies.<sup>18, 24-26</sup> The increase in strength with WBV is thought to be related to changes in the neuromuscular system.<sup>23-25</sup>

During resistance training changes in the nervous system allow more complete activation of the muscle by 1) increasing the number of motor units recruited and 2) by producing an increased firing rate and better synchronization of firing, thereby producing greater force production.<sup>27, 28</sup> One research group suggests that neural adaptations are the most relevant mechanism of strength gain not only in progressive resistance training, but also in individuals using WBV.<sup>24, 29</sup> Input of proprioceptive pathways, Ia, II, and Ib afferents, play an important role in production of force in muscle contractions.<sup>30</sup> During WBV these pathways are strongly stimulated, which activates the sensory receptors and results in reflexive muscle contractions.<sup>24, 31</sup> The increase in strength seen with WBV training might be the result of a more efficient use of the positive proprioceptive feedback loop in the generation of force.<sup>24</sup> The increase in force production may benefit individuals with TKA during their rehabilitation.

There are no studies that have investigated WBV as an adjunct treatment to physical therapy rehabilitation of individuals with TKA. Neither has the CAR been used to study the effect of WBV in individuals with a known voluntary muscle activation deficit such as those with TKA. The proposed research will compare the effect of WBV and traditional rehabilitation to traditional rehabilitation only in individuals with TKA with respect to specific treatment outcomes. The outcomes will include quadriceps femoris strength changes, voluntary activation levels, perceived pain, and function.

*Purpose*

The purpose of this study is to answer two research questions:

1-Does whole-body vibration effect the central activation ratio of the quadriceps femoris in individuals who have undergone total knee arthroplasty?

2-Does whole-body vibration plus traditional rehabilitation protocol result in a different magnitude of strength gains in the knee extensors than a traditional exercise protocol in individuals who have undergone total knee arthroplasty?

*Hypotheses*

Null: 1- There will be no difference in strength gain changes between the groups.

2- There will be no difference in volitional muscle activation change between the groups.

3- There will be no difference in perceived pain between the groups.

4- There will be no difference in the Timed-Up-and-Go Test (TUG) between the groups.

Alternative:

1- There will be greater strength gain changes in the group with WBV plus traditional compared to traditional alone.

2- There will be a greater change in central activation ratio change in the group with WBV plus traditional compared to traditional alone.

3- There will be equal or greater perceived pain change in the group with WBV plus traditional compared to traditional alone.

4- There will be a greater decrease time to complete the Timed Get-Up-and-Go Test in the group with WBV plus traditional compared to traditional alone.

*Independent variables*

1. Treatment

1- Traditional post-total knee arthroplasty rehabilitation protocol performed in physical therapy.

2- Whole-body vibration + traditional post-total knee arthroplasty rehabilitation protocol

2. Time: preintervention and postintervention

*Dependent variables*

1. Central Activation Ratio calculated from maximum volitional torque divided by maximum volitional torque + superimposed burst stimulation

2. Maximum volitional knee extension torque/force

3. Perceived pain levels at rest and with movement by subjects on a 100 mm Visual Analog Scale.

4. Timed-Up-and-Go test

*Limitations*

1- Subjects fear of possible pain during a fast, maximal voluntary muscle contraction may prevent them from producing a maximal contraction.

2- Subject population will not be truly randomized because subjects need to have undergone TKA.

3- Some subjects who qualify may not choose to participate in the study or be allowed by their surgeons to participate.

*Assumptions*

1- A decreased CAR reflects a deficit in the voluntary activation of quadriceps femoris of an individual.

2- Stimulation activates all motor units that were not maximally and volitionally activated during the contraction.<sup>32</sup>

3- Motor units that are not recruited or not discharging at their maximal frequency (incomplete activation) should yield a detectable force change as a consequence of the stimulation of their axons.<sup>33</sup>

4- Peak force 0.1 second before detection of the electrical signal is assumed to be the maximal volitional force or maximal voluntary contraction.

5- Individuals who have undergone total knee arthroplasty in the current study will have a deficit in the voluntary activation similar to those reported in previous published studies.

## Chapter 2

### Review of Literature

The review of literature will cover the prevalence of osteoarthritis, total knee arthroplasty as an end-stage treatment, traditional rehabilitation, persistent quadriceps weakness after surgery, muscle in-activation, muscle spindle and gamma loop, whole-body vibration, muscle activation testing with the superimposed burst stimulation technique to calculate the central activation ratio, the visual analog scale, universal goniometer for ROM assessment, and the TUG.

#### *Osteoarthritis and Total Knee Arthroplasty*

Osteoarthritis is common cause of disability and pain in older adults. Osteoarthritis affects 20 million Americans, affecting 12.1% of U.S. adults and is projected to increase in prevalence.<sup>1</sup> An estimated 40 million Americans have some form of arthritis or other rheumatic condition. That number is expected to climb to 59.4 million, or 18.2 % of the population, by the year 2020, according to a new report published as a collaborative effort between the National Institutes of Health (NIH), the Centers for Disease Control and Prevention, the Arthritis Foundation, and the American College of Rheumatology. This increase is largely due to the aging of the U.S. population. Osteoarthritis affects 70% of adults over 65 years old and is a major cause of disability.<sup>2</sup> In the United States, OA is second only to ischemic heart disease as a cause of work disability in men over age 50.<sup>1</sup> By age 40, most individuals have some osteoarthritic changes in the weight-bearing joints (e.g., hip and knee joints) and by age 75, virtually everyone has changes in at least one of these joints.<sup>34</sup> Radiographic changes

are seen in over half of all people older than age 65 with OA of the knee. Additional, data obtained from autopsy studies indicate that there is evidence of osteoarthritic damage in most people aged 65 and over.<sup>35, 36</sup>

Osteoarthritis affects the major weight-bearing joints of the body including the knee and hip and is also commonly seen in the hand and wrist. Knee OA presents to patients pain, loss of mobility and function which impacts a person's quality of life.<sup>3, 4</sup> No cure exists at the current time for osteoarthritis.

Treatments have focused on limiting the symptoms of OA and restoring or improving function.<sup>5</sup> Interventions include non-invasive treatments such as strengthening and ROM exercises,<sup>5-7</sup> modalities, pharmaceuticals including non-steroidal anti-inflammatory medication, and weight loss,<sup>4</sup> while invasive treatments such as surgery with the total joint arthroplasty are also used as a final treatment approach. Total joint arthroplasty is indicated for patients with pain and substantial functional disability. These patients do not have acceptable pain decrease and function restoration with conservative treatment and are not candidates for other reconstructive procedures such as arthroscopy.<sup>9-13</sup> Patients with end-stage OA and rheumatoid arthritis are the largest group for whom total joint arthroplasty is considered.<sup>9</sup> Osteoarthritis patients constitute the largest group receiving TKA.<sup>9</sup> The aging of the population is contributing to an increase in the prevalence of osteoarthritis and as a consequence, an increase in the number of total joint arthroplasty surgeries. In the United States and Canada together, over 300,000 TKA surgeries are performed each year.<sup>37</sup> The number of total knee arthroplasty in the United States is predicted to increase to half a million annually by 2030.<sup>38, 39</sup> Total hip

and total knee arthroplasty, which are acceptable and reliable treatments for end-stage osteoarthritis<sup>9</sup> were found to be effective in terms of health related quality of life.<sup>9, 14, 38</sup>

The increase in the prevalence of TKA has spurred additional investigation into the outcomes of TKA. Initially, success of total joint replacement was evaluated with measures of morbidity, operative complications and life time of prosthetic materials.<sup>9</sup> As improvements in total joint arthroplasty have been made and younger individuals are receiving total joint arthroplasty, these measures are less relevant to health-care efforts or benefits.<sup>9, 40, 41</sup> The desired outcomes of total joint arthroplasty are not only alleviating pain, but also improving mobility, quality of life, activities of daily living, decreasing requests for sick leave, and work disability.<sup>9, 42</sup>

The outcomes with total hip arthroplasty have been more successful than those found in total knee arthroplasty.<sup>9</sup> Age-matched controls were found to have higher performance in many areas compared to those who received TKA. Walking performance is about 20% greater in aged match controls than in those with TKA,<sup>19, 20</sup> while stair climbing performance is 50% greater.<sup>19</sup> Most patients report difficulty with heavy domestic activities after TKA at 6 months post surgery.<sup>21, 38</sup> Muscle weakness or lack of force generating capacity of the quadriceps femoris has been noted by investigators as a persistent problem after TKA. Acute postoperative force deficits of up to 60% have been reported, while 30% to 40% deficits have been noted at 1 and 2 years post-surgery.<sup>15, 43</sup>

The weakness associated with aging, injury and surgery leads to decrease in function and mobility, and increases the risk for further complications, such as falling. Loss of strength and muscle mass is associated with aging<sup>24, 44</sup> regardless of having



surgery; injury and surgery are likely to lead to additional strength loss. The loss of strength about the knee joint is associated with the development<sup>45</sup> and progression of joint degeneration.<sup>46, 47</sup> Muscle mass with preferential loss of type II fibers<sup>48</sup> has been associated with age-related decrease in physical activity and a reduced loading of the musculoskeletal system.<sup>24</sup> The loss of strength in the quadriceps femoris is associated with increased fall risk,<sup>8, 17, 18</sup> a change in speed and quality of sit-to-stand transfers,<sup>49</sup> stair-climbing performance,<sup>19</sup> and ambulation speed.<sup>19, 49</sup> Quadriceps weakness has been found to be the single strongest predictor of functional limitation in patients with knee OA.<sup>50</sup> Muscle weakness may result in a decrease in capacity for muscular control and may lead to premature fatigue when activities of daily living such as walking, climbing stairs, and getting up from chairs are performed.<sup>47</sup>

Recovery of quadriceps strength to normal levels is rare.<sup>38</sup> Individuals one year after TKA were found to have 29% (women) and 39% (men) weaker than age matched controls.<sup>19</sup> Silva et al<sup>43</sup> found 30.7% decreased strength in subjects after two years post TKA compared to aged-matched controls. A high percentage of weakness is seen in six month to 13-year-long term assessments of strength of the quadriceps post-operatively.<sup>43, 51, 52</sup>

The cause of the quadriceps weakness has been investigated. Muscle atrophy and muscle in-activation have been found to explain 85% of acute postoperative strength loss, while pain did not have a significant affect on the loss of strength.<sup>14</sup> Fortin et al<sup>37</sup> found that individuals who had TKA later in the natural history of functional decline due to OA of the knee resulted in worse postoperative functional status. Preoperative strength has a

major role in predicting functional outcome one year after TKA.<sup>38</sup> Traditional physical therapy directed rehabilitation has focused on restoring ROM and strength in order to increase functional, mobility, activities of daily living, and quality of life. Often, deficits remain that limit function. Silva et al<sup>43</sup> suggest that more thorough rehabilitation after TKA would improve functional outcomes. Adjunct or new means of strengthening may be beneficial in overcoming the strength and functional deficits.

#### *Traditional Rehabilitation for Individuals with Total Knee Arthroplasty*

The goal of traditional rehabilitation in regard to knee OA and post-TKA in the treatment of OA is to reduce pain and disability.<sup>5, 53</sup> The surgical operation removes the damaged cartilage and bone replacing it with a new man-made surface that restores the joint articulation, thus restoring motion and decreasing or eliminating pain.<sup>53</sup>

Rehabilitation also attempts to restore strength and mobility to allow a return to functional activity and higher quality of life. This is achieved through exercise to improve muscle strength, stability of joints, ROM, and aerobic fitness,<sup>5</sup> which are typically impaired in people with knee OA and who are post-TKA. Van Baar,<sup>5</sup> in a systematic review of randomized clinical trials of patients with TKA and THA, found that exercise therapy is beneficial in patients with OA of the hip or knee. The noted improvements are decreased pain, decreased self-reported disability, decreased observed disability, improved ambulation, and improved patient's global assessment of effect.<sup>5</sup> Although improvement was seen in all areas, the amount of improvement was small to moderate and needs to be enlarged.<sup>5</sup> This is in accordance with the fore mentioned residual deficits in function of those with TKA. In studies of OA, exercise therapy

appears to benefit those with mild-to-moderate OA the best. Exercise therapy may be recommended for patients with knee OA and hip OA with a mild-to-moderate stage of disease.<sup>5</sup> Despite improvement in the patient's rehabilitation with traditional exercise, residual problems after TKA have been noted in the literature as described previously. Thus, it is important to investigate new and developing means of rehabilitation and to understand the nature and cause of persistent muscle weakness, disability, and symptoms of those individuals who suffer from knee OA including those who have undergone total knee arthroplasty.

#### *Muscle In-activation*

The inability of a muscle to fully activate because of a decrease in the number of motor units recruited or a drop in the frequency of stimulation of the available motor units is muscle in-activation.<sup>54, 55</sup> Muscle contraction is a phenomenon that requires central and peripheral activation processes.<sup>54</sup> Voluntary muscle activation of skeletal muscle is a normal and essential part of movement and function. A decrement to muscle activation results in weakness of the muscle group and decreased function.<sup>56</sup> The ability to fully activate a muscle group depends on activating the maximum number of motor units available and reaching a maximal rate of neuronal discharge to the motor units.<sup>14, 55</sup> Muscle inhibition is the inability to fully activate a muscle.<sup>32</sup> Failure of voluntary muscle activation (central activation failure) is a reduction in the maximal force output of a muscle resulting from an inability to recruit all of the muscle's motor units or to attain the maximal discharge rate from the motor units that are recruited.<sup>14, 54, 55, 57, 58</sup> Muscle in-activation can be a result of complications or failure anywhere along the peripheral

pathways and/or central control mechanisms resulting in fatigue or decrements in force production.<sup>54, 55, 59-61</sup>

Mechanisms responsible for the reduced central motor drive during maximal dynamic contractions remain unclear, but would probably originate from supraspinal and spinal pathways, as indicated using magnetic cortical stimulation. A change in control from the cerebral cortex or cortical drive may be one cause of the incomplete activation during maximal voluntary contraction (MVC).<sup>59, 62</sup> Muscle in-activation can be a result of complications such as chronic pain<sup>16, 32, 63, 64</sup> or pain associated with surgical trauma,<sup>14</sup> joint effusion,<sup>65, 66</sup> immobilization,<sup>67, 68</sup> or joint damage.<sup>69</sup> TKA patients are affected by these complications, which results in a change in their voluntary activation of the quadriceps. The change in voluntary muscle activation are suggested to be a result of a change in afferent input from joint and muscle receptors that affect efferent pathways.<sup>32, 33, 70</sup> The altered afferent input, which may occur on the local joint level or spinal level, may cause a reflex-type muscle inhibition.<sup>32</sup> The diminished ability for complete recruitment within the motor neuron pool is thought to be caused in part by information originating from joint receptors, primarily mechanoreceptors, which send afferent signals to inhibitory interneurons that synapse on the motor neuron. Reduced activation might be due to a lower alpha-motor neuron excitability, induced by an increased inhibitory feedback from joint receptors of a golgi tendon organ,<sup>71</sup> or free nerve endings in the muscle, skin, and joint receptors.<sup>72</sup>

In knees with rupture of anterior cruciate ligament, loss of feedback from mechanoreceptors is thought to be the underlying mechanism of quadriceps femoris

weakness.<sup>70, 73</sup> Konishi et al<sup>70</sup> suggest that this is based on chronic high-threshold motor unit recruitment suppression during voluntary muscle contraction. Loss of receptors in the ACL leads to chronic reduction in Ia-feedback to muscles around the knee due to a lack of feedback from gamma motor neurons.<sup>70, 73</sup> It is suggested that loss of afferent feedback contributes to the weakness of the quadriceps femoris.<sup>52, 74</sup> Johansson et al<sup>75</sup> suggest that afferent feedback from knee joint receptors could only weakly affect alpha motor neurons. While in animal studies, gamma motor neurons are markedly affected by joint afferents.<sup>76</sup> Gamma motor neurons can influence alpha motor neurons through the gamma loop.<sup>70, 73</sup> Konishi et al<sup>70</sup> suggest that a decline of MVC and integrated electromyography (I-EMG) in subjects that had their knees anesthetized indicated that attenuation of joint afferents compromises the function of alpha motor neurons innervating the quadriceps femoris. They then placed prolonged vibration to the quadriceps tendons in order to deplete or inhibit the joint afferents and again noted a decrease in MVC and I-EMG, again suggesting the role of joint afferents in quadriceps weakness.<sup>70</sup> The ACL is also lost during TKA, while the PCL may be sacrificed or spared, thus suggesting that loss of joint afferents may lead to loss of strength in the quadriceps femoris of post-TKA patients. Whether the PCL was cut or retained did not affect the relative muscle strength of the quadriceps and hamstrings.<sup>43</sup> A significant loss of strength without muscle atrophy in the quadriceps has been noted by researchers.<sup>14, 52, 74</sup> In patients with total knee arthroplasty loss of strength in the quadriceps femoris was predominately related to failure of voluntary muscle activation and to a lesser degree by muscle atrophy.<sup>14</sup> Mizner et al<sup>14</sup> found using regression techniques that together, failure

of voluntary activation and muscle atrophy accounted for 85% of the strength loss in the quadriceps femoris after TKA. Individuals who have undergone total knee arthroplasty have not been able to voluntarily fully activate the quadriceps femoris muscle group, averaging an activation of about 70% to 74%.<sup>14, 16, 77</sup> Patients have been reported to have lost approximately half of their preoperative quadriceps strength in the first month after surgery.<sup>15</sup> Reduction in muscle activation contributes substantially to early postoperative weakness of knee extensors.<sup>14</sup> Healthy adults have been found to be able to voluntarily fully activate the quadriceps femoris muscle group at  $\geq 95\%$ .<sup>61, 78-87</sup> Knee pathologies are typically associated with reduced activation or inhibition of the quadriceps femoris muscle group.<sup>14-16, 74, 77, 88, 89</sup> A question arises, can the remaining structures (muscle spindle and other receptors in the joint capsule) be trained to compensate for the lost tissue receptors and thus increase strength?

### *Muscle Spindle*

Muscle spindles are proprioceptive intramuscular sensory receptors that sense changes in muscle length and rate of muscle length change.<sup>90, 91</sup> The number of muscle spindles per muscle varies (6 to 1300),<sup>92</sup> and the total number of muscle spindles in humans is around 27,500, with 4000 in each arm and 7000 in each leg.<sup>91</sup> Muscle spindles attach to the intramuscular connective tissue in parallel arrangement with the force-generating extrafusal muscle fibers and thus are sensitive to changes in muscle length and rate of change in muscle length. Muscle spindles vary in length from 0.5 mm to 10 mm. Muscle spindles are made up of 3 to 10 specialized fibers called intrafusal fibers. There are two types of intrafusal fibers that differ in the location of the nucleus, motor

innervation, and their contraction speed. The nuclear chain fiber has nuclei arranged in series while the nuclear bag fiber has the nuclei arranged in clusters. Myofilaments are found at the end of each type of intrafusal fiber.

Afferent supply in the central nervous system is divided into four groups according to axon diameter. Larger axons send nervous impulses more rapidly. All muscle spindles have group I afferents that have an ending that spirals around the mid-section of the nuclear chain and nuclear bag fibers, and some have group II afferents that primarily connect to nuclear chain fibers. Muscle spindles receive efferent innervation via gamma and beta motor neurons. Extrafusal skeletal muscle fibers are innervated primarily by alpha motor neurons. Gamma motor neurons innervate only intrafusal fibers at the myofilaments ends of the intrafusal fibers. Beta motor neurons have input to intrafusal fibers and extrafusal fibers. Each muscle spindle is innervated by 10 to 12 gamma motor neurons and a single beta motor neuron. When an action potential is sent along gamma and beta motor neurons to the muscle spindle the myofilaments in the spindle contract and pull on the equatorial center regions and thus increase stretch sensitivity of the nuclear center. The stretch to the mid-section of the intrafusal fiber can be sufficient to elicit afferent action potentials sent to the CNS. Thus, the muscle spindle afferents can be stimulated by gamma and beta innervation of the intrafusal fibers myofilaments and by passive stretch of the entire muscle. The sensitivity of the intrafusal fiber is altered by activity of the gamma and beta motor neurons so that response is enhanced or diminished to absolute changes in muscle length or the rate of change in muscle length.<sup>93, 94</sup>

The tendon stretch reflex is an example of the function of the muscle spindle. Mechanical deformation of the patellar tendon causes a change in the structural conformation of the muscle spindles nuclear area stimulating an afferent Ia signal to the CNS, synapsing on an alpha motor neuron returning to the quadriceps, and inhibiting the motoneurons cell bodies innervating the hamstring. The gamma motor system affects the sensitivity of the intrafusal fiber and is influenced from higher centers in the central nervous system. A similar reflex to the tendon stretch reflex is the vibratory tonic reflex.<sup>23</sup> A tonic vibratory-like reflex is thought to be elicited with whole body vibration that affects the gamma motor system by stimulating the muscle spindle which ultimately affects the force generating capability of the entire muscle.<sup>23</sup>

The muscle spindle sends a signal through Ia afferents to the central nervous system, which can in return send a signal to the intrafusal muscle fibers via gamma and beta motor neurons that adjust the tone of the intrafusal muscle fiber. The gamma motor neuron stimulates the intrafusal fibers causing a change in the central region of the muscle spindle that affects its sensitivity. The effect of the gamma neuron on the muscle spindle can be large enough to stimulate signal propagation to the central nervous system via the Ia neuron.

### *Measuring Muscle Inactivation*

The superimposed twitch technique is frequently used to study the degree of motor unit activation deficit in normal or non-injured, athletic, and patient population.<sup>95</sup> This method to test the amount of muscle activation involves maximally contracting a muscle volitionally and then superimposing an electrical stimulus onto the contracting



muscle.<sup>55,61</sup> If no augmentation of torque (force) is noted the muscle is said to be fully activated. If all the motoneurons have not been recruited or if they are firing at a submaximal rate, an increase in the torque or force curve will be noted.<sup>55,61</sup>

The activation of the muscle can be calculated in two ways, the interpolated twitch technique (ITT) and CAR. The ITT, originating from the work of Denny-Brown<sup>96</sup> and Merton,<sup>84</sup> is calculated by having the subject maximally (or sub-maximally) voluntarily contract the muscle being tested. During the contraction a superimposed electrical stimulus (single, doublet, or train) is delivered to the nerve or muscle (motor points). After the volitional contraction is ended one to two control contractions are recorded. A control contraction is a rise in force elicited by stimulation of the relaxed muscle. Comparison is done between the superimposed twitch or peak and the control twitch or peak in force, according to the following formula:

$$\text{Degree of activation (ITT)} = [1 - (\text{superimposed twitch} / \text{control twitch})] \times 100 \quad (1)$$

The superimposed twitch peak is the difference in torque or force from the maximal volitional contraction and the peak superimposed torque (force).<sup>33</sup> The control peak is the magnitude of the peak from stimulation of a relaxed muscle.<sup>33</sup>

The CAR is another method that measures the amount of muscle activation. The CAR is regarded as a primary variable in quantifying the central drive for muscle recruitment.<sup>97</sup> This technique used by Newham et al<sup>61</sup> and Kent-Braun and LeBlanc<sup>55</sup>, employs a similar technique, but compares the maximal volitional torque (force) to the superimposed + maximal volitional torque (force) according to the following equation:

Degree of activation (CAR) =  $(MVC / (MVC + \text{superimposed torque or force})) \times 100$  (2)

A CAR of 1.0 would indicate a fully activated muscle, while a ratio less than one would indicate a decrease in muscle activation.<sup>54, 55</sup> This technique has been used to study activation in many muscle groups, chronic low back pain and individuals with TKA.<sup>14, 16, 38, 54, 56, 63, 77, 98</sup> Taking the CAR and subtracting from 1 would give the percent of activation deficit or multiplying the CAR by 100 would give the percent of activation.

During a maximal volitional contraction the amount of noise in the high-intensity voluntary contraction may obscure the superimposed evoked torque.<sup>99</sup> Efforts to decrease the noise to signal ratio have included increased amplitude of the superimposed stimulus, submaximal contractions, and types (single, doublet or train) of superimposed stimulation. Increased amplitude of the stimulus may achieve a larger signal to noise ratio, but may also increase discomfort or may have over-flow to antagonistic muscles.<sup>99</sup> Submaximal stimulation has shown a curvilinear force curve instead of a linear force curve making prediction of the true maximal contraction difficult and potentially inaccurate, suggesting caution in extrapolating from a single datum point.<sup>99</sup> Submaximal contractions (20%) with doublet superimposed evoked contractions have shown superimposed evoked potentials greater than or equal to resting evoked potentials which could result in gross over-estimation of muscle inactivation.<sup>99</sup> A reduction in the series elastic component (SEC) of muscle has been suggested as a reason for the change in the evoked potential,<sup>80, 99, 100</sup> but this would require putting the muscle on stretch for enhancement of the twitch to be seen. Conversely, the need to take up the slack of SEC

would show a decrement. The curvilinear nature has been suggested to be the result of synergistic muscle.<sup>99, 101</sup> Williams and Bilodeau,<sup>101</sup> in a study using the ITT, found that stimulation of the biceps brachii and brachioradialis resulted in a greater activation index due to greater torque elicited at rest. They also concluded that the nonlinear relationship between interpolated and voluntary elbow torque is not explained by suboptimally activated synergistic muscles.<sup>101</sup> The current proposed research is investigating the quadriceps femoris which does not have synergistic muscles innervated by different nerves as is the case in the biceps brachii and brachioradialis.

Stackhouse et al<sup>54</sup> suggest the curvilinear shape of the MVC to CAR curve indicates that the CAR may be an insensitive measure at high voluntary efforts (> 90% MVE) secondary to being at the flat portion of the curve. In the proposed study a relative change of CAR is used and the average beginning activation level is ~74%, therefore a relative change should be able to be seen. Prediction of maximal torque is not being made in the proposed study, but a relative comparison between preintervention (treatment) and postintervention (treatment). Muscle activation levels, tested by these techniques, have been used to measure relative change in the muscle activation from preintervention to postintervention in many studies (exercise heat stress<sup>102</sup>, spinal manipulation of cervical spine<sup>32</sup>, TKA before surgery to post-surgery<sup>38</sup>, TKA with electrical stimulation<sup>77</sup>, whole-body vibration in healthy young subjects<sup>22</sup>, and chronic back pain.)<sup>63</sup>

Stackhouse et al<sup>54</sup> suggest if the electrical train stimulus allowed time for full summation of force, a linear relationship would exist between torque and CAR, but

shorter duration trains are used to decrease patient discomfort. The proposed study is not using CAR to predict force; force will be directly measured during a maximal contraction.

Stackhouse et al<sup>54</sup> suggest that if a linear relationship is used to interpret the CAR, clinicians may markedly underestimate a patient's deficit in force production. In their study a CAR of 0.80 was associated with 60% of maximal voluntary effort (MVE).<sup>54</sup>

Others have investigated the effect of single, doublet, and train stimulation in order to increase the signal to noise ratio.<sup>54, 55, 79, 99, 103</sup> Behm et al<sup>99</sup> found a train stimulus showed a slightly better, but not significant signal to noise ratio. No difference in ITT has been seen between single, doublet, and train stimulation of the muscle being tested.<sup>79, 99</sup> Suter and Herzog<sup>103</sup> suggest that train stimulation may provide more reliable estimates of muscle inactivation than single twitches. Kent-Braun and LeBlanc<sup>55</sup> suggest that a train is more sensitive to detect central activation failure. Stackhouse et al<sup>54</sup> found no difference in different train protocols.

Reliability of the technique (ITT) in quadriceps is very high (ICC= 0.96 with bipolar stimulation).<sup>99</sup> The reliability of the CAR technique was found to be even higher (ICC= 0.98).<sup>74</sup>

Electrodes are placed over nerves or motor points with these techniques. Rutherford et al<sup>89</sup> found no difference with femoral nerve or percutaneous stimulation.

Many studies using the ITT have tested each individual to find the optimal intensity of stimulation for the evoked stimulus.<sup>99, 101, 104, 105</sup> Other studies have used a standard stimulation intensity for all subjects in the study.<sup>74, 106-108</sup> The intensity of

stimulus with Grass S88 stimulator was found to be sufficient at 135 Volts in non-impaired individuals and in individuals with various knee pathologies.<sup>74, 106-108</sup>

Studies to collect torque or force data have used different methods of data collection including dynamometers or strain gauges with no indication of superiority one over the other. Dynamometers that have been used include the Kin-Com,<sup>14, 38, 77, 109</sup> Biodex,<sup>33, 102</sup> and Cybex.<sup>88</sup> Strain gauges have also been used to collect force.<sup>32, 87, 99, 105, 110</sup> The differences in the sensitivity of these various dynamometers and strain gauges may account for some of the variation noted in the literature regarding the muscle activation measured. The proposed study will use a strain gauge (Omegadyne, Inc., Stanford, CT, model: LC101-250), as the signal to noise ratio was improved compared to the available Biodex.

#### *Whole-Body Vibration*

Whole-body vibration is a new exercise mode that has been suggested as a means to strengthen the body and to be potentially useful in rehabilitation.<sup>22</sup> Cardinale and Bosco<sup>23</sup> in suggesting possible uses of whole-body vibration, contend that vibration could represent an effective exercise intervention for enhancing neuromuscular performance in athletes, reduce the effects of aging on the general population, and affect hormonal activity influencing training and rehabilitation of different pathologies.

Whole-body vibration is a multidimensional oscillatory motion from a mechanical stimulus that is applied to the body by standing on a vibration platform.<sup>23, 111</sup> Whole-body vibration is often performed unloaded, but can also be done with external resistance, for instance with a squat bar and weights. The intensity of the vibration is

determined by the amplitude, frequency, and magnitude of the oscillations.<sup>23</sup> It is suggested that low-amplitude, low-frequency mechanical stimulation of the human body is a safe and effective means to increase muscle strength.<sup>23</sup> Vibration as an exercise intervention was first applied by a Russian scientist, who found increased strength in the biceps from vibration to the upper extremity in well-trained subjects.<sup>112, 113</sup> Vibrating cables were used to increase strength of the biceps brachii.<sup>112, 113</sup>

Whole-body vibration has shown benefits in athletes' strength and performance,<sup>114-117</sup> as well as in the untrained,<sup>25, 118</sup> older adults,<sup>24</sup> and recently in certain patient populations.<sup>26, 111, 119, 120</sup> Whole-body vibration showed acute enhancement of vertical jump, mechanical power in healthy individuals, improved force-velocity and power-velocity curves in volleyball players.<sup>114, 115</sup> Other studies have not shown the acute enhancement of jumping after whole-body vibration, or in patellar reflex latency, but there was a short duration increase in reflex amplitude after vibration.<sup>29</sup> Exhaustive whole-body vibration showed an acute decrease in vertical jumping.<sup>121</sup> Chronic application ten days to six months of whole-body vibration has shown improvements in neuromuscular properties of human skeletal muscle.<sup>25, 116</sup> Torvinen et al<sup>25</sup> found an increase in vertical jumping of 2.0 cm after 2 months of vibration exercise and 11.2 kg increase in knee extension compared to the control group's change of -0.6 cm jumping height and knee extension increase of 4.8 kg. Whole-body vibration in young adults with a treatment duration of 10 days to 4 months demonstrated increases in strength.<sup>25, 118, 122</sup> Multiple brief applications of whole-body vibration for 4 months resulted in 16.6% increase in isometric knee extensor strength in untrained young women.<sup>118</sup> In the same

study a placebo vibration platform was used that had only 0.4 G compared to 2.28 to 5.09 G for the experimental group. Differences in the strength achieved between the groups suggest that the vibration itself influenced the strength gains and not the unweighted exercise alone.<sup>118</sup> The magnitude of the strength gains was equal to that of individuals who participated in an equal number of resistance training sessions.<sup>118</sup> Most studies have shown improved performance and/or strength as a result of whole-body vibration.

It has been suggested in other studies as well that muscle activation by whole-body vibration may result in strength gains equal to that of traditional strength training.<sup>114-116</sup> Whole-body vibration at 35 Hz and 2.5-5.0 mm amplitude with a duration of vibration progressively increasing to 30 minutes has been shown to increase strength in elderly women equal to that of a traditional progressive resistive exercise program over a 6-month protocol.<sup>24</sup> Strength gains in the older women were found to occur in the first 12 weeks of the protocol, while there was not a significant increase in strength during the next 12 weeks.<sup>24</sup> Whole-body vibration had equal isometric and dynamic strength gains to that of progressive resistance training in postmenopausal women.<sup>123</sup> Five weeks of whole-body vibration squats in recreationally trained men (n=7) increased strength in the 1 repetition maximum as did conventional squatting alone (n=7); the vibration squatting group had a greater but not significant increase in 1 RM squatting ( $p= 0.046$ ).<sup>124</sup> Ronnestad<sup>124</sup> suggests that an external load may be important to increase strength gains in whole-body vibration. If whole-body vibration can equal strength gains to that of traditional progressive resistive exercise, then, with an added external load the strength gains may be greater with whole-body vibration and an external load than the external

alone.<sup>124</sup> Acute changes in jump height, ground contact time, and isometric torque were seen in exhaustive squats with and without whole-body vibration.<sup>31</sup>

It is suggested by Cardinale and Bosco<sup>23</sup> that whole-body vibration has a great potential in therapeutic application, where it may increase muscular performance in patients and older adults.<sup>24</sup> A number of recent studies have started to investigate the potential of whole-body vibration in the rehabilitation setting.<sup>26, 111, 119, 120</sup> In the elderly, whole-body vibration has been shown to increase muscle performance,<sup>25</sup> and postural control.<sup>26</sup> Individuals with Parkinson's disease showed improvement in gait parameters and coordination after whole-body vibration treatment.<sup>119, 120</sup> The parameters of the vibration intervention were five series of 1-minute vibration and 1-minute rest intervals. Effects occurred in 10 minutes and lasted for 48 hours.<sup>120</sup> In a pilot study, individuals with multiple sclerosis participated in nine minutes of whole-body vibration and showed improvement in a sensory organization test (posturography test) and Timed-Up-and-Go test at all measurement points after the vibration out to 2 weeks compared to a placebo group.<sup>111</sup> Whole-body vibration is also being studied for its effect on trabecular bone formation and osteoporosis.<sup>125, 126</sup> The results have been mixed regarding the affects of vibration on bone density. An animal model study showed a decrease in the rate of bone density loss in induced postmenopausal rats that received whole-body vibration compared to control postmenopausal rats, while a sham operation group showed no increase in bone density after vibration.<sup>125</sup> A study of postmenopausal women after six months of whole-body vibration found increases in dynamic and isometric strength and hip bone mass density, while no increase in hip bone mass density was found in women with



progressive resistance training or in age matched controls.<sup>123</sup> Another study after 12 months of vibration and taking the drug Alendronate found no difference in bone density over that of Alendronate alone in postmenopausal osteoporotic Japanese women.<sup>127</sup> The study did find those who had whole-body vibration had a decrease in lumbar back pain.<sup>127</sup> Whole-body vibration was compared to isodynamic lumbar extension in patients with chronic low-back pain, where it was found that both exercise protocols resulted in a reduction of pain and pain related disability.<sup>122</sup>

Currently, no study could be found that investigated the use of WBV to strengthen quadriceps femoris in individuals with total knee arthroplasty. Only one study used a measure of muscle activation in the study of whole-body vibration showing no improvement in activation of the quadriceps.<sup>22</sup> Before vibration activation of the knee extensors was 95 ( $\pm 2\%$ ) and 90 seconds after 5 repetitions of 60 second 30 Hz and 8 mm amplitude whole-body vibration the activation level dropped to 90 ( $\pm 4\%$ ). At 180 minutes the activation level was at 91 ( $\pm 5\%$ ). Over the two week training period there was no improvement of muscle activation during voluntary effort. The study used healthy untrained students as subjects who could already activate these quadriceps femoris muscle at 95%. As noted previously other authors have found this to be in a normal range for the quadriceps femoris. It is not surprising then that there was no further augmentation in muscle activation. If a population with a known voluntary activation deficit were trained with whole-body vibration it is not known if the activation would change. It would be beneficial to investigate the effect of a training protocol with whole-

body vibration in individuals known to have a decrease in muscle activation of the quadriceps femoris, such as individuals with total knee arthroplasty.

De Ruyter et al<sup>22</sup> suggest that it is difficult to see how whole-body vibration would lead to neural adaptations and enhanced performance. They state that motoneuron recruitment in response to direct muscle vibration is rather limited, suggesting that vibration elicits a certain level of presynaptic Ia inhibition, which decreases further recruitment of motoneurons.<sup>22</sup> They also suggest that the vibration goes through the sole of the foot and is dampened by each joint in the lower extremity.<sup>22</sup> They state that vibration causes reciprocal inhibition of the antagonist muscle, but in whole-body vibration both agonist and antagonists are vibrated and may further enhance the inhibitory affects of vibration.<sup>22</sup> The flexed position of the knees and hip solicit co-contraction of the antagonistic hamstrings and quadriceps, and therefore the vibration platform facilitates contraction of both muscle groups. De Ruyter et al,<sup>22</sup> in non-published research, found a 10%-20% increase in EMG signal following vibration. They suggest the small increase indicates limited additional fiber recruitment.<sup>22</sup>

A benefit of whole-body vibration is the reduced stress of resistance training on older individuals. Kallinen and Markku et al<sup>128</sup> suggest that older adults are more likely to overload the musculoskeletal and cardiovascular system because of their diminished ability to adapt to high levels of loading, which may increase risk of injury or complications. Rittweger et al<sup>121</sup> suggest after an investigation on the acute effects of whole-body vibration in men, that the risk expected when vibration exercise is applied to the elderly is negligible. A study involving elderly women reported no adverse effects of

older women participating in whole-body vibration over a six-month period with increasing exposure to vibration up to 30 minutes per session by the end of the six months; instead most subjects enjoyed the vibration exercise and did not consider it a difficult work out.<sup>24</sup> Out of 89 subjects seven dropped out of the study due to mild knee-discomfort and three in the traditional resistance exercise group for patellofemoral dysfunction over the six month period.<sup>24</sup> No side effects were noted in the subjects with multiple sclerosis who participated in whole-body vibration.<sup>111</sup> A six-month study of whole-body vibration on postmenopausal women reported no vibration-related side effects.<sup>123</sup> A study of postmenopausal osteoporotic women who used whole-body vibration for 12 months had no incidence of vertebral fracture.<sup>127</sup> Whole-body vibration is a suitable and efficient strength training method for older women.<sup>24</sup> Increases in heart rate, blood pressure, and oxygen uptake during whole-body vibration are mild and thus risk to older individuals is low.<sup>122</sup>

The increase in strength noted in most studies on whole-body vibration may be related to the characteristics of the load imposed on the neuromuscular system.<sup>23</sup> Torinen et al<sup>25</sup> suggest that the muscle strength increase is due to intramuscular changes and to the extent of neural activation. The changes in the nervous system allow more complete activation of the prime movers of a specific movement (increase in the number of motor units recruited) and better coordination of the activation of the relevant muscles (the rate of firing and synchronization of firing), which lead to greater force production in the desired movement.<sup>27, 28</sup> Roelants et al suggest that neural adaptations are the most relevant mechanism for early strength gains not only in progressive resistance training

but also in individuals using whole-body vibration.<sup>24</sup> They<sup>24</sup> suggest that it is likely that whole-body vibration training produces a biological adaptation that is connected to the neural potentiation effect, similar to that produced by resistance and explosive strength training. The oscillating vibrations cause small changes in muscle length that stimulate muscle spindles, skin, pressure receptors (Merkel's receptor endings, Meissner's corpuscles, Ruffini nerve endings),<sup>25</sup> and proprioceptors (joint receptors); leading to generation of reflexes.<sup>111</sup> Input of proprioceptive pathways, Ia, II, and Ib afferents, play an important role in production of force in isometric contractions.<sup>30</sup> During whole-body vibration these pathways are strongly stimulated, which activates the sensory receptors and results in reflexive muscle contractions.<sup>24, 31</sup> The increase in isometric strength seen with whole-body vibration training might be the result of a more efficient use of the positive proprioceptive feedback loop in the generation of isometric force.<sup>24</sup> The view is emerging that vibration exercise is a means to alter central motor control patterns.<sup>31</sup>

#### *Whole-Body Vibration and Neuro System (muscle spindle and muscle activation)*

Skeletal muscle and bone are able to adapt and modify their functional capacity in response to stimuli<sup>23</sup>; muscle modifies its overall functional capacity through the overload principle in response to regular activity with high loads.<sup>129</sup> Changes within the muscle itself constitute the most important adaptation to resistive exercise.<sup>28, 130</sup> Muscle strength increases are the result of neurogenic and myogenic factors<sup>131</sup>; and specific adaptations to training depend on the training program used.<sup>27, 28</sup> Early (2 to 6 weeks to a few months) gains in strength have been attributed to changes in the nervous system as no increase in cross-sectional area of muscle is noted in the first several weeks of a

strength training program.<sup>25, 27, 28, 130</sup> Neural adaptations that occur are improved coordination, increased activation of the prime movers,<sup>131</sup> and recruitment and synchronization. The intensity of exercise or the amount of resistance or effort the muscle group exerts has a direct relation to the increase in force production by muscle hypertrophy and neural activation. During normal daily activity the body and muscular system are exposed to gravitational forces which result in necessary strength to counteract the action of gravity. Changes in the gravitational conditions experienced by the body result in changes in strength and function of the individual. Certain strength and explosive power training protocols are based on exercise that utilizes rapid variation of gravitational acceleration.<sup>114</sup> In decreased gravity environments a marked decrease in muscle mass and force-generating capability is noted.<sup>23, 132</sup> Microgravity environments could result from prolonged laying in bed or sedentary life style, which could be associated with individuals who need or who have recently undergone total joint replacement. An increase in resistance (such as weight lifting) will increase cross-sectional area of muscle and force production capability of muscle. Strengthening programs utilize increased resistance to over load the neuromuscular system and thus an increase in muscle strength. Whole-body vibration subjects the body and neuromuscular system to hypergravity actions due to the high accelerations.<sup>23, 25, 114, 115, 117</sup> Vibration is reported to increase gravitational force up to 14 g.<sup>23, 25, 114, 115, 117</sup> One study found gravitational forces of 2.5 to 6.4 g.<sup>25</sup> These gravitational force changes stress the body and its muscle-tendon structures. The mechanical alterations are thought to affect the nervous system and result in strength increases.

The mechanical action of the vibration produces rapid alterations in the length of the muscle-tendon complex as a result of the accelerations experienced. The alterations are detected by the sensory receptors (muscle spindle, skin, joint and pressure receptors)<sup>133</sup> that modulate muscle stiffness through reflex muscular activity of the muscle spindle and gamma motor loop efferents in the neuromuscular system.<sup>23, 25, 134, 135</sup> The vibration affects sensory receptors including the muscle spindle, which results in activation of alpha-motor neurons and initiates muscle contractions similar to tonic vibration reflex.<sup>136-138</sup>

During active muscle contraction, vibration elicits a nonvoluntary reflex muscle contraction similar the tonic vibration reflex. Muscle spindles are activated and lead to an enhancement of the stretch-reflex loop. The tonic vibration reflex has been used in rehabilitation to treat neurologically affected patients, such as cerebral vascular accident patients, in combination with active voluntary contractions of paretic muscles,<sup>139</sup> although these effects are often short lived.

Some studies suggest that the tonic reflex facilitates the activation of high-threshold motor units and may have an effect on recruitment patterns and on the number of fast-twitch fibers recruited.<sup>24, 122, 140, 141</sup> It is activation of these high-threshold motor units that plays an important role in muscle strength and power in older adults,<sup>142</sup> and it is thought that as these high-threshold motor units are lost, people typically become more sedentary. Muscle weakness of the quadriceps femoris following injury to the knee is thought to be affected by receptor afferents through the gamma motor neuron,<sup>73</sup> which inhibit or lessen the force production of the quadriceps femoris. If a vibratory stimulus is

able to stimulate the receptors and enhance the reflexive loop overcoming the inhibition and increasing strength and function in injured individuals, it would be a valuable adjunct treatment in rehabilitation.

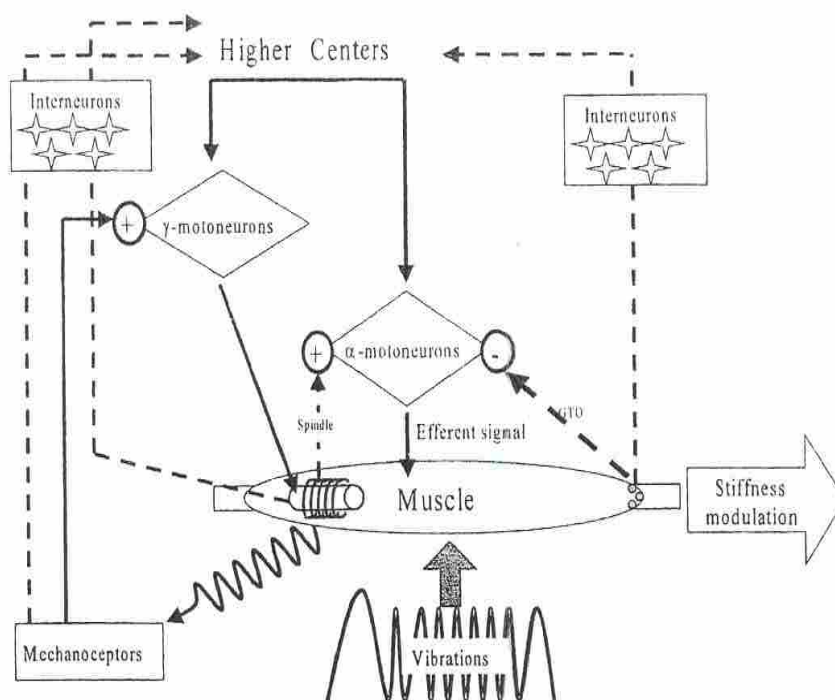


Figure 1. Schematic diagram illustrating stiffness regulation during vibration stimulation. The quick change in muscle length and the joint rotation caused by vibration trigger both alpha and gamma motor neurons to fire to modulate muscle stiffness.<sup>23</sup>

The primary endings of the muscle spindle are more sensitive to vibration than are the secondary endings and golgi tendon organs.<sup>23</sup> Vibration is sensed by sensory receptors that facilitate the gamma system during the application of vibration and enhance the sensitivity of the primary endings.<sup>23</sup>

Enhancement of the neuromuscular performance after vibration is probably related to 1) increased sensitivity of the stretch reflex, and 2) it is suggested that vibration appears to inhibit activation of antagonist muscles through Ia-inhibitory neurons, thus altering the intramuscular coordination patterns leading to a decreased braking force around the joints stimulated by vibration.<sup>23</sup>

Vibration is thought to influence central motor command. The primary and secondary somatosensory cortex, together with the supplementary motor area, constitutes the central processing unit of afferent signals.<sup>23, 143</sup> Vibration applied at different frequencies that is capable of producing kinesthetic illusion activates the supplemental motor area, thus the supplement motor area is activated by vibration. Vibration stimulus influences the excitatory state of the peripheral and central structures, which could facilitate voluntary movements. Current evidence does not allow an explanation of the specific neural adaptations that accompany a vibration treatment.<sup>23</sup> Varied results with vibration have been found. Short exposure enhanced voluntary strength exertion, while acute exposure to long-duration vibration reduced force generation in muscle.<sup>121</sup> The reduced force generation may be related to depletion of neurotransmitters.<sup>70, 73</sup> Vibration applied over weeks has shown increase in strength in the subjects tested. Suggested reasons for the variance in outcome of vibration treatment are 1) activation of inhibitory feedback from the golgi tendon organ, and 2) reduced sensitivity of muscle spindles, such as that caused by depletion of neurotransmitters or pre-synaptic inhibition.



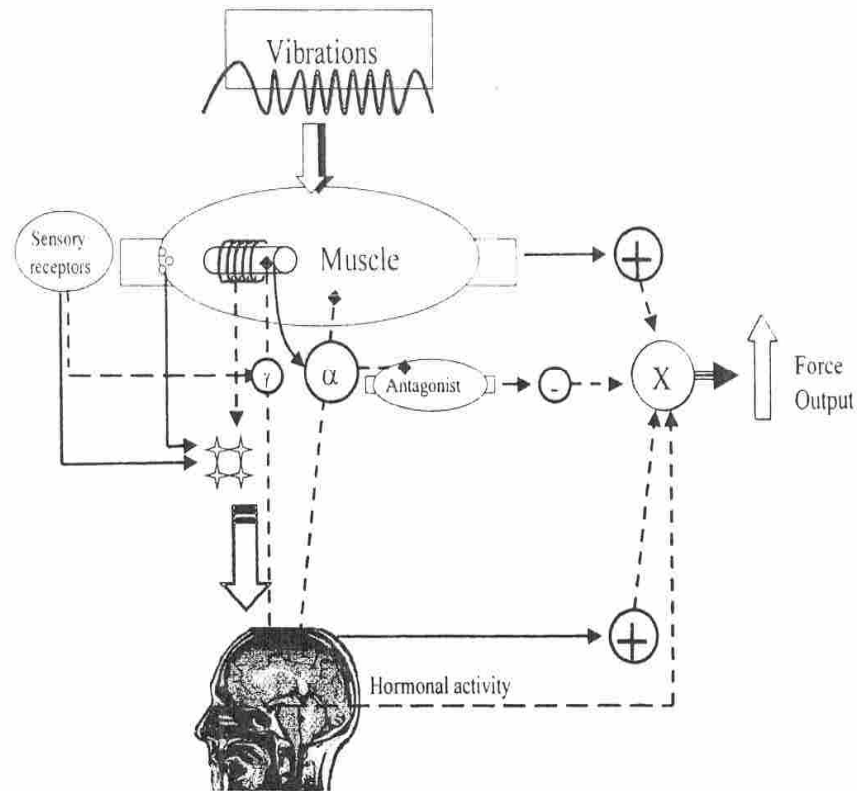


Figure 2. Schematic diagram illustrating the potential mechanisms that mediate the enhancement of force-generating capacity after acute and chronic exposure to vibration. Vibrations determine an increase excitatory state of the neuromuscular system due to an increase in the sensitivity of stretch reflexes and the stimulation of the specific areas of the brain. The central influences also influence the hypothalamus-hypophysis axis, which triggers the secretion of specific hormones. All these factors contribute to the increase in force-generating capacity of skeletal muscle.<sup>23</sup>

The potential mechanism determining an increase in neuromuscular performance by vibration in stimulation of sensory receptors/structures causes the neuromuscular system to produce reflex muscle activation. A relatively short vibration creates the potential for a more powerful and effective voluntary activation of skeletal muscle. This potential mechanism could be studied by various evoked responses, transcranial magnetic stimulation and the H-reflex.<sup>23</sup> The purposed study suggests the central activation ratio, which is used to measure the amount of voluntary muscle activation, as means to determine the affect of whole-body vibration on the central motor control mechanism and the activation level of the quadriceps femoris muscle following injury (in this case total knee arthroplasty, secondary to knee osteoarthritis). The amount of voluntary activation is based on the number of motor units recruited volitionally and the rate of firing of the motor units recruited. A deficit in the number or in the rate of the firing of the motor units would show muscle inactivation.

Other suggested mechanisms for the observed changes in strength and performance following whole-body vibration are hormonal factors.<sup>23</sup> A micro-gravity environment results in decreased androgen levels and growth hormone—a result of lack of physical tension on the musculoskeletal system; while strengthening exercises have shown to increase androgen and growth hormone levels.<sup>23</sup> Cardinale and Bosco<sup>23</sup> suggest that vibration exercise provides high stress on the musculoskeletal structures and requires a high level of neural activity. They suggest that vibration represents a strong stimulus for musculoskeletal structures due to the need to quickly modulate muscle stiffness to accommodate the vibratory waves. This response is mediated by monosynaptic and

polysynaptic afferent pathways, which are capable of triggering specific hormonal responses. A subsequent voluntary activation can be performed with central and peripheral structures in an elevated excitatory state. A study on the acute effects of whole-body vibration on the endocrine system of healthy men showed reduced plasma glucose and increased plasma norepinephrine concentrations, but did not change the circulating concentrations of other hormones measured.<sup>144</sup> Another considered mechanism of whole-body vibration's affect on the body is intensity of the exercise to reach perceived fatigue due to exercise.

Whole-body vibration showed a more rapid reaching of a comparable level of exhaustion and muscular fatigue compared to exercise without vibration.<sup>31, 145</sup> Whole-body vibration increases oxygen consumption compared to squatting without vibration.<sup>146</sup> Rittweger et al<sup>145</sup> suggest that the effects of exercise duration, vibration frequency, amplitude, and load that are optimum to evoke the observed neuromuscular excitability remain to be clarified in young adults, but also in athletes or elderly subjects and patients, after acute after chronic applications. The current study would further knowledge related to whole-body vibration's affect on a patient population who has undergone TKA.

#### *Timed-Up-and-Go-Test (TUG)*

The Timed-Up-and-Go (TUG) test measures the time it takes a patient to rise from an armchair (seat height 46 cm), walk 3 m, turn and return to sitting in the same chair. Subjects are asked to walk as quickly as they feel safe and comfortable. Subjects are allowed to use the arm rest of the chair to stand and sit down. The TUG is widely

accepted to measure mobility in older adults. It has a very high inter-tester (ICC = 0.99) and intra-tester reliability (ICC = 0.99)<sup>147</sup>

### *Visual Analogue Scale (VAS)*

The visual analogue scale is a popular instrument used to assess subjective feeling, such a pain. It is easy to administer and simple for the subject or patient to understand. The visual analogue scale is typically 100 mm long and is either represented as a vertical or horizontal line. Response is given by drawing a single perpendicular line to the VAS line, and the distance from the lowest anchor point (start of the line) to the subjects marked response indicates the magnitude of the perceived pain.<sup>148</sup> Revill, Robinson, Rosen and Hogg<sup>149</sup> found that rating of constant pain is reproducible and changes likely reflect real changes of opinion. Miller and Ferris<sup>150</sup> suggest that the VAS can be considered reliable and valid in most circumstances. A study found that in the VAS an individual determination has an imprecision of  $\pm 20$  mm,<sup>151</sup> while another study suggests that a change of 31% to 48% in the VAS is indicated to have a meaningful reduction in postoperative pain.<sup>152</sup> Thus, it appears a change of greater than 20 mm may be considered clinically significant. Experience with the VAS suggests that a better representation of change in pain can be achieved by allowing the subject to compare their pain recordings of previous VAS to the current VAS. Also a better representation of perceived pain can be achieved by dividing pain into types of pain such as current average pain for the last 24 hours at rest or current average pain level over the last 24 hours with movement. These categories of pain description will be used in the proposed study.

### *Goniometer*

The universal goniometer is a standard tool used to measure ROM in the knee. It is used both clinically and in research. The universal goniometer has been found to have high intra-tester (ICC= 0.997 flexion, ICC= 0.972 extension) and inter-tester (ICC= 0.977 flexion, ICC= 0.893 extension) reliability.<sup>153</sup> Criterion validity (r) varied from .975 to .987 for flexion and .390 to .442 for extension.<sup>153</sup> Brosseau et al<sup>153</sup> suggest that the same person perform each measurement of knee ROM. Knee ROM will be conducted after the manner of previously published methods.<sup>154</sup> The axis of the goniometer will be aligned with the lateral epicondyle of the femur. The distal arm of the goniometer will be aligned with the lateral malleolus of the fibula, and proximal arm aligned with the greater trochanter of the femur. Current knee ROM is the value of maximal active bending of the knee while the subject is lying supine. Knee extension is the angle of maximal active straightening with the patient's heel propped on a 6 inch block. If a patient achieves hyperextension of the knee during knee extension, then the degrees will be recorded as a negative number. Knee flexion ROM is the value of maximal active knee flexion while the patient is lying supine. Examination of ROM with this technique in patients with knee OA has good reliability (ICC= 0.96 for flexion, ICC= 0.81 for extension).<sup>155</sup>

## Chapter 3

### Methods

#### *Design*

A 2 x 2 (time and treatment) factorial design will be used in the study. The first factor is for time (2 levels –pretest and posttest separated by 4 weeks of treatment), the second factor is the treatment program (2 levels- traditional physical therapy rehabilitation only and traditional rehabilitation + whole-body vibration). The dependent variables are 1) Force production (at 75° of knee flexion<sup>14, 77</sup>) during a maximal knee extension isometric contraction, 2) the central activation ratio of the quadriceps at 75° of knee flexion during a maximal isometric knee extension contraction, 3) the TUG test, and 4) VAS of pain at rest and with movement will be done pretest to posttest. Knee joint ROM will be gathered as a descriptive statistic of the groups.

#### *Subjects*

Subjects for the study will be recruited from the Utah and surrounding counties. Subjects will volunteer for participation in the study. Subjects will sign a university approved institutional review board (IRB) informed consent. Subjects will be from 60 to 75 years of age and have undergone total knee arthroplasty by orthopedic surgeons and be scheduled for physical therapy in either home health and/or outpatient physical therapy. Subjects will be recruited from 3 to 6 weeks post surgery. Subjects will be randomly assigned to the experimental group or control group.

Exclusion criteria: Subjects with musculoskeletal involvement other than TKA that limits their function or if they have uncontrolled blood pressure, diabetes mellitus, neoplasm,

neurological disorders, fibromyalgia, have a cardiac pacemaker, or a body mass index (BMI: weight in kg/m<sup>2</sup> height) > 40 (morbidly obese) will not participate in the study.<sup>14</sup>

The minimal number of subjects proposed to be used in the study is 8 subjects per group for a total of 16 subjects. Hart et al<sup>156</sup> from previous data determined a priori that 16 subjects is necessary to find differences in quadriceps activation at an  $\alpha=.05$  while maintaining statistical power greater than  $1-\beta=.8$ , based on the observed group effect comparing quadriceps activation in subjects with low back pain. A study investigating the effects of WBV in patients with multiple sclerosis used 6 subjects in each group for a total of 12 subjects.<sup>111</sup> Another study which investigated electrical stimulation on strength increase of the quadriceps femoris in individuals with TKA had a total subject number of 8 with 5 in the experimental group and 3 in the control group.<sup>77</sup> Ronnestad<sup>124</sup> in a study of WBV used an n=7 for each group.

### *Testing protocol*

Subjects will participate in a baseline and a 4 week test of quadriceps femoris isometric strength, voluntary muscle activation, ROM and pain associated with the testing procedure and treatment protocols. Initial testing will begin after 3 to 6 weeks postsurgery.

### Pretest—Baseline

Subjects will read and sign the informed consent and personal information sheet. Data will be gathered in the order listed: 1) descriptive data, 2) VAS of pain, 3) knee joint ROM, 4) TUG test, 5) isometric strength and voluntary muscle activation testing.

1. Subject's height and weight will be collected.

2. Subjects will complete a VAS of average pain over the last 24 hours at rest and with movement. The VAS is a 100 mm horizontal line with anchor points of “no pain” and “worst imaginable pain.” The subject will mark with a single vertical line on the scale to indicate the magnitude of their average pain over the last 24 hours at rest and with movement. Strong<sup>148</sup> states the VAS is sensitive, simple, reproducible, and universal.

3. Active and passive knee flexion and extension ROM will be measured using a universal goniometer. Knee ROM will be conducted after the manner of previously published methods.<sup>14</sup> The axis of the goniometer will be aligned with the lateral epicondyle of the femur. The distal arm of the goniometer will be aligned with the lateral malleolus of the fibula, and proximal arm aligned with the greater trochanter of the femur. Knee extension is the angle of maximal active straightening with the subject in supine. If a subject achieves hyperextension of the knee during knee extension, then the degrees will be recorded as a negative number. Knee flexion ROM is the value of maximal active knee flexion while the subject is lying supine.<sup>14</sup> Examination of ROM with this technique in subjects with knee OA has good reliability (ICC= 0.96 for flexion, ICC= 0.81 for extension.<sup>155</sup> . The universal goniometer has been found to have high intra-tester (ICC= 0.997 flexion, ICC= 0.972 extension) and inter-tester (ICC= 0.977 flexion, ICC= 0.893 extension) reliability.<sup>153</sup> Criterion validity (r) varied from .975 to .987 for flexion and .390 to .442 for extension.<sup>153</sup> Brosseau et al<sup>153</sup> suggest that the same person perform each measurement of knee ROM.



4. Subject's will perform the TUG test;a patient is asked to rise from an armchair (seat height 46 cm), walk 3 meters, turn and return to sitting in the same chair. Subjects are asked to walk as quickly as they feel safe and comfortable. Subjects are allowed to use the arm rest of the chair to stand and sit down. The TUG is widely accepted to measure mobility in older adults. It has a very high inter-tester (ICC=0.99) and intra-tester reliability (ICC= 0.99).<sup>147</sup>

5. Subjects will then warm up on a bicycle ergometer (Magneciser, Chattanooga Group, Hixson, TN) for 5 minutes. Intensity will be determined by the patient's comfort level and the patient's ability to complete full revolutions on the bicycle ergometer.

6. Subjects will be set up for isometric strength and voluntary muscle activation testing. Quadriceps femoris strength and voluntary muscle activation (using the CAR) of the quadriceps femoris muscle will be tested. Both the operated knee and non-operated knee will be tested. The non-operated lower extremity will be tested first, in order to decrease possible anxiety about the test. The order of the testing will remain the same for the posttesting session.

#### Quadriceps Strength and Activation Testing

Subjects will be set in a motorized seat to allow knee positioning appropriate for the proper positioning of the strain gauge to the leg. Subjects will be positioned in the chair so that the hips are flexed to approximately 95° and their knee flexed to 75°. <sup>77</sup> An ankle cuff will be placed on the subjects' ankle at approximately 4 cm proximal to the lateral malleolus of the leg being tested to which a strain gauge will be attached. The

strain gauge (Omegadyne, Inc., Stanford, CT, model: LC101-250) will be positioned so that a 90° angle is achieved between the strain gauge and the subjects' lower leg. The strain gauge will be anchored to a stable bar attached to the seat frame. The thigh, pelvis, and trunk will be stabilized to the chair with inelastic straps. Two sponge electrodes (10X10 cm) or carbon electrode pads with conducting gel or self-adhering electrodes will be attached to the thigh with self-adhering elastic bands. The anode will be placed over the motor point of the rectus femoris and the cathode will be placed over the motor point of the vastus medialis.

Strength testing will follow the method established by Stevens, Mizner and Snyder-Mackler<sup>77</sup> and begins by instructing subjects to perform two 3-to 5-second voluntary isometric contractions at an intensity that they perceive as 50% to 75% of their maximal effort. These contractions function as a warm-up and to familiarize the subject with the testing procedure. The subject's quadriceps will be stimulated two times at ~100 volts and 135 V to familiarize the subject with the sensation of electrical stimulation. After the subject is familiar with the procedure and rests for 3 minutes, data collection will begin. Prior to each data collection, subjects will be told to maximally, isometrically contract their quadriceps for 3 to 4 seconds and not to volitionally lessen their contraction after the stimulus is felt. The subject will receive verbal encouragement from the tester during the contraction. During the contraction at approximately 2 seconds, a 135 V, 10-pulse, 100 pps train (1000 microsecond pulse duration) will be delivered to the muscle to assess whether the subject is maximally activating the quadriceps femoris muscle (burst superimposition technique).<sup>54, 55, 77, 157, 158</sup> A S88 stimulator with an SIU8T stimulus

isolation unit (Grass Instruments, Inc., Quincy, MA) will deliver the stimulus to the subject. At 1.8 seconds into the contraction a sound will be generated by a computer with customized software, upon which the examiner manually will press the stimulation switch. The subject will wear head phones in order not to hear the beep sound of the computer and thus not alter the contraction secondary to hearing the sound. The time of stimulation will be recorded by the customized software program. The data are digitized at 1500 Hz and analyzed by the custom software. With full activation, no increase in force should be seen and a CAR of one is achieved. The subject will perform three trials. Each trial will be separated by 3 minutes, in order to minimize the effects of muscle fatigue. The burst superimposition technique has been shown to be highly reliable in subjects without pathology (ICC= 0.98)<sup>74, 107</sup>, and has been used in studies with individuals with known pathology.<sup>14, 16, 38, 54, 74, 77, 98, 107, 159</sup>

7. Qualified subjects will be randomly assigned to either the traditional or whole-body vibration groups.

Subjects will participate in physical therapy as ordered by orthopedic surgeon from post-operation until beginning the study. After baseline measurements subjects will participate in traditional, or traditional and whole-body vibration rehabilitation for 4 weeks at three visits per week for a total of 12 visits. Subjects may miss up to two sessions, but not in the same week, before being discharged from the study. At the end of the four weeks (12 visits) subjects will be retested identical to pretesting at approximately the same time of day.

*Traditional rehabilitation*

Stevens, Mizner, and Snyder-Mackler<sup>77</sup> established a protocol of traditional TKA rehabilitation in a previous study. The following is the protocol with minor changes made to coincide with local orthopedic surgeons TKA protocol, such as use of CPM device for ROM. Physical therapy will be done at local clinics and/or in a home health setting according to the following protocol. An adherence log or chart records will be used to monitor the treatment received by the subjects.

## Range of Motion

1. Exercise bike (5 min progressing to ~15 min), started with forward and backward pedaling with no resistance until enough ROM for full revolution; progression: lower seat height to produce stretch with each revolution.
2. Active-assistive ROM for knee flexion, sitting or supine, using other leg to assist.  
(Wall slides, etc.)
3. Knee extension stretch with manual pressure (in clinic) or weights (at home).
4. Patellar mobilizations: 3x30 superior/inferior; medial/lateral, as needed.

## Strength

1. Quad sets, straight leg raises (without quad lag), hip abduction (side lying or theraband or machine), standing hamstring curls (theraband, chair scoots, or machine), seated knee extension, standing terminal knee extensions from 45° to 0°, step ups (5.08-15.24 cm), step downs and side steps, wall squats (squats) to 45°\* Nu-step, total gym, shuttle, 1 to 3 sets of 10 repetitions for all strengthening exercises.

2. Criteria for progression: exercises are to be progressed (eg, weights, step height, etc.) once the patient can complete the exercise correctly and feels maximally fatigued at the end of each set.
3. Progression: (0.454-0.907 kg) weights added to exercises, step-downs (5.08-15.24 cm), front lunges, and wall slides towards 90 ° knee flexion.
4. Weight bearing exercises will be done on total gym, shuttle, or in standing that are equivalent to the WBV exercises.

Pain and swelling, Incision mobility, Functional activities

1. Ice and compression as needed (duration of 10 to 20 minutes as directed by attending physical therapist)
2. Soft tissue mobilization until incision moves freely over subcutaneous tissue.
3. Ambulation training with assistive device as appropriate with emphasis on heel strike, push-off at toe-off and normal knee joint excursions.
4. Emphasis on heel strike, push-off at toe-off and normal knee joint excursion when able to walk without assistive device.
5. Stair ascending and descending step over step when patient has sufficient concentric/eccentric strength.

Monitoring vital signs: 1. Blood pressure and heart rate are monitored at initial evaluation and as appropriate.

#### *Whole-Body Vibration and Traditional Rehabilitation*

Subjects assigned to the whole-body vibration group will participate in traditional TKA rehabilitation exercises designed to increase ROM and reduce pain as have been

established as the accepted standard for care following TKA. Strengthening exercises will also be preformed, but as possible these exercises will be preformed during whole-body vibration according to the following protocol. The protocol is based after that used by Roelants, Delecluse, and Verschueren<sup>24</sup> in a study with whole-body vibration and older women. Whole-body vibration will be performed on the vibrating platform (Power Plate, Badhoevendorp, The Netherlands) using unloaded static and dynamic exercise. Subjects will be asked to wear the same footwear as able during the duration of the study. Subjects will be asked to report any adverse reactions or negative side-effects to the training.

#### Whole-Body Vibration Protocol

1. Start at 2 mm vibration and progress to 5 mm as tolerated and in accordance with exercise progression. Start with 35 Hz and progress to next level on power plate, 40 Hz
2. Start with basic exercises and then progress to more advance exercises.
3. Start with 1 repetition and progress to 3 repetitions.
4. 30 seconds up to 60 seconds per repetition.
5. Total duration of the vibration exposure during on WBV session is an important variable.<sup>24</sup> The total vibration duration the subject will receive is initially approximately 3 to 5 minutes and progressing to 18 minutes.
6. Follow progression according to overload principle<sup>24</sup>

Training volume and intensity low at beginning

- Progress slowly
- Increase duration of the vibration session

- Increase the number of series of one exercise (1 to 3 reps)
- Increase the number of exercises
- Increase training intensity by shortening rest period
- Increase training intensity by increasing amplitude (2.5mm to 5.0 mm)
- Change from two legged to one legged
- Maximum duration 18 minutes of vibration in combination of the various exercises.

Exercises:

Warm-up: 5 to 15 minute bike riding at a self-selected pace

1. Lunge step (step-up)

The subject will center their foot on the platform. They will flex 60° to 90° at the knees. Subject can rock forward and back on forward vibrated foot. Tell the subject not to let their knees extend beyond their toes. Instruct them to keep their back straight, head up, and maintain balance by holding onto handles.

2. ¼ squat or high squat (<50° to 60°)

The subject will stand with both feet on the platform, their feet slightly apart. They will bend at the knees to 50° to 60° of flexion. Instruct the subject not to let their knees extend beyond their toes. Instruct them to keep their back straight, head up, maintain balance by holding onto the bar.

### 3. Calves

The subject will stand with both feet on the platform, their feet slightly apart. They will flex slightly at the knees. Subject will rise up and down on their toes. Instruct them to keep their back straight, head up, maintain balance by holding onto the bar.

### 4. Wide stance, Dynamic squats

The subject will do squats with 3 second down and 3 seconds up alternating for the duration of the squat. The subject will stand with their feet apart, toes pointing slightly outwards, knees flexed to  $\sim 80^\circ$ . Instruct the subjects not to let their knees extend beyond their toes. Instruct them to keep their back straight, head up, maintain balance by holding on to the bar.

### 5. Calves deep

The subject will stand with both feet on the platform, their feet slightly apart. They will flexed to  $\sim 80^\circ$  at the knees. Subject will rise up and down on their toes. Instruct them to keep their back straight, head up, maintain balance by holding onto the bar.

### 6. Terminal knee extension

The subject will stand with both feet on the platform, their feet slightly apart. They will bend  $60^\circ$  to  $70^\circ$  at the knees. A theraband will be placed behind their exercised knee and pulled by assisting person. The subject will perform a dynamic squat contracting their quadriceps against the band by extending the knee against the resistance, then repeat by returning to the initial squat position. The subject will continue to perform



the exercise during the vibration. Instruct them to keep their back straight, head up, maintain balance by holding onto the bar.

#### 7. Squats with ball squeezes

The subject will stand with both feet on the platform, their feet slightly apart. They will bend 60° to 70° at the knees. A weighted ball (5 kg to 8 kg) will be placed between their knees. The subject will squeeze the ball in the squat position for the duration of the vibration. Instruct them to keep their back straight, head up, maintain balance by holding onto the bar.

#### *Posttest*

Posttesting will follow that done during pretesting.

#### *Data analysis*

Data will be analyzed to investigate if differences exist between the groups. Statistical analysis will include T-test (pretest to posttest average change between groups with post hoc test to determine the differences) for the CAR. Hotelling's  $T^2$  test will be conducted to find differences in the change in MVIC, pain and TUG between the groups.

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Appendix A-1 Questionnaire

## Subject Information

Name: \_\_\_\_\_

Age: \_\_\_\_\_ Height: \_\_\_\_\_ Weight: \_\_\_\_\_ Gender: Male Female

Date of Surgery: \_\_\_\_\_

Orthopedic Surgeon: \_\_\_\_\_ Operated leg: Right or Left

Diagnosis leading to knee replacement: \_\_\_\_\_  
(OA osteoarthritis, RA rheumatoid arthritis)Have you had or are planning on having knee replacement on your other leg. Yes or No  
If yes, explain: \_\_\_\_\_

Are you currently involved in physical therapy? Yes or No

Yes; Home Health or Outpatient. Where? \_\_\_\_\_

Name of physical therapist: \_\_\_\_\_

Are you currently taking pain medication? Yes or No

Name of medication? \_\_\_\_\_

Do you have any of the following: Circle your answer.

Yes or No High blood pressure. IF YES, are you taking medication for your high blood  
pressure? Yes or No

Yes or No Diabetes

Yes or No Cancer

Yes or No Fibromyalgia

Yes or No Cardiac pacemaker

Yes or No Neurological disorders

What prosthesis was used? \_\_\_\_\_

What approach was used? Medial or other? \_\_\_\_\_

Was computer assisted surgery used? Yes or No

Appendix A-2 Informed Consent Form



## Consent to be a Research Subject

### Introduction

This research study is being conducted by Wayne Johnson, MSPT, CSCS, doctoral candidate and Dr. Bill Myrer at Brigham Young University. The goal of the study is to determine how traditional rehabilitation and whole-body vibration affect muscle performance, functional ability and perceived pain in people who have had total knee replacement surgery. You were selected to participate because you have recently undergone total knee replacement and responded to an advertisement.

### Procedures

You will be asked to complete a subject questionnaire. You will be randomly assigned to a traditional physical therapy exercise group or a traditional physical therapy group with whole-body vibration. You will participate in a baseline measurement of your strength, muscle activation, function ability and perceived knee pain. You will participate in standard physical therapy and/or whole-body vibration after total knee replacement for 12 visits over 4 weeks. You may miss up to 2 visits. If more than 2 visits are missed you will be withdrawn from the study and may lose further treatment sessions at BYU. Further treatment can be received according at the outpatient clinic at the discretion of the attending physical therapist. After 4 weeks you will be re-assessed. Your will spend about 40 to 60 minutes for each testing session at BYU. The time of treatment at the physical therapy clinic will be determined by your physical therapist. Total participation time in the study should be about 15 hours.

### Risks/Discomforts

You will experience the usual discomfort or pain associated with total knee replacement and muscle soreness or discomfort from exercising after surgery. There is a slight risk of brief discomfort from an electrical stimulus during part of the strength testing. Whole-body vibration has not been reported to produce adverse side-effects in persons using whole-body vibration.

### Benefits

Physical therapy after total knee replacement is shown to be beneficial. Participation in the study does not limit the rehabilitation you would already be receiving. The whole-body vibration may or may not improve your rehabilitation.

### Confidentiality

All information provided will remain confidential and will only be reported as group data with no identifying information. All data, including questionnaires, will be kept in a locked storage cabinet and only those directly involved with the research will have access to them. After the research is completed, the questionnaires and records will be destroyed.

### Compensation

You will be given a \$15 gift card to a local restaurant. Subjects will be responsible for the cost of normal therapy beyond that covered by Medicare or their insurance provider, if they attend an outpatient clinic, regardless of group assignment. No added cost will be charged for treatment at the outpatient clinic for the vibration treatment or for treatment

given beyond the normal course of physical therapy. There is no charge for the testing or any treatment received for either the control or experimental group at the Human Performance Research Center (HPRC) at BYU in conjunction with this study. Subjects may choose to have their therapy done at the HPRC, this applies to both the control and vibration group.

**Participation**

Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy of any reprisal from the researchers.

**Questions about the Research**

If you have questions regarding this study, you may contact Wayne Johnson, MSPT at 830-5911, [awj23@byu.edu](mailto:awj23@byu.edu) or Dr. Bill Myrer at 422-2690, [bill\\_myrer@byu.edu](mailto:bill_myrer@byu.edu).

**Questions about your Rights as Research Participants**

If you have questions you do not feel comfortable asking the researcher, you may contact Dr. Renea Beckstrand, IRB Chair, 422-3873, 422 SWKT, [renea\\_beckstrand@byu.edu](mailto:renea_beckstrand@byu.edu).

I have read, understood, and received a copy of the above consent and desire of my own free will and volition to participate in this study.

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Appendix B Raw Data

1. Maximal Voluntary Isometric Contraction  
(MVIC) for Involved Total Knee Arthroplasty  
Limb

Subject	MVIC pre	MVIC post	MVIC difference
1	8.04	18.92	10.88
2	9.93	13.72	3.79
3	7.65	21.41	13.76
4	5.86	8.07	2.21
5	13.11	17.37	4.26
6	22.29	26.53	4.25
7	7.45	13.06	5.62
8	17.49	32.32	14.83
12	5.63	21.87	16.24
13	8.24	15.14	6.90
15	16.18	19.52	3.34
17	12.92	15.41	2.50
18	8.45	18.96	10.51
19	9.29	25.43	16.14
20	6.83	27.36	20.53
21	17.42	24.42	7.00

2. Maximal Voluntary Isometric Contraction (MVIC)  
for Uninvolved limb

Subject	MVIC pre	MVIC post	MVIC difference
1	33.79	38.25	4.45
2	21.89	22.41	0.52
3	41.42	47.21	5.79
4	3.13	2.85	-0.28
5	23.93	21.13	-2.79
6	45.72	40.27	-5.45
7	33.58	25.92	-7.66
8	14.51	34.77	20.26
12	19.18	26.59	7.41
13	25.02	17.92	-7.10
15	27.77	30.84	3.07
17	30.58	27.30	-3.29
18	23.96	35.14	11.18
19	23.09	37.98	14.89
20	32.82	42.81	9.99
21	35.32	77.47	42.15

## 3. Timed Up and Go Test

Subject	TUG pre	TUG post	TUG diff
1	11.0	7.5	3.5
2	19.0	10.0	9.0
3	9.0	6.0	3.0
4	12.0	10.0	2.0
5	19.0	11.0	8.0
6	10.0	7.4	2.6
7	9.5	7.0	2.5
8	17.3	10.2	7.2
12	10.0	6.9	3.1
13	11.5	9.0	2.4
15	11.7	8.7	3.0
17	9.0	8.2	0.7
18	6.8	6.1	0.7
19	16.5	9.0	7.4
20			
21			

## 4. Central Activation Ratio of the Involved Total Knee Arthroplasty Limb

Subject	CAR pre	CAR post	CAR diff
1	0.99	0.99	0.00
2	0.99	0.97	-0.02
3	0.82	1.00	0.18
4	1.00	1.00	0.00
5	0.99	0.99	0.00
6	0.77	0.96	0.19
7	0.82	0.99	0.17
8	0.82	0.91	0.09
12	0.98	0.95	-0.03
13	0.94	1.00	0.06
15	0.97	0.99	0.01
17	0.91	0.98	0.07
18	0.90	0.95	0.05
19	0.94	0.92	-0.02
20	0.98	0.98	0.00
21	0.99	1.00	0.01

5. Central Activation Ratio of the Uninvolved Limb

Subject	CAR pre	CAR post	CAR diff
1	1.00	0.99	-0.01
2	1.00	1.00	0.00
3	0.97	1.00	0.02
4	1.00	1.00	0.00
5	0.99	1.00	0.01
6	1.00	0.99	-0.01
7	0.96	0.98	0.02
8	0.94	0.98	0.04
12	1.00	0.91	-0.09
13	0.98	0.96	-0.01
15	0.91	0.85	-0.05
17	1.00	1.00	0.00
18	0.86	0.94	0.08
19	0.97	0.98	0.01
20	0.99	1.00	0.01
21	0.80	0.94	0.14

6. Perceived pain levels with a horizontal 100 mm visual analog scale

Subject	VASrestpre	VASmovepre	VASrestpost	VASmovepost	VASrestdiff	VASmovediff
1	8	21	5	4	3	17
2	64	23	18	11	46	12
3	12	22	2	8	10	14
4	23	53	6	15	17	38
5	3	8	1	3	2	5
6	27	41	29	62	-2	-21
7	19	28	7	9	12	19
8	21	31	15	64	6	-33
12	0	45	0	9	0	36
13	12	29	1	6	11	23
15	18	33	6	13	12	20
17	45	15	11	13	34	2
18	14	52	31	20	-17	32
19	62	34	2	20	60	14
20	50	50	15	15	35	35
21	17	18	13	13	4	5

## 7. Total knee range of motion for TKA and contralateral limb

Subject	pre TKA ROM	post TKA ROM	pre contra ROM	post contra ROM
1	112	127	145	145
2	86	113	127	126
3	91	101	131	131
4	94	112	127	123
5	88	107	111	118
6	99	117	130	136
7	88	92	107	104
8	99	96	120	121
12	76	104	124	128
13	92	118	113	122
15	82	111	124	131
17	104	118	121	123
18	118	119	137	127
19	85	101	132	130
20	106	124	127	128
21	96	115	102	125

## 8. Change in knee range of motion for TKA and contralateral limb

Subject	TKA Flex diff	TKA ext diff	contra flex diff	contra ext diff
1	12	3	12	3
2	18	9	18	9
3	7	3	7	3
4	11	7	11	7
5	21	-2	21	-2
6	11	7	11	7
7	4	0	4	0
8	1	-4	1	-4
12	21	7	21	7
13	20	6	20	6
15	21	8	21	8
17	11	3	11	3
18	0	1	0	1
19	15	1	15	1
20	18	0	18	0
21	19	0	19	0