BILATERAL AND UNILATERAL STRENGTH TRAINING IN POST-MENOPAUSAL WOMEN

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ABSTRACT

The purpose of the study was to determine the effects of bilateral (BL) and unilateral (UL) strength training on the bilateral deficit and lean tissue mass in post-menopausal women. The bilateral deficit is a phenomenon seen in resistance training where the strength of two homologous limbs contracting simultaneously is less than the sum of the strength of each limb contracting unilaterally. The bilateral deficit was computed as a bilateral index: BI(%) = 100[BL strength/(Left UL strength + Right UL strength)]-100. A negative BI indicates a bilateral deficit. There were two hypotheses for the study: 1) Changes in the bilateral deficit would be specific with training; BLD would be reduced with BL training (BI would move in the positive direction); and the BLD would increase with UL training (BI would move in the negative direction); and 2) It is expected that the UL training group would show a greater increase in muscle mass since there is a strength deficit during BL contractions (Seki and Ohtsuki, 1990).

Post-menopausal women (n = 26) were randomly assigned to either BL (n= 14; age = 55.8 $\pm$ 8.2) or UL (n= 12; age = 54.8 $\pm$ 6.5) training groups. Pre and post one maximal repetitions (1-RM) of BL, left UL and right UL strengths were measured for the leg press (LP), lat pulldown (LAT) and knee extension (KE) exercises. Whole, lower and upper (arms and trunk) body lean tissue mass were assessed by dual energy x-ray absorptiometry. The participants trained three times per week for six months using a whole body program with eight-ten repetitions for two sets per exercise. A dependent (one-sample) t-test was used to assess baseline BI for all three exercises to determine if the BI was different from zero, which would indicate a BLD. A two-factor analysis of variance (ANOVA) with repeated measures on the second factor (time, pre/post training) was used to analyze changes in the BI for LP, LAT and KE, as well for changes in bone mineral free lean tissue mass for the whole, lower and upper body. Initially there was a BLD in the LP and LAT exercises ($p < 0.05$), however not for KE ($p = 0.095$). There was a significant time by group interaction for the BI for LP, LAT and KE ($p < 0.05$), with the BI increasing on average by 7.8% (moved in the positive direction) for the BL group and decreasing by 1.1% for the UL group (moved in the negative direction). Tukey post-hoc testing indicated that the BL training significantly increased the BI for LP and KE for the BL group ($p < 0.05$) and the BI was significantly different after training between the groups ($p < 0.05$) for all exercises. Strength training increased lean tissue to a similar extent in both groups for whole, lower and upper body measures ($p < 0.05$). All of the strength measures (1-RM) increased over time ($p < 0.05$), with no differences between groups. These results indicate that the BLD decreased with BL training for LP and KE and there is a trend for UL training to increase the BLD (n.s.). These results suggest that 1) specific BL training can decrease the BLD and; 2) UL and BL training are equally effective for increasing lean tissue mass in post-menopausal women.

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DEDICATION

I would like to dedicate my thesis to my family, who were my greatest source of encouragement. First of all, I would like to say thank you to my parents. Your constant support and belief in me allowed me to strive for my goals. Your faith that I can accomplish anything gives me to courage to believe.

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CHAPTER 1

Introduction and Review of Literature

1.1 Introduction

Strength is the ability of the nervous system to maximally stimulate muscle fibers to contract and manipulate an object against a given resistance. Muscular strength is an important component for physical activity and for the performance of tasks of daily living. A phenomenon that is commonly observed is that maximal strength generating capacity is compromised when homologous limbs contract bilaterally. This is referred to as the Bilateral Deficit (BLD), which occurs when the maximal voluntary strength of simultaneous bilateral contraction is less than the sum of the strengths of right and left limbs when contracting alone (Howard and Enoka, 1991; Jakobi and Chilibeck, 2001; Kawakami et al., 1998). The magnitude of the BLD is often expressed as a bilateral index (BI) where BI(%) = 100[Bilateral strength/(Left Unilateral strength + Right Unilateral strength)]-100 (Howard and Enoka, 1991; Taniguchi, 1997; 1998), with a negative BI indicating a BLD. Henry and Smith (1961) first observed a BLD while examining grip strength. Since then, BLD has been shown in both large and small muscle groups (Howard and Enoka, 1987; Koh et al., 1993; Oda and Moritani, 1994; Schantz et al., 1989; Secher et al., 1988; Vandervoort et al., 1984;), athletic and non-athletic populations (Secher et al., 1988; Schantz et al., 1989), and in male and female subjects (Schantz et al., 1989). The bilateral strength of various subjects has been reported to range from 3% to 25% lower than the summed unilateral strengths (Archontides and Fazey, 1993; Jakobi and Chilibeck, 2001). It is thought that the BLD is caused by neural inhibition when attempting to contract two homologous limbs simultaneously (Vandervoort et al., 1984).

There is a distinct gap in the literature when it comes to investigating the BLD and older individuals. Hakkinen and colleagues (1995; 1996a; 1996b; 1997) and Owings and Grabiner (1998) are the only ones who investigated the BLD using older individuals. As well, the results pertaining to the BLD of this population are ambiguous; Owings and Grabiner (1998) found a BLD with knee extension while Hakkinen and colleagues (1995; 1996a; 1996b; 1997) did not. Since there are age-related changes to the neuromuscular system and consequently, strength and function, it is important to examine whether this neural phenomenon does occur.

It is thought that the BLD is trainable and can be reduced or possibly eliminated with specific bilateral training. The BLD is reduced with bilateral training and increases with specific unilateral training (Taniguchi, 1997). This may have implications when recommending appropriate training for those involved in sports where unilateral contractions predominate (i.e. boxing, cycling, running) compared to sports where bilateral contractions predominate (i.e. weight lifting, rowing).

Given that one can produce greater strength outputs when performing unilateral contractions, it has been suggested that unilateral training may be of greater benefit if an individual is attempting to build muscle mass (Jakobi and Chilibeck, 2001; Vandervoort et al., 1987). This hypothesis has never been tested with a rigorous training program.

This training strategy may be of benefit for individuals such as the elderly, who have reduced muscle mass.

The goals of this thesis were to determine whether a BLD actually occurs in an ageing population, whether bilateral and unilateral training can change the BLD and whether unilateral training can be used as a strategy for increasing muscle mass in older individuals.

1.2 Review of Literature

Throughout the review of literature the phenomenon of the BLD and its possible causes will be reviewed in depth. As well, the effects of specific lateral training on the BLD and how UL training may be more beneficial for muscle hypertrophy will be investigated. Lastly, sarcopenia (loss of muscle mass with ageing) will be reviewed as well as the possible benefits of UL training for reversing sarcopenia.

1.2.1 The Bilateral Deficit

Since Henry and Smith (1961) reported a reduced maximal strength during bilateral handgrip, compared to the summed unilateral efforts, there have been a large number of studies investigating the bilateral deficit. Although most studies show the existence of a BLD, the occurrence of the BLD is more consistent for certain movement patterns than others. Also, within a certain movement pattern the context of the BLD varies widely across studies. There are consistent BLD results in studies examining a leg press action (combined hip, knee and ankle extension) (Rube and Secher, 1990; Schantz et al., 1989; Secher, 1975; Secher et al., 1978; 1988; Taniguchi, 1997; 1998;

Vandervoort et al., 1984; Van Soest et al., 1985) whereas the results are conflicting with knee extension (Hakkinen et al., 1995; 1996; 1996b; 1997; Howard and Enoka, 1991; Jakobi and Cafarelli, 1998; Roy et al., 1990; Owings and Grabiner, 1998; Schantz et al., 1989). Howard and Enoka (1991), Owings and Grabiner (1998), and Roy et al. (1990) were the only ones who found a BLD during knee extension. The knee extension results may be ambiguous due to statistical problems with power (i.e. limited number of subjects in each group) or possibly due to methodological differences across the various studies. The variability seen in the literature when comparing leg press and knee extension BLD results may also be related to an issue of task complexity. The ability for the central nervous system (CNS) to maximally activate several muscle groups simultaneously, such as in a complex movement of leg press, may be compromised as compared to that of a simple task movement of knee extension (Schantz et al., 1989).

As aforementioned, the BLD is observed with upper body exercises, however the occurrence is not as common as found with leg press. The first documented occurrence of a BLD was with handgrip strength (Henry and Smith, 1961) and since, other authors have demonstrated a BLD in both arm extension (combined shoulder and elbow extension) (Taniguchi, 1997; 1998) and elbow flexion exercises (Oda and Moritani, 1994; 1995a; Seki and Ohtsuki, 1990). However, others have failed to find a BLD during upper body exercises (Secher et al., 1988; Vandervoort et al., 1987). Differences in habitual activity of the legs and arms may be the cause for the BLD differences. The legs are commonly used in an asynchronous motor pattern therefore they would not be accustomed to or trained for bilateral movements (Vandervoort et al., 1987), whereas the arms and hands are more commonly used bilaterally during lifting and carrying objects (Vandervoort et al., 1987), therefore they should demonstrate a smaller BLD.

There is strong empirical evidence that a strength BLD will occur in many different populations. As well, through electromyogram (EMG) measurements there is a neural BLD which accompanies the strength BLD (Oda and Moritani, 1994; 1995a; 1995b; Ohtsuki, 1981a; 1981b; Rube and Secher, 1990). However, amidst all the evidence, which supports the existence of a neural limitation there is also a large number of studies that have not found a BLD, either in strength or neural measurements. These studies have drawn the conclusion that the CNS is capable of maximally activating bilateral muscle groups at the same time (Hakkinen et al., 1995; 1996; 1996b; 1997; Herbert and Gandevia, 1996; Jakobi and Caffarelli, 1998; Schantz et al., 1989; Vandervoort et al., 1987). From the conflicting evidence it is hard to draw definitive conclusions of the neural mechanism of the BLD. As well, to add further controversy, a biomechanical mechanism has also been suggested as a causative mechanism of the BLD. However, there is stronger empirical evidence for a neural limitation (Kawakami et al., 1998; Oda, 1994; 1995a; 1995b; Ohtsuki, 1981a; 1981b; Owings and Grabiner, 1998; Rube and Secher, 1990; Vandervoort et al., 1984; Van Soest et al., 1985) than there is for a biomechanical limitation (Herbert and Gandevia, 1996).

In conclusion, the movement complexity may be a determining factor of the appearance of a BLD in some movements (leg press and lat pulldown) but not in others (knee extension). In addition, other movement patterns besides knee extension need to be examined for a BLD in older individuals since this could possibly have an impact for increasing or maintaining muscle mass and strength in this population. As well, more investigation is needed to determine if a neural limitation is the cause of a BLD.

1.2.2 Mechanisms

1.2.2.1 Biomechanical differences during bilateral versus unilateral efforts

Herbert and Gandevia (1996) stated that the ability to contract large muscle groups together may be limited, not by neural drive, but by the ability to maintain postural stability. Excessive joint/body movement may have a negative impact on the amount of force that an individual can apply to the apparatus (Ohtsuki, 1981b). In two subsequent studies, Ohtsuki (1981a; 1981b) controlled biomechanical factors involved in handgrip strength. In both studies, a deficit was observed in bilateral strength production, as well as neural activation, as measurement by EMG. Since biomechanical factors were successfully controlled for, neural limitations of muscle activation were concluded to be the cause of the BLD.

In an attempt to investigate the effects of biomechanical factors on BL and UL contractions, Secher et al. (1988) discovered that changes in position and joint angle did not interfere with BL contractions during a leg press action. The authors concluded that a BLD incurred by their subjects during leg press was not the result of a biomechanical limitation. Further research may be needed to substantiate these studies before this mechanism can be eliminated.

1.2.2.2 Neural Mechanisms

It has been suggested that the bilateral deficit may be the result of nervous system inhibition (Kawakami et al., 1998). More specifically, an impairment of the CNS has been proposed as a limiting factor when maximally activating bilateral muscle groups at the same time (Hakkinen et al., 1997; Schantz et al., 1989). The consequence of this impairment is shown at the muscular level where a reduced activation and recruitment of the fast twitch muscle fibers is thought to occur (Howard and Enoka, 1991; Kawakami et al., 1998).

It is possible that the neural limitation can be the result of division of attention (Ohtsuki, 1981a; 1994) or interhemispheric inhibition (Ferbert et al., 1992). If a strength BLD is in fact due to neural limitations then there should be a corresponding deficit in the EMG measurements, as well as in the strength production during bilateral compared to unilateral efforts (Howard and Enoka, 1991).

<u>EMG Studies</u>

Most studies that used EMG found deficits in EMG along with strength during the BL movements of a leg press action (Vandervoort et al., 1984; Rube and Secher, 1990; Van Soest et al., 1985), knee extension (Owings and Grabiner, 1998), plantar flexion (Kawakami et al. 1998), elbow flexion (Oda, 1994; 1995a; 1995b), and handgrip (Ohtsuki, 1981a; 1981b). There are also studies that did not find a reduced EMG measurement accompanying the strength reduction (Howard and Enoka, 1991; Schantz et al., 1989). However, EMG measurements have limitations such as a noisy average of neural activity that may impede detecting small changes in muscle activation (Howard and Enoka, 1991). Other limitations such as electrode pick up diameter, interelectrode distance, time when the integration was started and the time constant for integration (Oda, 1994) can affect the results and make it difficult to compare the various studies.

Interhemispheric Inhibition

One suggested cause for the neural limitation seen with the BLD is interhemespheric inhibition. Interhemespheric inhibition occurs when activation of one cerebral hemisphere interferes with the activation of the other through neural connections (Ferbert et al., 1992). The left hemisphere is activated when contracting muscles on the right side of the body, whereas the right hemisphere is activated with muscle contractions on the left side of the body. Both hemispheres are activated with BL movements (Oda and Moritani, 1995b) therefore an interaction and/or inhibition between the two hemispheres may be occurring during bilateral contractions (Wyke, 1969; Ohtsuki, 1981b; 1983). Oda and Moritani (1995b) demonstrated an inhibition when they examined movement related cortical potentials over the two hemispheres during handgrip contractions. Compared to UL effort, cortical potentials and strength output were reduced during bilateral contractions.

Division of Attention

Division of attention between limbs has also been proposed as a probable cause for the reduced activation and recruitment of muscle fibers during BL conditions (Ohtsuki, 1981a; 1994). However, researchers have concluded that division of attention is not a plausible cause since reciprocal bilateral muscle contractions with nonhomologous muscle groups (extension and flexion) (Ohtsuki, 1983) or co-contraction of nonhomologous muscles (arm and leg) (Howard and Enoka, 1991; Schantz et al., 1989) have not resulted in a BLD. However, the activation involved in nonhomologous muscle contractions may not be identical to the activation involved with right vs. left homologous muscle groups. Therefore, caution needs to be used when interpreting this conclusion and eliminating division of attention as a cause.

In summary, it is very probable that the BLD is due to a neural limitation, however more research is needed to determine which neural mechanism (interhemispheric inhibition vs. division of attention) is the limiting factor. As well, more empirical evidence is needed before the biomechanical factor is dismissed as a plausible cause. Neither biomechanical nor neural mechanisms will be measured in our study. It is possible that biomechanical factors will be controlled for, in the training and testing of the participants, although not with the formal intention of determining the cause of the BLD. During testing, a hip belt will be worn to avoid excessive hip movement during leg press and knee extension. As well, the participants will be observed for maintenance of proper form and posture during training.

1.2.3 Effects of Training on the BLD

1.2.3.1 Strength

There are a limited number of research studies that have examined the effects of training on the BLD, and those that have been done are relatively short in duration (Coyle et al., 1981). However, it has been demonstrated that specific bilateral training does have a profound effect on the BLD.

Effect of training status on the BLD has been examined in a number of cross-sectional studies with equivocal results. Howard and Enoka (1991) examined a group of untrained subjects, cyclists (UL trained group) and weight lifters (BL trained group). Knee extension strength was measured for all groups during BL and UL contractions. Untrained subjects showed a BLD while both the cyclists and weight lifters did not. The lack of a BLD for the cyclists was unexpected since they are involved in a predominantly UL sport. However, their actual training program (which was not documented) may have included BL contractions. The weight lifters, whose training involved mainly BL efforts demonstrated a bilateral facilitation (where bilateral strength was actually greater than the summed unilateral strength) during the knee extension testing.

When examining the effects of specific BL training, Secher (1975) found similar results with three different calibres of oarsmen (club vs. national vs. international) during leg press testing. The BL strength was the greatest with the group that had been intensely trained bilaterally (international calibre). This group exhibited a bilateral facilitation while the other two lesser-trained groups showed a BLD. The testing exercise (leg press) was a comparable movement to the rowing action for all subjects. It appears the intensity of specific BL training, as well as the type of lateral training (BL vs. UL), are factors for BL performance.

In contrast, other authors have found no differences between trained and untrained subjects (Schantz et al., 1989; Secher et al., 1988). Secher et al. (1988) compared untrained subjects to cyclists and weight lifters. All three groups demonstrated a BLD during a leg press exercise regardless of the status of training. The trained subjects (cyclists and weight lifters) may not use the same test movement (i.e. a leg press action can performed in a seated, supine or standing position) during their training programs and this may be why there was a BLD with bilaterally trained subjects. BL performance was enhanced with familiarization to the testing apparatus, therefore it was concluded that movement-specific training can improve BL performance.

Schantz and colleagues (1989) examined the effects of various types and levels of training in a number of groups (untrained, physical education students, professional ballet dancers, and national weight lifters) on BLD during leg press. Training status had no effect on the BLD. In order for the training to be effective in influencing the BLD, it may have to involve training on the same apparatus used for testing (Schantz et al., 1989).

When subjects are trained and tested on the same apparatus, an effect of training on the BLD is apparent. Bilateral training increases bilateral strength and reduces the BLD, whereas unilateral training increases unilateral strength and increases the BLD (Hakkinen et al, 1996a; Taniguchi 1997; 1998). Hakkinen, et al. (1996a) trained subjects for 12 weeks using either unilateral or bilateral knee flexion and extension. The increases in strength were specific to the mode of training. The bilaterally trained group increased BL strength more than the unilaterally trained group (19 ± 12% and 13 ± 8% respectively), while the unilaterally trained group increased their right (17 ± 11%) and left (14 ± 14%) UL strengths to a greater extent than the bilaterally trained group (right = 10 ± 18%; left = 11 ± 11%). This finding supports the theory of training specificity indicating that bilateral training is more likely to reduce the BLD and unilateral training is more likely to increase the BLD.

In two separate studies Taniguchi (1997; 1998) trained subjects for six weeks using unilateral and bilateral arm and leg extension. Taniguchi (1997; 1998) quantitatively expressed the BLD as the bilateral index (BI) which is a ratio between summed unilateral and bilateral strengths: BI(%) = 100[Bilateral strength/(Left Unilateral strength + Right Unilateral strength)]-100 (Howard and Enoka, 1991; Taniguchi, 1997; 1998), with a negative BI indicating a BLD. For leg extension in both studies the bilaterally trained group had a positive shift in BI (increased BI 9.3 ± 3.7% (1997) and 6.0 ± 3.7% (1998)). The unilaterally trained group had a negative shift in BI (BI decreased 3.9 ± 2% (1997) and 8.5 ± 3.3% (1998)). Similar trends were seen in the arm extension measurements (Taniguchi, 1997; 1998) as well as handgrip (Taniguchi, 1997). For arm extension, the bilaterally trained group had a positive shift in BI (BI increased 0.1 ± 4.1% (1997) and 1.8 ± 3.1% (1998)) and the UL group had a negative shift in BI (decreased BI 5.0 ± 2.1% (1997) and 1.8 ± 2.1% (1998)). The BLD in handgrip strength was found to decrease with BL training (BI increased 4.0 ± 2.2%) and increase with UL training (BI decreased 1.3 ± 0.9%) (Taniguchi, 1997). In both studies, subjects were trained and tested on the same apparatus and consistently demonstrated specificity to training with regards to changes in the BLD.

Although all of these training studies demonstrated a specific effect of type of training (UL vs. BL) on the BLD (Hakkinen et al., 1996a; Taniguchi, 1997; 1998), the changes in the BLD were quite variable across the different exercises. This may in part be due to the rather short durations (6-12 weeks) of training. One purpose of this thesis is to re-examine this specificity of training on a number of exercises over a longer duration of training (i.e. 24 weeks).

1.2.3.2 Effects of Bilateral and Unilateral Training on Hypertrophy

With a BLD the summed UL strengths is greater than the BL strength during maximal voluntary contraction. If an individual were lifting a greater weight, over a given number of sets and repetitions, there would be a stronger stimulus for hypertrophy. If an individual is exhibiting a BLD during a movement then it is possible that UL training will result in greater increases in muscle mass since more weight can be lifted compared to BL training (Seki and Ohtsuki, 1990). When examining the literature for the effects of BL and UL training on hypertrophy the results are very limited.

Hakkinen et al. (1996a) examined a middle-aged group (age 43-57 years) and an elderly group (age 59-75) of men and women randomized to either UL or BL training of the knee extensors for 12 weeks. The BL and UL training groups both exhibited 10-14% increases in the cross-sectional area of Quadriceps femoris, with no differences between groups. Initially there was not a BLD for knee extension in any of the groups; therefore, theoretically UL or BL training would not make a difference for the action trained (i.e. knee extension).

More research is needed to determine whether UL training is more beneficial than BL training for inducing muscle hypertrophy by examining these two types of training during exercises for which there is a consistent BLD (i.e. leg press). This would have important implications for athletes, but also for groups that are susceptible to muscle loss, such as the elderly. Age-related reduction of muscle mass is discussed in the next section.

1.2.4 Sarcopenia and Ageing

"Sarcopenia, from the Greek meaning poverty of flesh, was a term proposed by Irwin Rosenberg to indicate the loss of muscle mass and strength caused by normal ageing" (Roubenoff, 2001). "Normal" ageing would then contribute to decreases in physiologic capacity (Kirkendall and Garrett, 1998). All the major systems experience a similar reduced capacity and this in turn contributes to weakness, fatigue, slowness and limitations on both daily living and exercise activities (Kirkendall and Garrett, 1998). Both men and women are affected by the ageing process, which leads to structural and functional changes in the neuromuscular system that are quite prominent by the onset of the sixth decade (Aniansson Gustafsson, 1981; Essen-Gustavsson and Borges, 1986; Frontera et al., 1991; Larsson et al., 1978; Lexell et al., 1983; 1988; Vandervoort et al., 1986). A major characteristic of the ageing process is a decrease in muscular size and strength (Tzankoff and Norris, 1977), which in turn will affect function (Borkan et al., 1983; Tzankoff and Norris, 1977). Sarcopenia is thought to be mediated by muscle morphological changes (Aniansson et al., 1981; Aniansson et al., 1986; Essen-Gustavsson and Borges, 1986; Hakkinen et al., 1996a; Larsson et al., 1978; Lexell et al., 1983; 1988), such as a decreased muscle fiber area (size) and/or a decrease in the total number of muscle fibers (Aniansson et al., 1986, Hakkinen et al., 1996a, 1996b, 1997). The fast twitch muscle fibers appear to be particularly affected

(Aniansson et al., 1981; 1986; Essen-Gustavsson and Borges, 1986; Grimby et al., 1982; Larsson et al., 1978; Larsson, 1983; Tomonaga, 1977).

1.2.4.1 The Rate and Pattern of Sarcopenia

Skeletal muscle mass has consistently been reported in the literature to be significantly lower in the elderly (Gallagher et al., 1997), with the cause being unclear. Gallagher et al. (1997) stated a variety of possible mechanisms responsible for the age-related reduction of muscle mass: (1) disuse atrophy; (2) under nutrition and (3) neurogenic and hormonal (growth hormone, insulin-like growth factor I, androgens) mechanisms.

There is a general consensus in the literature that muscle mass does decline with age, but the rate of decline tends to fluctuate. Skeletal muscle mass decreases approximately 30-40% during the course of an individual's life (Grimby et al., 1982; Larsson et al., 1978; 1979) with approximately 10-15% lost per decade after the age of 60 years (Vandervoort, 1992).

There is a close relationship between the patterns of muscle mass and strength losses: until 20-29 years there is a steep increase, with a peak occurring between 25 and 30 years; a maintenance phase occurs until approximately 50 years and; after 50-59 years a steeper decline in both strength and muscle mass is observed (Frontera et al., 1991; Larsson, 1982; Young et al., 1984). The findings of Hakkinen et al. (1996a; 1996b) suggest that the decline is more substantial at the onset of the sixth decade for both men and women.

The cross-sectional area (CSA) of the quadriceps has been shown to be 25% less between the third and the eighth decades (Young et al., 1985). It is thought that muscle mass reductions are accompanied by subsequent increases in intramuscular fat mass and connective tissue with age (Larsson et al., 1979; Overend et al., 1992a; Rice et al., 1990). Therefore muscle mass may be reduced even though the cross-sectional area of the limb is not altered. For this reason, using CSA as a sole measurement of muscle mass can result in misleading conclusions and studies utilizing this method need to be interpreted with caution. A measurement of muscle mass using more sensitive methods such as muscle biopsies, computed tomograghy (CT) scans or dual energy x-ray absorptiometry (DEXA) scans would be more accurate.

The age-related declines in strength appear to be different for a variety of muscle groups (Aniansson et al., 1986; Frontera et al., 1991; Hakkinen et al., 1996b). It is quite possible that this is related to the decreased levels of daily physical activity seen with an ageing population (Hakkinen et al., 1997). The arms and legs are involved in very different movements and with age one might decrease the amount and intensity that they use their legs (walking, climbing stairs, etc) but not their arms (Tzankoff and Norris, 1977; Hakkinen et al., 1995). This difference may also be attributed to "inherent differences in the ageing process between different muscle groups" (Gallagher et al., 1997).

When examining the literature, the lower extremities, particularly the Vastus lateralis, show a greater loss in muscle strength and fibers, especially the fast twitch fibers (Grimby et al., 1982) after the age 60 years (Aniansson et al., 1981; 1986; Essen-Gustavsson and Borges, 1986). The knee flexors and extensors appear to be affected the most by age (Larsson et al., 1979; Tomonaga et al., 1977) with both a reduction in muscle fiber size and strength. It is possible that a decline in leg use, as mentioned in the previous paragraph, would enhance the loss of muscle size and strength of the knee flexors and extensors. A different pattern of loss was observed with gastrocnemius and soleus muscles with a maintenance phase for muscle mass and strength until 60 years, then a dramatic decrease (Kent-Braun and Ng, 1999). The gastrocnemius has a greater composition of fast twitch muscle fibers (Kawakami et al., 1998) and after the age of 60 years, there is a progressive decline in fast twitch muscle fiber area (Aniansson et al., 1981; 1986; Essen-Gustavsson and Borges, 1986). Therefore the general muscle fiber decline coincides with the specific strength declines of gastrocnemius and soleus.

When examining declines in muscle mass and strength a linear pattern was observed with both the arms (Gallagher et al., 1997; Lexell et al., 1988) and legs (Gallagher et al., 1997). Gallagher et al. (1997) measured the appendicular skeleton (arms and legs) and discovered women decreased muscle mass approximately 0.4 kg per decade (10.8% over five decades) and men decreased muscle mass approximately 0.8 kg per decade (14.7% over five decades). Lexell et al. (1988) concluded that there is a 2% decrease in the number of muscle fibers per year and a 3% decrease in muscle strength per year after the age of 25 years for the Biceps brachii. Others have concluded that there is a greater loss of muscle mass and strength of the lower body when compared to the Biceps brachii (Gallagher et al., 1997; Grimby et al., 1982), however the pattern appears to be similar. The magnitude differences between the upper and lower body may be the result of habitual activity differences between the upper and lower body, with the lower body having the greater reductions in activity levels (Tzankoff and Norris, 1977; Hakkinen et al., 1995).

In conclusion, the pattern of decline of muscle mass and strength were similar for the upper and lower bodies; however the rate of decline differed for the upper and lower bodies, as well as for the various muscle groups of the lower extremities. These variations may be the result of differing habitual activities and intensities, fiber composition and the corresponding age-related declines of muscle fiber types.

1.2.4.2 Cause of Age-Related Sarcopenia

The age-related decrease in muscle mass and strength is well accepted in the literature (Borges et al., 1989; Campbell et al., 1973; Essen-Gustavsson and Borges, 1986; Larsson, 1983; Overend et al., 1992a; 1992b); however, the cause of the decline remains controversial. Some studies have found that either muscle fiber atrophy (Aniansson et al., 1986; Grimby et al., 1982) or a decrease in number of muscle fibers (Lexell et al., 1983) is the contributing factor while others have concluded that they both contribute to the changes (Larsson et al., 1979).

Both denervation and physical inactivity can lead to changes in muscle fiber morphology (Hakkinen et al., 1996b). These changes seem to be accelerated after the age of 70 years (Aniansson et al., 1986). Motor neuron abnormalities may lead to a selective atrophy and the loss of muscle fiber quantity (Campbell et al., 1973; Grimby et al., 1982; Tomonaga et al., 1977). Lexell et al. (1988) proposed that the neurons might lose contact with the muscle fibers, which would lead to irreparable damage and possible death of the muscle fiber. The fast (type II) motor neurons and muscle fibers may be preferentially lost during ageing, as suggested by Campbell et al. (1973). If so, one would expect to see a corresponding decrease in strength and muscle mass with muscles that have a greater proportion of fast twitch muscle fibers (eg. Gastrocnemius). This has been documented in the literature as discussed previously.

Decrease in Muscle Fiber Size

The decrease in CSA of whole muscle with age has been attributed to a decrease in muscle fiber size (Grimby et al., 1982). It appears that the fast-twitch muscle fibers are more affected by sarcopenia (Hakkinen et al., 1995; 1996b). After the age of 60 years, there is a progressive decline in the fast twitch muscle fiber area, but not the slow twitch fiber area (Aniansson et al., 1981; 1986; Essen-Gustavsson and Borges, 1986). Furthermore, after 70 years, there tends to be an accelerated decline of fast twitch fibers (Aniansson et al., 1986). The decrease in fast twitch fiber size may be partly explained by disuse and a decline in physical activity levels (Aniansson et al., 1981; 1986). More specifically, a decrease in high intensity activity may result in a preferential decrease in fast twitch fiber size since this type of activity is necessary for the recruitment of these fibers.

If the upper body and lower body do in fact have different patterns and rates of sarcopenia, then it is realistic to expect the muscle morphology to differ as well. In order to determine muscle morphology changes, Grimby et al. (1982) and Aniansson et al. (1986) examined differences between Vastus lateralis and Biceps brachii in men and women over 70 years. They discovered that the fiber area for the fast twitch fibers decreased in the Vastus lateralis muscle but not in the Biceps brachii. The fiber composition remained unchanged in both muscle groups, which could lead to the conclusion that the fiber size, not number, is decreasing with age or that slow and fast twitch muscle fibers are decreasing at the same rate. One needs to be cautious of accepting this as the sole causative agent of sarcopenia since there is also strong evidence for the decline of number of muscle fibers.

Decrease in Muscle Fiber Number

There are two possible mechanisms by which muscle fibers are lost with ageing: 1) the muscle fibers may become denervated which would result in their degradation and 2) the fibers may get injured some way and then die off (Lexell et al., 1983). Lexell and colleagues (1983) counted fibers from whole-muscles during autopsies and concluded that the total number of muscle fibers declined between 30-70 years of age. This progressive loss of fibers is thought to affect primarily the fast twitch fibers (Larsson et al., 1978; 1979).

It is postulated that the motor neuron that innervates the fibers dies off (Campbell et al., 1973) which leads to muscle fiber atrophy and eventually, death. A shift in fiber composition has been observed so that the amount of slow twitch fibers increased while the fast twitch fibers decreased (Larsson et al., 1978). It was reasoned that this decline in the fast twitch fibers might have been caused by selective denervation (Larsson et al., 1978). In order to preserve as many of the muscle fibers as possible, collaterals from the remaining slow twitch motor neurons expand to the denervated muscle fibers (Kirkendall and Garrett, 1998; Roubenoff, 2001), which could lead to fiber type conversion to a slower isoform (Grimby et al., 1982). This would result in a greater proportion of slow muscle fibers and consequently a lower potential for strength production. Slow twitch muscle fibers are typically slow contracting, fatigue resistant, and have lower strength output, as compared to fast twitch muscle fibers (Kirkendall and Garrett, 1998).

It seems unlikely that there would be a sole contributor to sarcopenia. With increasingly sedentary patterns the muscle fibers would be used less often, especially the fast muscle fibers that are responsible for rapid movements. It is possible that with the ageing process there is selective death of the motor neurons that innervate the fast twitch fibers; therefore, these fibers would atrophy and eventually die off. A decrease in muscle fiber size may occur as the result of motor neuron death (i.e. atrophy), prior to muscle fiber death. Therefore, it is likely that it is the combination of decreased muscle fibers size and numbers that contribute to the loss of muscle mass and strength.

Previously, subjects from the current study were included in a larger sample, which was compared to young women for muscle mass (Chilibeck et al., 2000a; 2000b) and strength differences (Chilibeck et al., 2000b). The lean tissue mass (Chilibeck et al., 2000a; 2000b) and the strength (Chilibeck et al., 2000b) of the older women were significantly less than the younger women. Therefore the women of our study have already begun to demonstrate age-related decreases in muscle mass and strength.

1.2.5 Capacity of Ageing Muscle for Increasing Strength and Hypertrophy

Strength training can serve as an effective intervention to prevent and/or reverse the effects of age-related atrophy and diminished strength (Charette et al., 1991; Chrusch et al., 2001; Fiatarone et al., 1990; 1994; Frontera et al., 1988; Hakkinen et al., 1995; Klitgaard et al., 1990; Treuth et al., 1994). Many studies have shown that older men and women still retain the capacity to increase their muscular strength 93-174% (Charette et al., 1991; Fiatarone et al., 1990; Frontera et al., 1988, Nichols et al., 1993), which can have strong implications for individuals who have significantly decreased muscle strength and mass.

The findings of various authors (Charette et al., 1991; Fiatarone et al., 1990; Frontera et al., 1988) indicate that with sufficient training volume, ageing muscle is capable of strength increases. Frontera et al. (1988) examined knee extensor strength training in males 60-72 years and found that after 12 weeks of training there was a 107% increase in their one repetition maximum (1-RM). Fiatarone et al. (1990) found a 174% increase in 1-RM after eight weeks of knee extension strength training in an extremely elderly population (mean age 90 $\pm$ 1 yr). As well, Charette et al. (1991) demonstrated a 93% increase in women's knee extension 1-RM after 12 weeks of strength training (mean age 69 $\pm$ 1.0 yr). The large increases that can be observed after a relatively short period of time may be due to an initially low training state, but demonstrate that older muscle is still very adaptable.

Older individuals retain a capacity for hypertrophy and neuromuscular responses to strength training, which is similar to younger individuals (Cureton et al., 1988) when the load, intensity and duration of the strength training are sufficient (Brown et al., 1990; Charette et al., 1991; Frontera et al., 1988; Hakkinen et al., 1995; 1996a; Kirkendall et al., 1998; Pyka et al., 1994; Treuth et al., 1994). Muscle size has been shown to increase up to 17% (Brown et al., 1990; Hakkinen et al., 1996a) with size increases in both the slow and fast twitch muscle fibers (Pyka et al., 1994), particularly the fast twitch (Charette et al., 1991; Pyka et al., 1994). As a result, this could enhance an older individual's performance and strength of quick movements with short durations, such as lifting an object or standing up from a chair, since these movements are more dependent on fast twitch muscle fibers.

In order to determine the effects of strength training on hypertrophy and body composition Nichols et al. (1993) and Ryan et al. (1995) used DEXA measurements with older women (50-69 years). Nichols et al. (1993) concluded there was a 4% increase in lean body mass after 24 weeks of training and after 16 weeks of training Ryan et al. (1995) found a 3% increase in lean body mass. These findings demonstrate the effectiveness of strength training in older women for eliciting hypertrophy and add support to the notion that older individuals still retain this ability. This could possibly have a large impact for program prescription, as well as motivation for an older individual to initiate a training program.

The capacity for hypertrophy in older individuals appears to differ across muscle groups. The potential for hypertrophy of the knee extensors was found to be unaffected by age while the hypertrophic capacity of the elbow and knee flexors appear to be compromised with age (Welle et al., 1996). There is uncertainty as to why there would be a limitation with hypertrophy of the knee flexors but not the knee extensors since both are equally affected by age in regards to muscle size and strength. As well, the reason for the reduced hypertrophy of the elbow flexors is unclear since the lower, not upper, body is the most affected by age (Aniansson et al., 1986; Grimby et a., 1982). It is possible that the type of training that was used in the study is an important factor. A whole body regimen could minimize the gains of a single muscle group as compared to focusing on one or two groups (Campbell et al., 1995). Therefore comparisons of studies may be limited due to variations of the training programs and the results should not be generalized to all muscles.

Some authors concluded that older individuals have a reduced hypertrophic response; however the length of the training program may also be a factor. Hypertrophy does not usually occur with the early, rapid gains in muscular strength (Campbell et al., 1995; Cureton et al., 1988; Fiatarone et al., 1994; Welle et al., 1996). Instead, initial strength increases are mainly due to neural adaptations, with hypertrophy contributing to strength three to five weeks later (Chilibeck et al., 1998; Moritani and deVries, 1979). This is supported by the findings of Young et al. (1983) and Luthi et al. (1986) when they found that there were dramatic strength increases but the muscle size at the time of measurement had only increased slightly. These early strength gains may be the result of the nervous system adapting to the new stimulus by possibly increasing motor neuron activation and motor unit synchronization (Sale, 1988). EMG measurements indicate that both motor neuron activation (Moritani and deVries, 1979) and motor unit synchronization (Milner-Brown et al., 1975) increase following strength training. These neural adaptations always occur within the first few weeks of the training program, before the onset of hypertrophy and it is plausible that they are a necessity for hypertrophy (Sale, 1988).

A second possible explanation for a lack of hypertrophy observed in some studies may be a lack of precision in the methods used for assessing hypertrophy (i.e. girth measurements) (Moritani and deVries, 1979; 1980). When more sensitive measures of muscle tissue are used (biopsies, CSA by CT scans, DEXA), muscle hypertrophy accounts for a portion of the strength gains in the elderly (Fiatarone et al., 1990).

The subjects of our study have been previously compared to a group of younger women, as reported earlier. From the strength and lean tissue mass results, it was concluded that the older women had experienced declines in both strength and muscle mass, which were at least in part due to age-related changes. It is expected that the women of our study will increase their strength and this will be at least partly due to hypertrophy. Neural factors may also be playing a role in the strength increases, however they are not being directly measured. Instead DEXA, which is a sensitive instrument for assessing lean tissue mass, will be used to determine muscle hypertrophy. Six months should be long enough for the neural adaptations to occur therefore the study length may also help to determine the role hypertrophy plays in increasing muscle strength.

1.2.6 Training Considerations for Older Women

It has been demonstrated that healthy older people can safely engage in sustained strength training programs of moderate intensity (Pyka et al., 1994) that involves a whole body regimen (Charette et al., 1991). Throughout the literature, most training studies use progressive strength training (Charette et al., 1991; Fiatarone et al., 1990; 1994; Frontera et al., 1988; Hakkinen et al., 1996a; Pyka et al., 1994) with both concentric (lifting) and eccentric (lowering) contractions. The majority of the strength training programs were either 8 or 12 weeks. Many participants may be severely deconditioned and may have muscloskeletal limitations therefore it was quite common for the intensity to initially be set at a low level, approximately 50% of their 1-RM (Alison and Keller, 1997). Intensity is usually then progressively increased to approximately 70-80% of their 1-RM for the remaining weeks of the program (Frontera et al., 1988). This is done so the training stimulus (intensity and duration) is sufficient enough to increase muscle mass and strength (Hakkinen et al., 1996a).

The program should emphasize whole body training (Ebben and Jensen, 1998) with possibly a greater focus on leg strength. This recommendation is based on the finding that elderly people tend to have the greatest loss of muscle strength and size in their legs (Gallagher et al., 1997), due to a reduction in use. The upper body (arms) is thought to have the least amount of change in habitual activity with age (Tzankoff and Norris, 1977) therefore changes in this area are not as great. As people age they seem to take the stairs less often or not walk as far, whereas activities such lifting and carrying objects may not be reduced as much.

There are two major considerations when dealing with an older female population and exercise. The first consideration is that they will have a reduced maximal exercise capacity and secondly, there will be an increased occurrence of conditions that may possible limit their tolerance (Alison and Keller, 1997) such as osteoarthritis, fibromyalgia, osteoporosis or cardiovascular disease. It is important to ensure that the program includes multi-joint, functional exercises, which the participants are capable of performing (Alison and Keller, 1997; Ebben and Jensen, 1998). The functional exercises will help to improve their coordination, proprioception and balance (Ebben and Jensen, 1998).

In conclusion, ageing individuals are fully capable of participating in general physical activity and regimented exercise programs. However, due to possible reductions in exercise capacity and limiting conditions, each program should be realistic and individually tailored to meet the needs and capabilities of the participant. In regards to our study, our training program follows the suggestions of Alison and Keller (1997) for the progression of exercise intensities and a whole body training to ensure the program is safe and maximally beneficial to the participants.

1.2.7 Limitations in the Literature

There are a number of limitations in the literature, mainly concerning the lack of investigation into the occurrence of BLD in older populations, trainability of the BLD and the optimal program for increasing muscle mass in older individuals.

A shortcoming in the literature is the limited study population. In regards to the BLD literature, the majority of study samples comprised young individuals, particularly college aged males, and generalizations can only be made to this population. There are only two groups of investigators that have examined the occurrence of a BLD in an ageing population (Hakkinen et al., 1995; 1996a; 1996b; 1997; Owings and Grabiner, 1998) and their results are equivocal. If there is in fact a strength limitation during BL contractions, then this could influence methods used to increase an older individual's strength.

There is also a limited amount of research regarding the trainability of the BLD. The studies, which have investigated this aspect of the BLD, have conclusively shown that the BLD can be decreased with BL training and increased with UL lateral training.

This can be applied to both ageing and athletic populations since they can train for specific movement patterns (i.e. for ageing: UL: walking; BL: carrying objects; for athletes UL: throwing; BL: rowing). It is unclear to what extent the BLD can be changed due to the short length of existing studies. A study of longer duration is therefore needed.

The ability for ageing muscle to adapt to an increased workload has been shown repeatedly in ageing individuals. However, the optimal program for increasing muscle size has not been determined. If unilateral contractions allow greater strength output, compared to bilateral contractions, then perhaps unilateral training would be most beneficial.

1.3 Statement of the Problem

A limited number of studies have been conducted which have examined the trainability of the BLD. The few studies that have been done generally focused on a younger, particularly male, population and are short in duration. As well, the optimal program for increasing muscle mass in older individuals has not been established. The purpose of this study is to examine the effects of BL and UL training on the BLD as well as on the capacity of ageing women to increase their muscle mass and strength using UL compared to BL training.

1.4 Research Hypotheses

1.4.1 The changes in BLD will be specific with training; BLD will be reduced with BL training (BI will move in the positive direction); and the BLD will increase with UL training (BI will move in the negative direction).

1.4.2 The UL training group will show a greater increase in muscle mass since a strength deficit occurs during BL contractions (Seki and Ohtsuki, 1990).

CHAPTER 2

Methods

2.1 Subjects

Twenty-nine women who were not previously involved in formal strength training were recruited from the Saskatoon area. Newspaper ads and posters were used to recruit participants. The subjects were also participating in another study examining bone mineral density. The exclusion criteria are from the larger bone study and included hormone replacement therapy or bisphosphonates, medications such as thyroid medications, diuretics, or corticosteroids (all which affect bone) and diseases that affect bone such as Crohns Disease and Cushing Disease. Also severe osteoporosis (a bone mineral density greater than 2 standard deviations below the age-matched mean) was an exclusion criterion. All subjects were Caucasian, with an age range of 45 to 74 years, and there were three subjects in the bilateral group and one subject in the unilateral group who were limited by knee osteoarthritis. As well, the menopause status (years post menopause) of the groups was 7.3 ± 8.1 years (range 1-29 years) for the bilateral group and 6.9 ± 7.1 years (range 1-24 years) for the unilateral group.

The purpose of this study and the possible benefits and risks of participation were explained to the subjects. The participants filled out a consent form (Appendix H). The subjects were randomly assigned to either a bilateral or a unilateral training group. The study was approved by the University of Saskatchewan Ethics Committee and supported by the Health Sciences Utilization Research Commission, Saskatchewan.

The physical characteristics of the subjects are presented in Table 2.1. There were initially 29 subjects who began the study and the subjects were randomly assigned to either the bilateral ($n = 16$) or unilateral ($n = 13$) training group. Of the 29 participants who started the program, 26 (BL group, $n = 14$; UL group, $n = 12$) completed all six months of training. Lack of time and interference with work were reasons for two of the dropouts and the third participant broke her ankle in an accident unrelated to the training program. A one-factor ANOVA showed no significant differences between groups for age, $F(1,24) = 0.105$, $p = 0.748$, height $F(1,24) = 0.002$, $p = 0.963$, and weight, $F(1,24) = 0.047$, $p = 0.831$.

Table 2.1 Age, Weight and Height of Participants

	BL Group (n = 14)	UL Group (n = 12)
Age (yr)	55.8 ± 8.2	54.8 ± 6.5
Weight (kg)	71.5 ± 13.4	70.3 ± 13.7
Height (cm)	164.6 ± 4.4	164.7 ± 5.9

Note. No significant differences between the groups.
Values are means ± SD.

2.2 Research Procedures

2.2.1 Measurements

Strength. The one repetition maximum (1-RM) of bilateral and unilateral strengths were assessed before and after training, on a Hammer Strength machine for leg press (LP) and knee extension (KE) and a Pulse machine for lat pulldown (LAT). The machines had split lever arms, which allowed the subjects to do either unilateral or bilateral testing. The machines involved in testing were altered so that the leg press, knee extension and lat pulldown machines had plates to join the levers together for bilateral testing. The orders of the bilateral and unilateral efforts were randomized. The test order of the machines was consistent with the leg press first, lat pulldown second and knee extension last. A standard warm-up consisted of riding a cycle ergometer for five minutes followed by leg and arm stretches. In order to familiarize the subjects with the movements a warm-up was done on each machine before the 1-RM testing. The subjects performed 10 repetitions at a light weight and then a couple of single repetitions at progressively heavier weights (still below their maximum though). During the 1-RM testing, with each successful attempt the weight was increased two-ten kg, depending on the ease with which the subject performed the movement. It took approximately six-eight attempts to reach the participant's 1-RM. A successful attempt for the leg press and knee extension included the subjects extending their legs to the required position. The seat for leg press was adjusted so the participant's knees were in approximately 90° of flexion. A hip belt was worn during the leg press and knee extension tests to try to eliminate excessive hip movement. For the knee extension and leg press, the subjects had to move from approximately 90° to 10° of flexion. A successful attempt for leg press included the subject being able to extend her legs to approximately 10° of flexion. For knee extension there were stoppers placed at the top end of the range of motion (approximately 10° of flexion) and the subjects had to touch the stoppers for a successful attempt. For lat pulldown, the participants started with their arms above their head with a slight bend in their elbow joint. The seat was adjusted to a height, which made the elbow position possible. For a successful attempt the participant had to pull the lever down to their chin. During each of the tests, there was a two-minute rest interval between each attempt to avoid muscle fatigue. The precision (reproducibility) of 1-RM testing was determined on ten of the women for measures of leg press and lat pulldown and for eight women for knee extension, as presented in Table 2.2. This involved performing the strength tests on two separate days, one week apart. To calculate reproducibility, the method error of repeated measurements was used, expressed as a coefficient of variation (Chilibeck et al., 1994). For bilateral leg press and unilateral leg press the coefficients of variation were 3.0% and 2.7%, respectively. For bilateral knee extension the coefficient of variation was 4.3% and for unilateral knee extension the coefficient of variation was 3.7%. The coefficient of variation was 1.9% for both bilateral and unilateral lat pulldown. The level of precision is deemed sufficient to demonstrate the expected changes in strength with training (Charette, et al., 1991) with sufficient statistical power.

Table 2.2 Reproducibility of Strength Measures for Bilateral and Unilateral Test Exercises in Women on Two Separate Days One Week Apart

	Mean Value (and SD)				ME expressed as CV%*
	Day 1		Day 2		
Bilateral Leg Press (n = 10)	136	(20)	134	(18)	3.0%
Unilateral Leg Press (n = 10)	79	(23)	81	(22)	2.7%
Bilateral Knee Extension (n = 8)	44	(14)	45	(14)	4.3%
Unilateral Knee Extension (n = 8)	25	(7)	25	(6)	3.7%
Bilateral Lat Pulldown (n = 8)	40	(12)	40	(12)	1.9%
Unilateral Lat Pulldown (n = 10)	28	(7.7)	28	(7.7)	1.9%

Note. *ME = method error; CV = coefficient of variation

Dual Energy X-ray Absorptiometry. Bone mineral free lean tissue mass was assessed by dual energy x-ray absorptiometry (DEXA) on a Hologic QDR 2000 densitometer both before and after training for whole, lower and upper (arms and trunk) body at the Department of Nuclear Medicine in the Royal University Hospital. All scans were performed by qualified personnel and analyzed by the same individual to reduce variability. The participants laid in a supine position within the specific boundaries marked on the table with a soft tissue standard placed beside them while the machine scanned them from head to toe. The precision (reproducibility) of lean tissue mass for both the whole body and segmental scans on DEXA-Hologic QDR 2000 have been determined previously on a group of 10 subjects (Wallace, 1995). To calculate reproducibility, the method error of repeated measurements was used, expressed as a coefficient of variation. The coefficients of variation were 4.1% for the arms, 1.19% for the legs, 0.67% for the trunk and 0.54% for the whole body. This level of precision is deemed sufficient to demonstrate the expected changes in lean tissue mass with training (Chilibeck, et al., 1998) with sufficient statistical power (Chilibeck, et al., 1994).

2.2.2 Strength Training

The strength training was supervised at the University of Saskatchewan College of Kinesiology Strength Training Laboratory. The subjects trained three times per week for six months. The training session exercises included leg press, knee extension, lat pulldown, biceps curl, hamstring curl, shoulder press, chest press, back extension, and hip extension, flexion, adduction, and abduction. Each exercise was performed with eight to ten repetitions for two sets. A rest interval of two minutes between each set was included. The machines had split lever arms, which allowed the subjects to do either unilateral or bilateral training. A plate joining the levers together was kept on the leg press and lat pulldown machines for the bilateral workouts. The training weights for the bilateral participants for these two exercises were adjusted to include the weight of the plates. The knee extension machine also had a plate to join the levers together for bilateral testing, but the plate was kept off the machine during training because it was very difficult to attach and remove.

For the first two to three weeks of training there was an accommodation period. During this time the subjects performed only one set of 12 repetitions for each exercise. The weights for the leg press, lat pulldown and knee extension were approximately 50-60% of the subjects' 1-RM. For the other nine exercises, a weight was selected which allowed the subjects to perform 12 repetitions. After the subject completed three training sessions a second set of one exercise was added for the fourth session. After that a second set of one exercise was progressively added until each of the 12 exercises were performed with the required two sets. The weight was adjusted in accordance to the individual's strength increases so the subject was only able to perform eight to ten repetitions. Once the subject was able to perform ten repetitions with good form, the weight was increased by 1.1 kilograms per side. The subjects were supervised during every training session to ensure proper form and lifting techniques. As well, after an exercise was increased, the subject was closely monitored to ensure that lifting technique was not compromised. Training logs with the amount of weight and numbers of repetitions were kept for every training session.

2.3 Data Analysis

The Bilateral Index (BI), which is a ratio between bilateral and unilateral strengths, was calculated from the left unilateral, right unilateral and bilateral 1-RM values. The BI is computed as:

BI (%)= 100[bilateral strength/(right unilateral strength + left unilateral strength)]-100 (Howard and Enoka, 1991; Taniguchi, 1997; 1998).

A negative index will indicate the bilateral strength is less than the sum of unilateral strengths (i.e. bilateral deficit). A positive index will indicate the bilateral strength is greater than the summed unilateral strengths (i.e. bilateral facilitation). (Taniguchi, 1997).

2.4 Statistical Analysis

This study involved a within and a between subjects design. The independent variables were time (before training vs. after training) and group (BL group vs. UL group). The dependent variables were bilateral index and bone mineral free lean tissue mass.

There were two hypotheses for this study: 1) Changes in the BLD will be specific with training; BLD will be reduced with BL training (BI will move in the positive direction); and the BLD will increase with UL training (BI will move in the negative direction); and 2) It is expected that the UL training group will show a greater increase in muscle mass since there is a strength deficit during BL contractions (Seki and Ohtsuki, 1990).

Statistical analysis was performed using the software program SPSS Professional Statistics 6.1, for Windows. An alpha level of < 0.05 was used for all statistical tests. Descriptive statistics were used to examine the physical characteristics of age, height and weight. The changes in BI (for leg press, knee extension and lateral pulldown) and bone mineral free lean tissue mass (for whole, lower and upper body) between groups were assessed with two-factor analysis of variance (ANOVA) with repeated measures on the second factor (time, pre/post training). Changes in training load (percentage of pre-training 1-RM) between groups were assessed with a two-factor analysis of variance with repeated measures on the second factor (time, pre/mid/post training). A one-factor ANOVA was used to analyze differences between groups for pre strength measures, pre BI (LP, LAT, KE), pre bone mineral free lean tissue mass (whole, lower and upper body), attendance, weight, height and age. To determine if the BI was significantly different from zero, a dependent (one-sample) t-test was used to assess baseline BI for leg press, knee extension and lat pulldown exercises. If the BI was significantly different than zero, this would indicate there was a BLD for that exercise.

CHAPTER 3

Results

The purpose of the study was to determine the effects of BL and UL strength training on the BLD (as measured by the Bilateral Index) and bone mineral free lean tissue mass. It was hypothesized that changes in the BLD would be specific with training; (1) the BLD would be reduced with BL training (BI would move in the positive direction) and (2) the BLD would be increased with UL training (BI would move in the negative direction). The second hypothesis was that the UL training group would show a greater increase in muscle mass since a strength deficit occurs during BL contractions (Seki and Ohtsuki, 1990).

3.1 Baseline Measures

An ANOVA of the baseline 1-RM strength measures and the BI showed no difference between groups for all exercises tested ($p > 0.05$). There were no baseline differences between groups for age, height and weight ($p > 0.05$) (Table 2.1). There were no baseline differences between groups for whole ($p = 0.938$), lower ($p = 0.934$), and upper ($p = 0.798$) body measurements of bone mineral free lean tissue mass. A dependent (one-sample) t-test determined that the baseline BI for leg press ($-12.7 \pm 6.9\%$) and lat pulldown ($-8.8 \pm 7.8\%$) was significantly different from zero ($p = 0.001$)

indicating a BLD for these exercises. The baseline knee extension BI (-4.3 ± 12.6%) was not significantly different from zero ($p = 0.095$).

3.2 Bilateral Index

Leg Press

There was a group x time interaction for the bilateral index for the leg press, $F(1,24) = 4.904$, $p = 0.037$. The BI for LP increased 4.4 ± 2% for the BL group ($p < 0.05$) and decreased 1.1 ± 4.7% for the UL group ($p > 0.05$), as shown in Figure 3.1. Tukey post-hoc testing indicated that the BI for the LP increased significantly in the BL group and that BI after training was significantly different between groups ($p < 0.05$).

Knee Extension

There was a time main effect for the bilateral index for knee extension, $F(1,24) = 8.008$, $p = 0.009$. There was a group x time interaction for the bilateral index for the knee extension, $F(1,24) = 9.956$, $p = 0.004$. The BI for KE increased 14.9 ± 5.7% for the BL group ($p < 0.05$) and decreased 0.1 ± 1.3% for the UL group ($p > 0.05$), as shown in Figure 3.2. Tukey post-hoc testing indicated that the BI increased significantly with training in the BL group and that the BI after training was significantly different between groups ($p < 0.05$).

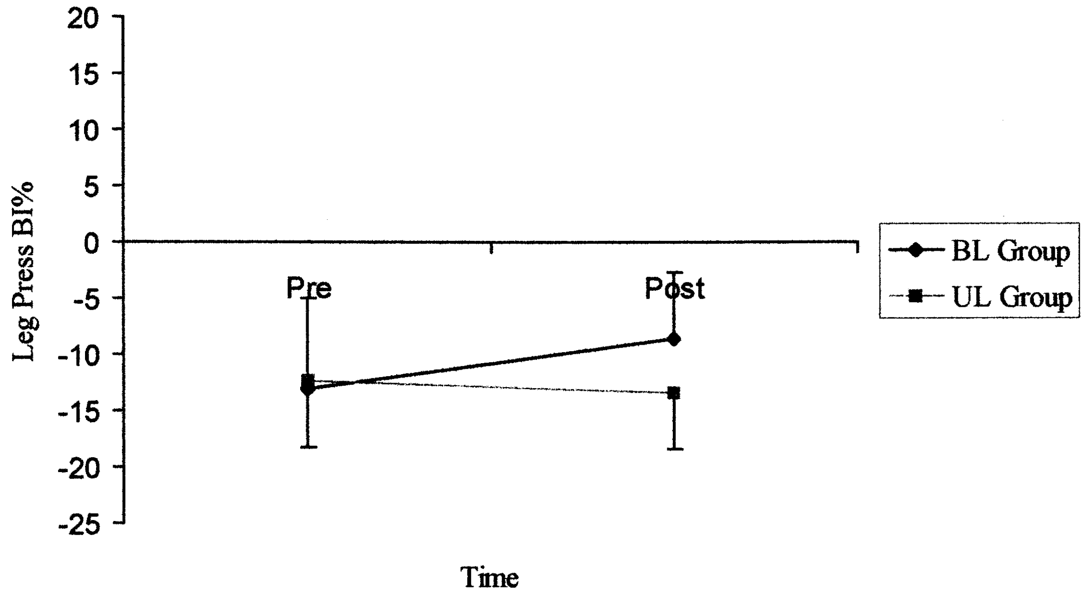

Figure 3.1. Changes in Bilateral Index (BI%) for Leg Press of the BL and UL Training Groups

BL group increased the BI significantly ($p < 0.05$)
BI after training was significantly different between groups ($p < 0.05$).

Note. Error bars on all graphs represent standard deviation (SD).

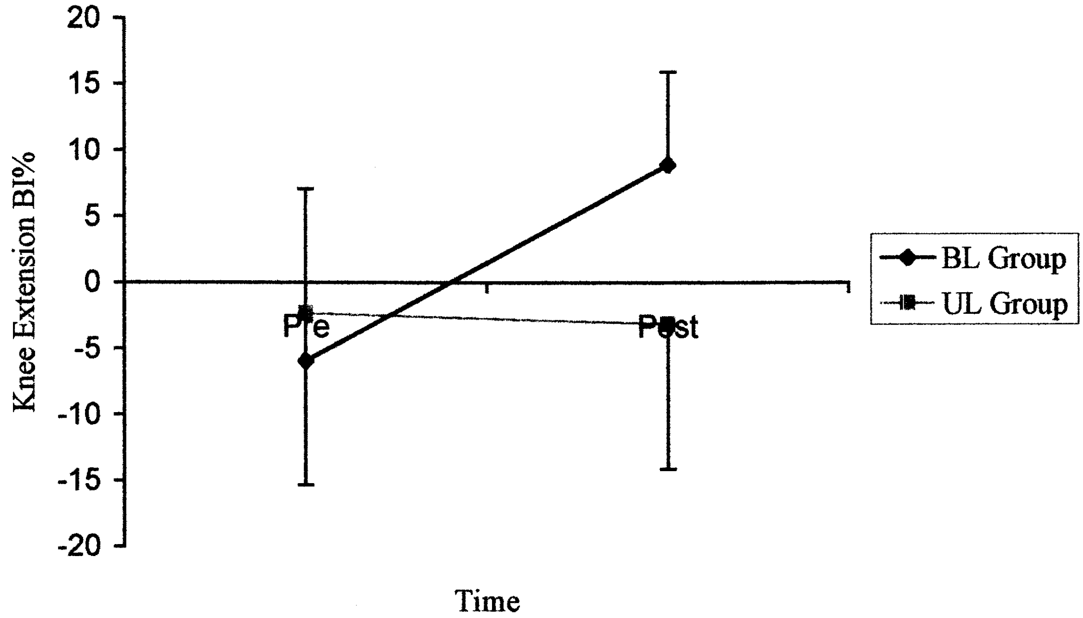

Figure 3.2. <u>Changes in Bilateral Index (BI%) for Knee Extension of the BL and UL Training Groups</u>

BL group increased the BI significantly ($p < 0.05$)
BI after training was significantly different between groups ($p < 0.05$).

Lat Pulldown

There was a group x time interaction for the bilateral index for the lat pulldown, $F(1,23) = 9.116$, $p = 0.006$. When the data was examined there was an outlier for this test and the subject was excluded from this analysis. From the adjusted data, the BI for lat pulldown increased $2.9 \pm 5.1\%$ for the BL group ($p > 0.05$) and decreased $3.9 \pm 3\%$ for the UL group ($p > 0.05$), shown in Figure 3.3. Tukey post-hoc testing indicated that BI was significantly different after training between the groups ($p < 0.05$).

3.3 Bone Mineral free Lean Tissue Mass

Bone mineral free lean tissue mass for the whole, lower and upper body increased to a similar extent over time for both BL and UL groups (group x time, $p > 0.05$). The only group x time interaction that approached significance was for the lower body ($p = 0.097$). There was a time main effect for whole body ($p = 0.000$), lower body ($p = 0.000$) and upper body ($p = 0.001$) measures of bone mineral free lean tissue mass, shown in Figures 3.4, 3.5 and 3.6 respectively.

3.4 Strength Measures

All measures for bilateral and unilateral strength before and after training are shown in Table 3.1. There was a significant time main effect for each measure ($p < 0.05$) but no group x time interactions.

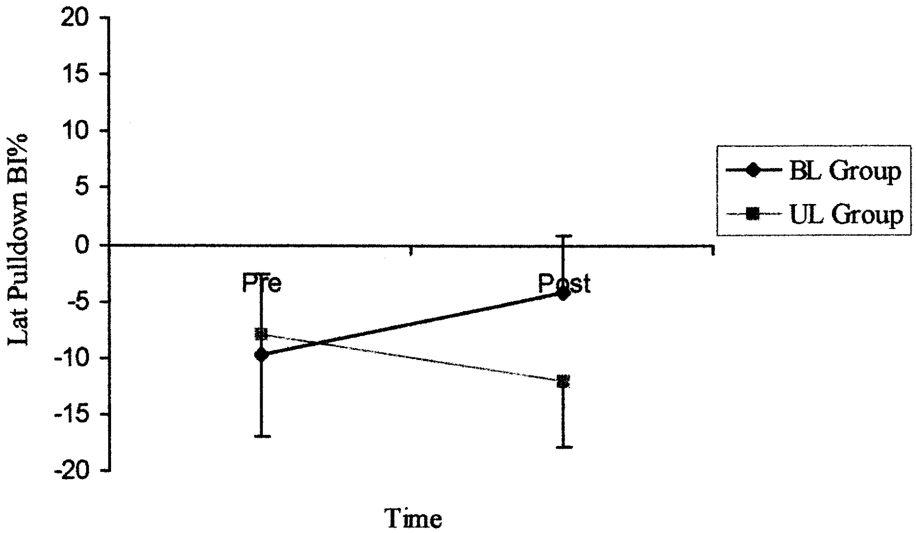

Figure 3.3. <u>Changes in Bilateral Index (BI%) for Lat Pulldown of the BL and UL Training Groups</u>

BI after training was significantly different between groups ($p < 0.05$).

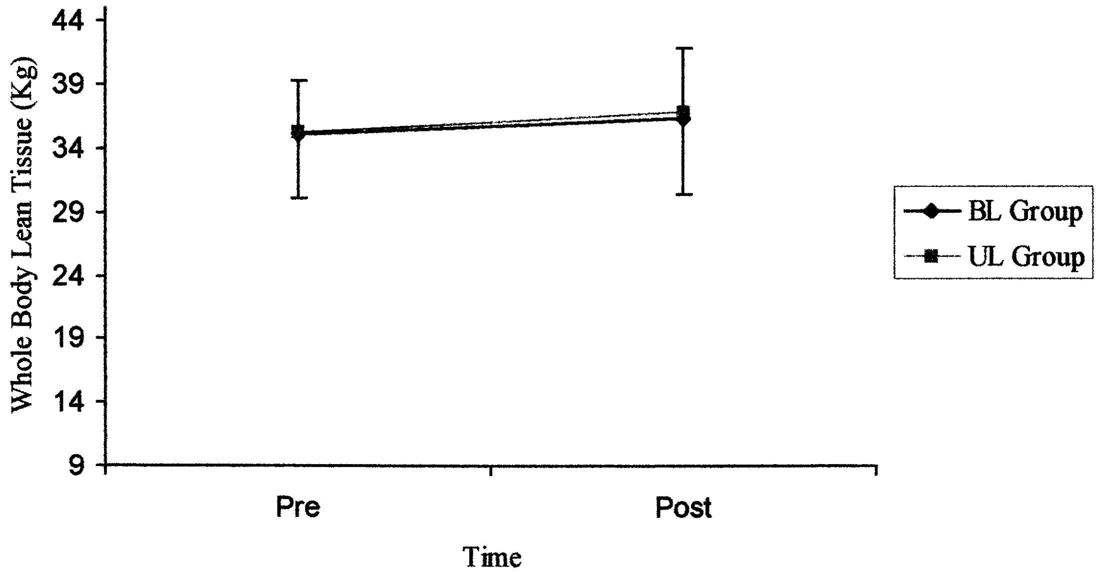

Figure 3.4. <u>Changes in Whole Body Bone Mineral free Lean Tissue Mass of the BL and UL Training Groups</u>

Time main effect ($p = 0.000$)

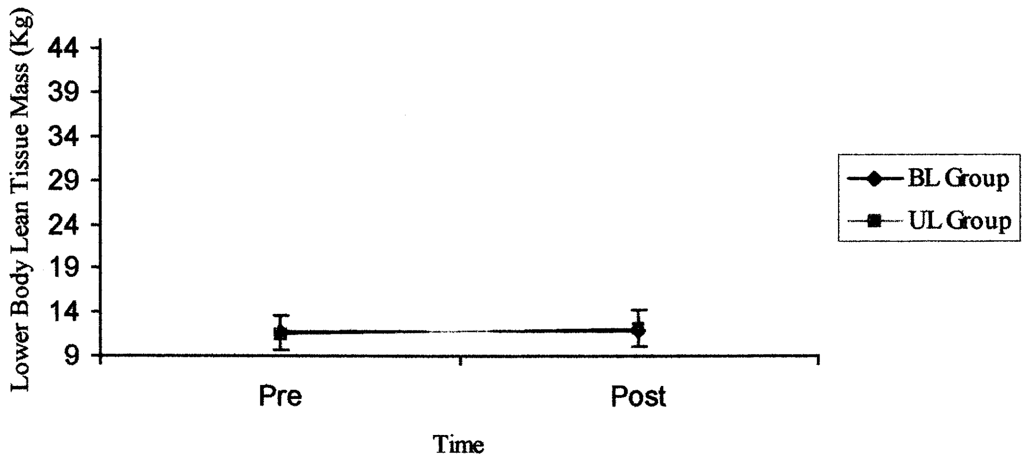

Figure 3.5. Changes in Lower Body Bone Mineral free Lean Tissue Mass of the BL and UL Training Groups

Time main effect (p = 0.000)

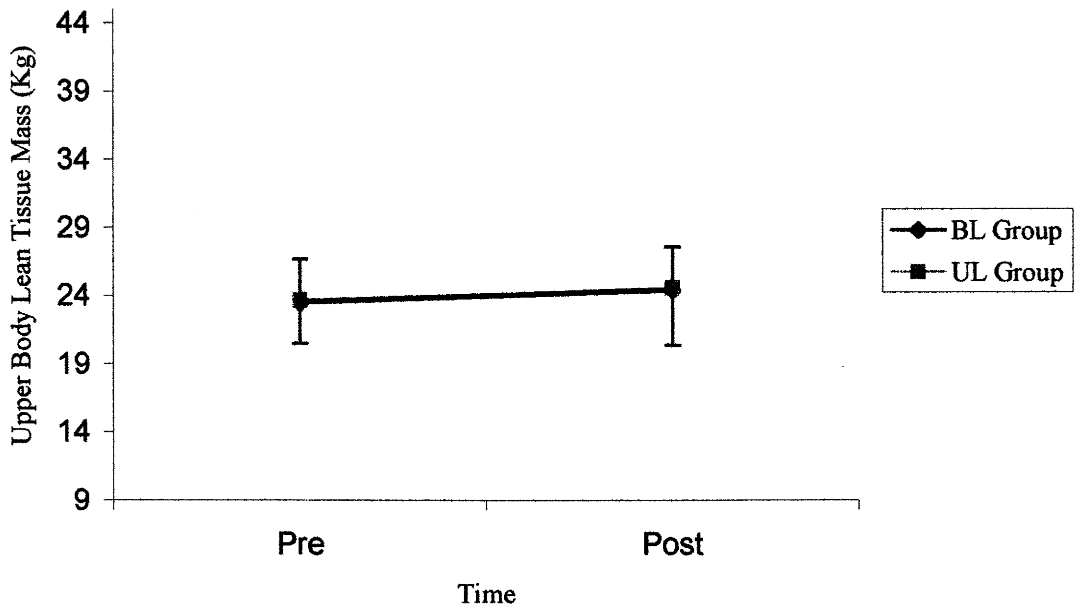

Figure 3.6. Changes in Upper Body Bone Mineral free Lean Tissue Mass of the BL and UL Training Groups

Time main effect ($p = 0.001$)

3.5 Training Load

A two-factor ANOVA showed that there was no difference between groups for the training load for leg press and lat pulldown ($p > 0.05$) but the groups did differ for the knee extension training load ($p = 0.045$), with the UL group having a higher load at all three measurements (time, pre/mid/post test) for knee extension (UL Group: pre = 53.16 ± 8.43%, mid = 72.15 ± 12.10%, post = 86.86 ± 17.05%; BL Group: pre = 46.61 ± 11.99%, mid = 63.42 ± 23.27%, post = 66.76 ± 25.50%). There was a significant time main effect for each measure ($p = 0.000$).

3.6 Attendance

A one-way ANOVA showed that there was no difference between groups for attendance $F(1,23) = 2.418$, $p = 0.134$. The UL group had an attendance rate of 82% (range = 63.8% to 97.1%) while the BL group had an attendance rate of 76% (range = 57.7% to 95.7%).

Table 3.1 Pre and Post Strength Measures for Bilateral and Unilateral Test Exercises

	BL Group		UL Group	
	Pre (n = 14)	Post (n = 14)	Pre (n = 12)	Post (n = 12)
BL Leg Press (kg)	113.46 ± 36.09	146.72± 40.81	98.73 ± 27.77	124.65 ± 32.95
UL Right Leg Press (kg)	65.10 ± 19.10	80.44 ± 20.18	55.78 ± 13.38	71.88 ± 18.60
UL Left Leg Press (kg)	64.04 ± 19.19	79.16 ± 20.84	56.34 ± 14.78	71.41 ± 14.71
BL Knee Extension (kg)	36.91 ± 11.98	47.96 ± 11.62	37.28 ± 8.25	50.93 ± 15.48
UL Right Knee Extension (kg)	20.21 ± 5.25	22.96 ± 5.18	19.42 ± 4.74	26.58 ± 10.62
UL Left Knee Extension (kg)	18.52 ± 5.86	21.26 ± 6.85	19.42 ± 4.74	27.46 ± 11.27
BL Lat Pulldown (kg)*	38.52 ± 6.59	48.30 ± 8.67	38.34 ± 8.03	52.53 ± 15.28
UL Right Lat Pulldown (kg)*	22.48 ± 3.70	26.48 ± 4.99	21.68 ± 4.83	30.57 ± 9.7
UL Left Lat Pulldown (kg)*	20.10 ± 3.30	24.03 ± 4.29	20.27 ± 4.60	29.64 ± 10.19

Note. * BL group n = 13
Values are means ± SD.

CHAPTER 4

Discussion

The purpose of this study was to investigate the effect of bilateral and unilateral strength training on the bilateral deficit (as reported by the bilateral index) and bone mineral free lean tissue mass in post-menopausal women. Twenty-six women completed six months of either UL or BL strength training and underwent 1-RM tests of UL and BL of leg press, lat pulldown and knee extension, as well as measurements of bone mineral free lean tissue mass before and after training. There were two hypotheses for this study: 1) The changes in the BLD would be specific with training; BLD would be reduced with the BL training (BI would move in the positive direction); and the BLD would be increased with UL training (BI would move in the negative direction); and 2) The UL training group would show a greater increase in muscle mass since there is a strength deficit during BL contractions (Seki and Ohtsuki, 1990).

4.1 Bilateral Index

The bilateral deficit (BLD) is a neural phenomenon that has been consistently reproduced in a variety of movements and contractions. A BLD occurs when the sum of the unilateral strengths is greater than the bilateral strength during maximal voluntary contractions (Howard and Enoka, 1991; Kawakami et al., 1998). A bilateral index can be used to compute the magnitude of the BLD: BI(%) = 100[BL strength/(right UL strength + left UL strength)]-100 (Howard and Enoka, 1991; Taniguchi, 1997; 1998). A negative BI indicates a BLD and a positive BI indicates a bilateral facilitation. In all the studies that examined a leg press action (combined hip, knee and ankle extension), a BLD was found (Rube and Secher, 1990; Schantz et al., 1989; Secher, 1975; Secher et al., 1978; 1988; Taniguchi et al., 1997; 1998; Vandervoort et al., 1984; Van Soest et al., 1985). For this study the baseline BI for leg press was –12.7 ± 6.9% and significantly different from zero, which indicates a BLD. The BLD results from this study support these previous works and add consistency to this body of literature. A leg press action involves coordinated movement at a number of joints (combined hip, knee and ankle extension) and is deemed a complex exercise. Task complexity plays a role in learning and coordination of an exercise (Rutherford and Jones, 1986) therefore it is possible that task complexity is part of the reason for the consistent BLD findings with leg press.

When other types of movements were examined, such as a single joint movement (simple task) of knee extension, the results are conflicting. Howard and Enoka (1990) and Roy et al. (1990) were the only ones to find a BLD with knee extension while various other authors did not (Hakkinen et al., 1995; 1996a; 1996b; 1997; Jakobi and Cafarelli, 1998). For this study, the baseline BI for knee extension was –4.3 ± 12.6% (n.s.). Initially both groups of the current study did not exhibit a BLD for knee extension, which is in accordance with Hakkinen et al. (1995; 1996a; 1996b; 1997) and Jakobi and Cafarelli, (1998). The simplicity of the task may not have restricted the subjects' coordination of the movement, which could possibly allow for a smaller difference between the strengths of a two-legged vs. a one-leg movement.

In regards to the upper body, the BLD results are fairly consistent with a BLD being demonstrated with elbow flexion (Oda and Moritani, 1994; 1995a; Seki and Ohtsuki, 1990), elbow extension (Seki and Ohtsuki, 1990) and arm extension (bench press movement) (Taniguchi, 1997; 1998). Even though our study did not measure elbow flexion or extension, our upper body exercise of lat pulldown (which includes elbow flexion as a portion of the movement) produced a BLD for both groups at the start of the training program. The baseline BI for lat pulldown was $-8.8 \pm 7.8\%$ and was significantly different from zero. Task complexity does not seem to be a limiting factor for producing an upper body BLD since deficits were found in both simple (elbow flexion and extension) and complex (lat pulldown and bench press movements) exercises. A possible explanation for the differences between upper and lower body may be that upper body does not have to undergo the same learning and coordination phases (as with leg press) due to the habitual activity and the greater bilateral use of the arms (Taniguchi, 1997; Vandervoort et al., 1987).

When comparing the upper and lower portions of the body in the literature, a BLD occurs consistently in the lower body with the exception of a simple task exercise, such as knee extension, and is fairly consistent in the upper body, and this is supported by our results. The magnitude of the BLD varies between the upper and lower body, with larger deficits being found in the lower body compared to the upper body (Jakobi and Chilibeck, 2001). Our study seems to supports the magnitude pattern since the leg press BLD appears to be greater than the lat pulldown BLD; however, this was a trend that was noticed but it was not statistically determined. The BLD magnitude differences may be, at least partly, the result of differences of habitual activity patterns in the arms and legs. The legs are commonly used in an asynchronous motor pattern therefore they would not be accustomed to or trained for bilateral movements (Vandervoort et al., 1987) and would incur a greater difference between bilateral and unilateral strengths. The arms and hands are more commonly used bilaterally during lifting and carrying objects (Taniguchi, 1997; Vandervoort et al., 1987), which may result in the arms having a smaller difference between bilateral and unilateral strengths.

As reported above, the research regarding whether individuals exhibit a BLD is extensive, however the research examining the changes in the BLD with training is very limited. The bilateral index (BI) is used to compute the magnitude of the BLD, with a negative BI indicating a BLD. Previous research has indicated that BL training of the upper and lower limbs results in the BI moving in the positive direction (i.e. decreasing the BLD), while UL training results in the BI moving in the negative direction (i.e. increasing the BLD) (Taniguchi, 1997; 1998). The proposed hypothesis that changes in the BLD would be specific to the type of training were based on these findings. The leg press and knee extension results of the BL group from this study support this hypothesis. For each of our measures there was a group x time interaction with leg press and knee extension BI moving in the positive direction for our BL group. For the UL group, there was a trend for the BI to move in the negative direction for all three measures. The statistical power (limited number of subjects) of the study may be one reason why the change in BI of UL group was not significant since small changes may have not been detected.

The results of our BL group are in accordance with the findings of Taniguchi (1997; 1998) and Secher (1975) with leg press training and the findings of Howard and

Enoka (1991) with knee extension training. For the leg press action, the changes from our study are slightly lower than what previous research has indicated. Taniguchi (1997; 1998) trained subjects for six weeks with a leg press exercise in two separate studies. The change in the BI for the leg press exercise was greater in both the BL groups (9.3 ± 3.7% and 6.0 ± 3.7%) and the UL groups (-3.9 ± 2% and -8.5 ± 3.3%) for these two studies when compared to our study (BL group increased 4.4 ± 2%; UL group decreased 1.1 ± 4.7%). There are some important differences between our study and Taniguchi's such as subject age and training protocol. In both of the Taniguchi studies (1997; 1998) the subjects were younger (approximately 21 years) than our subjects therefore there may be differences in training responses. As well, the subjects for Taniguchi (1997; 1998) only trained the test movement (leg press) whereas our training protocol incorporated a whole body regimen. If the test exercises were not done first, fatigue may limit the amount of weight that could be lifted, which could then affect the strength increases.

Secher (1975) cross-sectionally compared three groups that had different levels of BL training (Olympic, national and club oarsmen). Secher (1975) concluded that the largest impact on the BLD comes from intense BL training. The group that had the greatest BL training (Olympic oarsmen) actually had BL strength that was greater than the summed UL strengths and therefore exhibited a bilateral facilitation (BLF). The other two lesser-trained groups showed a BLD. Our results did not show a BLF with leg press; however after only six months of training the participants were not considered to be highly bilaterally trained. The time may not have been long enough to entirely overcome the coordination limitations associated with BL complex movements, although the subjects were making improvements as was shown with the positive shift in the BI after six months of training.

In another cross-sectional study, Howard and Enoka (1991) found differences for knee extension BI between an untrained group (–9.5 ± 6.8%), a unilaterally trained group (cyclists) (-6.6 ± 7.1%) and a bilaterally trained group (weight lifters) (+6.2 ± 4.7%). The training BI reported for our study was lower than what these authors found with the exception of the bilaterally trained groups. Their bilaterally trained group had a BI of +6.2 ± 4.7% while our BL group had a BI of +8.9 ± 6.9% after BL training. In both Howard and Enoka (1991) and our study, the bilaterally trained groups exhibited a bilateral facilitation (BLF) for knee extension. This strongly supports part of our first hypothesis, which predicted that BL training would decrease the BLD. In both cases, the participants were able to eliminate the BLD indicating that the BLD is indeed trainable. This would be very helpful to populations that would benefit from maximizing their ability to contract their limbs bilaterally. Under normal conditions, an ageing individual would experience a reduction in muscle mass and strength, therefore it would be beneficial to maximize their arm strength during BL contractions to enable them to continue with habitual activities such as lifting and carrying objects.

The two previous studies (Howard and Enoka, 1991; Secher, 1975) cross-sectionally examined the impact of BL training on the BLD with younger, athletic populations. Hakkinen et al. (1996a) worked with a group of middle-aged and elderly men and women and trained them for BL and UL knee extension. In order to quantify their BLD results they used a BL/UL strength ratio, which is similar to the BI. They determined after 12 weeks of training that the BL/UL strength ratio increased 7% in the

BL training group and decreased 2% in the UL training group. The BL training group increased their BL strength more so than their UL strength therefore this would cause an increase in the value of the strength ratio. The UL training group increased their UL strength to a greater extent, which would cause a decrease in the strength ratio value. Even though the subjects from this study did not exhibit BLD at the beginning of the program, the direction of change that occurred with the two lateral types of training were similar to our study.

During the BL testing portions of our study, there was a bar that was added to the knee extension apparatus. During training, the bar was not used because it was very difficult to put on and take off the machine. Therefore, during testing the subjects were performing 'true' bilateral contractions and during training their legs were working independently. They still performed bilateral contractions, however each limb was responsible for lifting the weight on its own, as opposed to the limbs jointly lifting it. This type of BL training does not appear to have had compromised the BL testing and the BI since these subjects were able to increase their BL strength to the point where their knee extension BL strength was greater than the sum of their UL strengths (i.e. BLF has occurred).

To our knowledge, there have been no studies examining the trainability of the BLD in regards to the lat pulldown exercise. However, we did not expect the effect of lateral specific training of lat pulldown to affect the BLD any differently than the other two exercises. Taniguchi (1997; 1998) examined the trainability of the BLD using arm extension action and found that the BI increased (0.1 ± 4.1% and 1.8 ± 3.3%) for the BL groups and decreased (5.0 ± 2.1% and 8.5 ± 3.3) in the UL groups for the two studies respectively. The BI for lat pulldown for our bilaterally trained group increased 2.9 ± 5.1% and decreased 3.9 ± 3% for the unilaterally trained group, however there was no statistical significance with either group. Nonetheless, there appears to be a specific trend for the BL training group to decrease their BLD (i.e. BI shifts in the positive direction) and for the UL training group to increase their BLD (i.e. BI shifts in the negative direction) since the Tukey's post-hoc testing indicated that the groups' BI were significantly different from each other after training.

The baseline measures of the BI for leg press, lat pulldown and knee extension were statistically tested to determine if they were significantly different from zero, which would indicate that there was a BLD for that exercise. Initially there was a BLD for the leg press and lat pulldown exercises; however, not for knee extension. When examining the initial knee extension results, there is a smaller BI (-4.3% vs. –12.7% and -8.8% for LP and LAT, respectively) and larger variability for knee extension (12.6% vs. 6.9% and 7.8% for LP and LAT, respectively). The small BI and large variability for this exercise is consistent with the literature. Whether a BLD actually occurs with this exercise is debatable. This is also true when the BI results for knee extension are examined for each of our subjects. Prior to the training, there was a large range (-28.2% to +16.4%) of BI results for both groups, which would contribute to a small effect and large variability. BL training resulted in large increases in knee extension BL strength for the majority of subjects (in the BL group), which affected the increases in the BI. Therefore, at least partly due to the treatment, the effect was increased and the variability was reduced (-8.9 ± 6.9%) for knee extension in the BL training group.

In conclusion, after six months of training had been completed, the BL training group showed a decrease in magnitude of the BLD for leg press and knee extension (lat pulldown was not significant). In this group, the BLD for knee extension was decreased enough that it was eliminated and a BLF was shown (BI = +8.9%). There was a trend for the unilateral training group to increase the magnitude of the BLD for all three exercises, however statistical significance was not reached. Even though there were different magnitudes of change for the groups and the three exercises, it is concluded that specific BL training can influence the BLD. Tukey's post-hoc analyses determined that BL training had a strong effect on increasing the BI, while UL training had a weaker effect (not significant) on decreasing the BI. It is possible that there is a limitation as to how large the BLD can be. Our subjects may have been close to this limit before training and hence, could not increase their BLD notably. It is also possible that the statistical power was limited and small differences between the BL and UL groups may not have been detected.

One purpose of this thesis was to re-examine the lateral specificity of training on the BLD over a longer duration (i.e. 24 weeks). Our magnitude of changes in the BLD, as measured as a BI, were not as large as what some studies found (Taniguchi, 1997; 1998), nor were the direction of the changes similar for all exercises. Even though some of the results were not significant, the greater length of time of this study is still beneficial for eliminating a learning aspect, which may limit the strength changes.

4.2 Bone mineral free lean tissue mass

Our second hypothesis was that UL training would increase lean tissue mass to a greater extent than BL training. This hypothesis is based on the assumption that the UL group would be lifting more weight with each limb, due to the strength deficit, which would be present with the BL movements (Seki and Ohtsuki, 1990). The results of the study did not support this hypothesis, although there did appear to be a trend in the data to indicate that the UL group increased the lower body bone mineral free lean tissue mass more than the BL group ($p = 0.097$). When examining knee extension training load, the means for the UL group were greater and significantly different from the BL group. This indicates that the UL group was lifting more weight, which would influence the muscle mass increases. On the other hand, the leg press training load was not significantly different between the groups. Therefore the overall UL strength output for the lower body may not have been sufficient enough to evoke a greater increase in lower body muscle mass for the UL group, which would have been significant. One possible reason for the knee extension training intensities being higher for the UL group was that a greater number of the BL subjects had knee osteoarthritis. In these cases, the training weight was reduced for the affected leg.

The lower body appeared to increase lean tissue mass more so than the upper body for the UL training group. Although not statistically significant, this is further supported by the BI data since the starting BLD in the leg press was substantial (BI = $-12.7 \pm 6.9\%$), whereas the starting BLD for lat pulldown was relatively small (BI = $-8.8 \pm 7.8\%$). This would indicate the participants were lifting more weight during leg press UL contractions, which could lead to a greater increase in lower body muscle mass for the UL group.

There were significant changes in both groups with training for upper, lower and whole body bone mineral free lean tissue mass. All of the participants increased their lean tissue masses due to the training stimulus, regardless of the type of training. Even though there were no added hypertrophy benefits for the participants who trained unilaterally, the results indicate a significant health benefit for both groups. Muscle loss is a predominant characteristic of ageing, however, the rate of decline seen in the muscle tissue can be influenced by physical activity. By engaging in the training, both groups incurred the benefits of increasing their muscle mass.

A general characteristic of the ageing process is sarcopenia, which consequently is thought to be responsible for a decrease in muscular strength. The morphological and structural changes of muscle tissue can lead to a number of detrimental consequences such as the increased risk of osteoporosis, frequency of falls and fractures (Kirkendall and Garrett, 1998).

In an effort to determine age-related differences in women for arm muscle mass the subjects of this study were included in a larger sample of older women (57 ± 7 yrs) and compared to younger women (21 ± 2 yrs) (Chilibeck et al., 2000a). The older women had 3.2 ± 6.2 kg of lean tissue mass which was significantly lower than the younger women's measurement of 4.0 ± 5.6 kg. In a second study, some of our subjects were included in a larger group of older (63 ± 4 yrs) women that had significantly lower isokinetic bench press strength (228 ± 72 newton-meters) and upper body lean tissue mass (trunk and right arm) (21.6 ± 2.8 kg) compared to a group of younger women (21

± 2 yrs) (strength = 328 ± 53 newton-meters; lean tissue mass = 24.5 ± 2.4 kg) (Chilibeck et al., 2000b). Of this larger group of older women, six of the subjects took part in our study (61 ± 2 yrs) and had a strength of 211 ± 87 newton-meters and a lean tissue mass of 20.8 ± 1.9 kg. Consequently the women in this study had most likely undergone a degree of sarcopenia with loss of strength.

The patterns of skeletal muscle strength and mass have been documented as having a steep increase up to the age of 20-29 years; a maintenance phase until approximately 50 years; and after 50-59 years of age there is a dramatic decline in both muscle mass and strength (Frontera et al., 1991; Larsson, 1982; Young et al., 1984), with a drastic decline in muscle mass and strength at the onset of the sixth decade (Hakkinen et al., 1996a; 1996b). The subjects would generally fall into the range of the maintenance phase with only six of our subjects over 60 years; however it was concluded that the women of this study had started a decline in muscle mass and strength (Chilibeck, 2000a; 2000b). A possible explanation for the discrepancy may be related to occupational and leisure activities. The subjects of this study had never undergone any previous strength training; as well they were a fairly inactive group prior to the study. Since neither the previous studies nor this study assessed occupational and leisure activities it is difficult to draw definite conclusions. A second explanation could be that the population used to report the patterns of muscle mass and strength losses consisted mainly of males. It is possible that there are gender differences, which have not been accounted for in the literature, since some gender comparisons of sarcopenia did not control for body weight, stature and age differences (Gallagher et al., 1997).

The lower limbs, especially the knee extensors and flexors, seem to be the most affected by age (Gallagher et al., 1997; Grimby et al., 1982; Janssen et al., 2000; Larsson et al., 1979; Tomonaga, 1977). It is possible that this is influenced by age-related changes in lower and upper body activity patterns (Hakkinen et al., 1997). The movements in which the arms and legs are involved in are very different therefore it is possible that with age, one might decrease the amount that they use their legs (walking, climbing stairs, etc) but not their arms (Tzankoff and Norris, 1977). This is supported in our study since the lower body (increases = absolute 0.85 kg; relative 7%) adapted more to the training stimulus than the upper body (increases = absolute 0.52 kg; relative 2%), however this was not statistically determined. The training intensities were similar for the upper and lower body exercises therefore it is unlikely that this is a contributing factor. It is possible that our subjects have begun to change the habitual use of their legs and the lower body is starting to become deconditioned; therefore, the lower body strength improvements may be accentuated due to retraining (Wilmore and Costill, 1994).

There are numerous ways to determine the body composition of individuals, such as dual energy x-ray absorptiometry (DEXA), hydrostatic weighing (HW), bioelectrical impedance and so forth. For our study we determined bone mineral free lean tissue mass using DEXA and our results are comparable to other authors who used DEXA or HW. Over the six months of training our participants increased their whole body lean tissue mass by $3.9 \pm 7.8\%$; this is similar to previous findings which utilized DEXA as a measurement tool in older individuals: Nichols et al. (1993) found a 4% increase in lean body mass after 24 weeks of strength training in older women (67.8

years); Ryan et al. (1995) found a 3% increase in fat-free mass after 16 weeks of strength training in women 50-69 years. Yarasheski et al. (1995) also demonstrated equivalent increases (4%) in fat-free mass using hydrostatic weighing after 16 weeks in men 64-75 years.

Pyka et al. (1994) and Yarasheski et al. (1999) both concluded from their work with DEXA that there was no change in fat-free mass after 15-16 weeks of training. However, by examining their strength results one may conclude that the load of training was not sufficient enough to procure large changes in strength or body composition.

Overall the bone mineral free lean tissue mass increases observed in both our groups are comparable to previous findings. Hypertrophy is at least partly responsible for the strength increases observed with the two training groups. Although not measured, neural adaptations were most likely strongly influencing the strength increases in the initial weeks of the program. Even though there were no apparent benefits for training bilaterally vs. unilaterally in regards to gains in lean tissue mass, different modes of training (BL vs. UL) should be considered for the upper and lower body. This would result in general muscle mass increases and specific (BL vs. UL) strength increases, which would allow functional training of daily, habitual activities.

4.3 Strength Measures

As individuals grow older and sarcopenia occurs, there are detrimental effects on the muscle strength of the body. Strength training has been shown to be a very effective tool in reversing the age-related losses of muscle mass and strength. Increases in knee extension strength over a short period of time (8 to 12 weeks) have been substantial, ranging from 93% to 174% (Charette et al., 1991; Fiatarone et al., 1990; Frontera et al., 1988). A common conclusion for these studies was that an ageing population is still capable of increasing their muscular strength, and by large amounts (range 93-174%).

A number of studies have investigated the effects of strength training; however a limited number of studies have investigated the effects using an older female population. Furthermore, the majority of the studies concentrated on bilateral lower leg training, with the emphasis on the knee extensors. Fiatarone et al. (1990) trained the knee extensors in an elderly population (mean = 90 ± 1 year) and found the strength to increase 174% in 8 weeks. Charette et al. (1991) trained a slightly younger population of women (mean = 69 ± 1.0 year) for 12 weeks and found their strength of the knee extensors to increase by 93%. The results of our study show increase in knee extension strength, however the magnitude was not nearly as high (33.3 ± 33.9%). Our participants (mean age = 55.3 ± 7.3 years) were younger compared to the previous two studies therefore the strength losses and atrophy may not be comparable to what would be occurring with the advanced years. It is possible that our subjects were not as severely deconditioned as in previous studies, especially in Fiatarone's study. This could possibly affect the magnitude of the strength gains of our subjects.

Our leg press strength increases (27.8 ± 15.9%) are comparable to what Charette et al. (1991) found with an older group of women (28.3 ± 5.7%). It appears that when the task complexity increases, there are less rapid gains in strength as well as muscle mass (Chilibeck et al., 1998). With a simple exercise (such as knee extension) there are both substantial muscle mass and strength gains after only a few weeks of training

(Charette et al., 1991; Fiatarone et al., 1990; Frontera et al., 1988). Complex exercises (such as leg press) involve movement at more than one joint and would involve increased stabilization of the prime movers (Rutherford and Jones, 1986). Therefore the strength of the stabilizers would need to be increased primarily, and then the strength of prime movers could be increased (Rutherford and Jones, 1986). This may at least partly explain the greater strength increases with knee extension (33.3 ± 45.3%) as compared to leg press (27.8 ± 15.9%) for our study. The differences between the simple (knee extension) and complex (leg press) exercises of our study are not that large; however delay of strength increase due to task complexity may be better demonstrated by Charette et al. (1993). Using the same groups, knee extension increased 93% compared to a 28% increase with leg press. As the task complexity increases, the time for the strength gains increases.

When examining the literature, only one study was found examining the effects of strength training on the upper body, and it was with males (mean age = 63 ± 2.7 years) (Brown et al., 1990). After 12 weeks of training, their subjects exhibited a 48% increase in elbow flexion. Strength increases occurred in lat pulldown (which has elbow flexion as part of the movement) for our study with a 34% increase after six months of training. It is difficult to compare our results with those of Brown et al. (1990) since the same movement was not investigated. As well, in order to compare genders, lean tissue mass should be accounted for and the relative changes should be compared and these were not reported by Brown et al. (1990).

It has been consistently shown in the literature that when an individual begins a training program, the exercises should be as specific as possible and mimic the particular type, speed and force of contraction of the movement pattern (Sale and MacDougall, 1981). In our study, one group performed all the training exercises bilaterally (with the exception of hip exercises) and the other group did the exercises with one limb at a time. It was thought that: 1) the BL group would increase their BL strength more than the UL group; and 2) the UL group would increase their UL strength more than the BL group. These expectations were based on previous work done by Hakkinen et al. (1996a), Howard and Enoka (1991), Secher (1975) and Taniguchi (1997). The results of our study demonstrated that the groups increased their strengths for each measure in a similar manner, which does not support the previous findings. Regardless of there not being a significant interaction between the groups, each group significantly increased their strengths over time and this is an overall benefit to the subjects. It is not apparent why there were not lateral specific increases in strength since the training intensities and the length of the training program were sufficient. One possible explanation is there may a statistical power problem due to small group sizes and it is possible that small changes were not deemed significant.

Overall, the groups were successful at increasing their strengths with the training program, although the groups did not differ. Increasing task complexity may delay gains in strength although the overall strength gains should not be limited if the training length is sufficient. Also it seems the capability of muscle to respond to a training stimulus is not compromised with age, which again, would be very beneficial for an ageing population.

One thing that should be noted is side effects experienced by some of the subjects, which may have been at least partially due to strength training. One such side effect is an increased aggravation of knee osteoarthritis. Knee extension for four subjects was limited due to pain in the knee joint during this exercise. Occasional flare-ups occurred and the subject experienced joint stiffness and increased pain with normal activities. Two subjects were also diagnosed with fibromyalgia prior to the study. One of these participants experienced a few flare-ups (immobility, pain) throughout the study. However, it is unlikely that these flare-ups were due solely to the exercise since the participant had experienced these for years. Other adverse side effects were general muscle and joint soreness and stiffness; although once the participants had been exercising for a few weeks, the soreness and stiffness experienced the day after training diminished.

4.4 Implications of Results

It is well documented that with increased age there are significant losses in both muscle mass and strength. These variables are closely related and can have profound effects on one another. If an individual is able to maintain their muscle mass and consequently their muscle strength, this can be advantageous. Not only would the individual be less susceptible to falls, fractures and effects of osteoporosis (Kirkendall and Garrett, 1998) but also they could maintain their independence and control over their lives. Therefore strength training can help decrease the morbidity that is usually associated with age since they would retain function and increase their quality of life.

It was hypothesized that the UL training would be more beneficial to an ageing population since it is possible that there is a stronger stimulus for hypertrophy with UL training. Our results did not show any added benefit with UL training as compared to

BL training. Even though BL and UL training did not have differing effects on bone mineral free lean tissue mass, the functionality of habitual activities may need to be considered when strength training. Specificity of training is an important principle of training programs and it can also be applied to daily living activities. Our habitual patterns differ between our arms and legs, with the arms being more involved in BL movements while the legs are used unilaterally (Vandervoort et al., 1987), as well with age individuals tend to decrease the amount that they use their legs (Tzankoff and Norris, 1977). When an individual is trying to maintain/increase muscle mass and strength then the habitual patterns of the limbs need to be considered. It would be helpful to recommend that the individual train the arms bilaterally and the legs unilaterally therefore the movement patterns used in everyday activities can be specifically trained for. As a result, both types of training (UL vs. BL) would be beneficial to ageing people to help keep them active throughout their later years and to retain a functional capacity.

4.5 Summary

The BLD is a neural phenomenon that is influenced by the lateral specificity of training. The BLD tends to be decreased with BL training and increased with UL training. Although this change in the BLD (as measured by the BI) was of a lesser magnitude than in previous studies, it followed a similar pattern as in those studies for the BL group's leg press and knee extension. The specificity of training is an important aspect when trying to increase a particular type of muscle strength, whether for a daily living action or physical activity.

The two specific types of training in this study had similar effects on bone mineral free lean tissue mass and muscle strength. Regardless of the type of training, the subjects incurred the benefits of increased muscle mass and strength. This was in agreement with other studies that an older population still retains the capability to increase both their muscle mass and strength. There was a greater increase in muscle mass of the lower body, which appeared to respond more to the training stimulus. As well, different lower body exercises had different strength responses compared to previous findings. The magnitude of increase for leg press strength was comparable to other studies; however, the magnitude of increase for knee extension strength was not as great as previous studies but it had a similar time effect. Although there were no previous studies, which examined the effects of strength training on lat pulldown, our results were similar to increases observed with elbow flexion.

CHAPTER 5

Summary and Conclusions

5.1 Summary

The objective of this study was to examine the BLD (as measured by the BI) and the effects of BL and UL strength training on the deficit and bone mineral free lean tissue mass. Twenty-six post-menopausal women participated in the study; all were residents of Saskatoon and surrounding area. They strength trained three times a week for six months. The training program consisted of exercises for the whole body with each exercise being performed for two sets with 8-10 repetitions.

Testing was performed before and after training to determine the participants' maximum BL, right UL and left UL strengths (1-RM) for leg press, knee extension and lat pulldown. A BI was calculated to determine the magnitude of the BLD for each exercise (LP, KE and LAT). Bone mineral free lean tissue mass was assessed using dual energy x-ray absorptiometry for whole, lower and upper body.

Data was analyzed using a 2 (group) X 2 (time) ANOVA with repeated measures on the second factor for changes in BI (for leg press, knee extension and lat pulldown) and bone mineral free lean tissue mass (for whole, lower and upper body). This analysis revealed group x time interactions for all BI measures. Tukey's post-hoc testing determined that the BL group had significant increases in the BI for leg press and knee extension. For the bone mineral free lean tissue mass there was a time main effect but no interaction between group and time.

Initially, a BLD was found in the leg press exercise, which is in accordance with the literature. A BLD was also found with lat pulldown; however, not with knee extension. There is less evidence in the literature to support the occurrence of a BLD within these exercises. The change in BI in this study was slightly lower than previous studies. However, the pattern of the BI responses to BL training were similar to those found in previous studies for leg press and knee extension. We concluded that the BLD is trainable and is influenced by specific bilateral training.

A further finding of this study was that there was no difference for increasing bone mineral free lean tissue mass by training bilaterally or unilaterally. Subjects were able to increase muscle mass by engaging in either form of training.

5.2 Conclusions

1. A BLD was found in an exercise that has been consistently reporting deficits (leg press), and in an exercise that has not been previously examined (lat pulldown). A BLD was not found in knee extension, which is an exercise that has shown inconsistent results.

2. The BLD was influenced differently by BL and UL training protocols; it decreases with BL training and there is a trend for the BLD to be increased with UL training (n.s.).

3. There was no added benefit for strength training unilaterally for increasing bone mineral free lean tissue mass.

4. An ageing female population is able to exhibit a BLD initially and to decrease or eliminate the deficit with BL training for the lower body.

5. An ageing female population still retains the capability to increase their muscle mass and strength which would help to partially reverse the effects of sarcopenia.

5.3 Recommendations

1. Further research is needed to determine the trainability of the BLD. This information would be valuable to an ageing population so they can train for the 'function of habitual activity'. The arms and legs are used differently therefore it would benefit the individual to train them differently and specifically for the movement patterns which are typical during everyday activities.

2. Even though an athletic population was not used in our study, the results could be indirectly related to this population. Knowledge of the trainability of the BLD could be important to athletes who participate in BL sports (rowers, weight lifters) since BL training would be specific to their sports-related movements and they would be eliminating BL limitations.

3. Future research is needed on the influence of complexity of exercises on the BLD since deficits are always found with complex movements (leg press) but not simple movements (knee extension). This could possibly help to determine the cause of the BLD and whether it is definitely a neural limitation or a separate restraint altogether.

4. There is a need for more research to be conducted with women, especially ageing women. Compared to men, there is less research on older women with regards

to muscle mass and strength and how they are affected by training. As well, the BLD training studies mostly examined younger men and women. Again, if subsequent studies used this population then the information produced by such research could be applied to the specific population to improve their function and quality of life.

5.4 Limitations

1. The sample size of the study may not have been large enough to have sufficient power to detect changes in the BI for the UL group and differences between groups for lean tissue mass. The UL group tended to have a greater change in lower body lean tissue mass, but this failed to reach statistical significance ($p = 0.097$).

2. An ageing population is always afflicted with age-related problems such as osteoarthritis. Since this is a "normal" condition for this age group we did not control for it. The BL group had a slightly higher incidence of osteoarthritis, particularly in their knees (BL group = 3; UL group = 1). The problems with knee osteoarthritis limited the amount of weight the subject could lift during the testing and especially the training sessions for the leg press and knee extension exercises. Therefore the maximum benefits of BL training on the BLD may not have occurred. Also in the BL group, two participants had been diagnosed with fibromyalgia. One of them had a series of flare-ups in a number of different muscle groups. As a result, the training volume had to be reduced and gradually moved back up. Again, the maximum benefits of BL training may not have been observed.

3. The BI is a sensitive measure when determining changes in the BLD; however, not all studies that examined the trainability of the BLD used a BI to quantify

their deficits. Some compared the group's means of the strength measures and others used a BL/UL strength ratio. However, the leg-strength ratio is similar to the BI since it still takes into account changes in all measures of strength, BL, right UL and left UL. If the measures used to compute the magnitude of the BLD are not similar then it is difficult to compare the various studies for the effects of training on the BLD.

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APPENDIX A

2 (Group) X 2 (Time) ANOVA with Repeated Measures

for the Leg Press BI

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	35.565	1	35.565	1.741	.199
	Greenhouse-Geisser	35.565	1.000	35.565	1.741	.199
	Huynh-Feldt	35.565	1.000	35.565	1.741	.199
	Lower-bound	35.565	1.000	35.565	1.741	.199
TIME * GROUP#	Sphericity Assumed	100.157	1	100.157	4.904	.037
	Greenhouse-Geisser	100.157	1.000	100.157	4.904	.037
	Huynh-Feldt	100.157	1.000	100.157	4.904	.037
	Lower-bound	100.157	1.000	100.157	4.904	.037
Error(TIME)	Sphericity Assumed	490.198	24	20.425		
	Greenhouse-Geisser	490.198	24.000	20.425		
	Huynh-Feldt	490.198	24.000	20.425		
	Lower-bound	490.198	24.000	20.425		

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
TIME	Pillai's Trace	.068	1.741[b]	1.000	24.000	.199
	Wilks' Lambda	.932	1.741[b]	1.000	24.000	.199
	Hotelling's Trace	.073	1.741[b]	1.000	24.000	.199
	Roy's Largest Root	.073	1.741[b]	1.000	24.000	.199
TIME * GROUP#	Pillai's Trace	.170	4.904[b]	1.000	24.000	.037
	Wilks' Lambda	.830	4.904[b]	1.000	24.000	.037
	Hotelling's Trace	.204	4.904[b]	1.000	24.000	.037
	Roy's Largest Root	.204	4.904[b]	1.000	24.000	.037

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP#
Within Subjects Design: TIME

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TIME	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
TIME	Linear	35.565	1	35.565	1.741	.199	.068
TIME * GROUP#	Linear	100.157	1	100.157	4.904	.037	.170
Error(TIME)	Linear	490.198	24	20.425			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Intercept	7250.379	1	7250.379	120.663	.000	.834
GROUP#	50.256	1	50.256	.836	.370	.034
Error	1442.113	24	60.088			

APPENDIX B

2 (Group) X 2 (Time) ANOVA with Repeated Measures

for the Knee Extension BI

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	638.302	1	638.302	8.008	.009
	Greenhouse-Geisser	638.302	1.000	638.302	8.008	.009
	Huynh-Feldt	638.302	1.000	638.302	8.008	.009
	Lower-bound	638.302	1.000	638.302	8.008	.009
TIME * GROUP#	Sphericity Assumed	793.577	1	793.577	9.956	.004
	Greenhouse-Geisser	793.577	1.000	793.577	9.956	.004
	Huynh-Feldt	793.577	1.000	793.577	9.956	.004
	Lower-bound	793.577	1.000	793.577	9.956	.004
Error(TIME)	Sphericity Assumed	1912.951	24	79.706		
	Greenhouse-Geisser	1912.951	24.000	79.706		
	Huynh-Feldt	1912.951	24.000	79.706		
	Lower-bound	1912.951	24.000	79.706		

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
TIME	Pillai's Trace	.250	8.008[b]	1.000	24.000	.009
	Wilks' Lambda	.750	8.008[b]	1.000	24.000	.009
	Hotelling's Trace	.334	8.008[b]	1.000	24.000	.009
	Roy's Largest Root	.334	8.008[b]	1.000	24.000	.009
TIME * GROUP#	Pillai's Trace	.293	9.956[b]	1.000	24.000	.004
	Wilks' Lambda	.707	9.956[b]	1.000	24.000	.004
	Hotelling's Trace	.415	9.956[b]	1.000	24.000	.004
	Roy's Largest Root	.415	9.956[b]	1.000	24.000	.004

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP#
Within Subjects Design: TIME

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TIME	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
TIME	Linear	638.302	1	638.302	8.008	.009	.250
TIME * GROUP#	Linear	793.577	1	793.577	9.956	.004	.293
Error(TIME)	Linear	1912.951	24	79.706			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Intercept	19.638	1	19.638	.118	.735	.005
GROUP#	230.750	1	230.750	1.382	.251	.054
Error	4006.399	24	166.933			

APPENDIX C

2 (Group) X 2 (Time) ANOVA with Repeated Measures

for the Lat Pulldown BI

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
FTIME	Pillai's Trace	.010	.223[b]	1.000	23.000	.641
	Wilks' Lambda	.990	.223[b]	1.000	23.000	.641
	Hotelling's Trace	.010	.223[b]	1.000	23.000	.641
	Roy's Largest Root	.010	.223[b]	1.000	23.000	.641
FTIME * GROUP#	Pillai's Trace	.284	9.116[b]	1.000	23.000	.006
	Wilks' Lambda	.716	9.116[b]	1.000	23.000	.006
	Hotelling's Trace	.396	9.116[b]	1.000	23.000	.006
	Roy's Largest Root	.396	9.116[b]	1.000	23.000	.006

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
FTIME	1.000	.000	0	.

Tests the null hypothesis that the error covariance matrix of the orthonormaliz ed transformed dependent variables is proportional to an identity matrix.

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

	Epsilon[a]		
Within Subjects Effect	Greenhouse -Geisser	Huynh-Feldt	Lower-bound
FTIME	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormaliz ed transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are display ed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept+GROUP#
Within Subjects Design: FTIME

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	FTIME	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
FTIME	Linear	6.641	1	6.641	.223	.641	.010
FTIME * GROUP#	Linear	271.339	1	271.339	9.116	.006	.284
Error(FTIME)	Linear	684.568	23	29.764			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Intercept	3554.685	1	3554.685	55.371	.000	.707
GROUP#	114.055	1	114.055	1.777	.196	.072
Error	1476.556	23	64.198			

APPENDIX D

2 (Group) X 2 (Time) ANOVA with Repeated Measures

for Whole Body Bone Mineral free Lean Tissue Mass

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	24491197	1	24491197	27.953	.000
	Greenhouse-Geisser	24491197	1.000	24491197	27.953	.000
	Huynh-Feldt	24491197	1.000	24491197	27.953	.000
	Lower-bound	24491197	1.000	24491197	27.953	.000
TIME * GROUP#	Sphericity Assumed	278070.98	1	278070.98	.317	.578
	Greenhouse-Geisser	278070.98	1.000	278070.98	.317	.578
	Huynh-Feldt	278070.98	1.000	278070.98	.317	.578
	Lower-bound	278070.98	1.000	278070.98	.317	.578
Error(TIME)	Sphericity Assumed	21027913	24	876163.04		
	Greenhouse-Geisser	21027913	24.000	876163.04		
	Huynh-Feldt	21027913	24.000	876163.04		
	Lower-bound	21027913	24.000	876163.04		

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
TIME	Pillai's Trace	.538	27.953[b]	1.000	24.000	.000
	Wilks' Lambda	.462	27.953[b]	1.000	24.000	.000
	Hotelling's Trace	1.165	27.953[b]	1.000	24.000	.000
	Roy's Largest Root	1.165	27.953[b]	1.000	24.000	.000
TIME * GROUP#	Pillai's Trace	.013	.317[b]	1.000	24.000	.578
	Wilks' Lambda	.987	.317[b]	1.000	24.000	.578
	Hotelling's Trace	.013	.317[b]	1.000	24.000	.578
	Roy's Largest Root	.013	.317[b]	1.000	24.000	.578

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP#
Within Subjects Design: TIME

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TIME	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
TIME	Linear	24491197	1	24491197	27.953	.000	.538
TIME * GROUP#	Linear	278070.98	1	278070.98	.317	.578	.013
Error(TIME)	Linear	21027913	24	876163.04			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Intercept	6.67E+10	1	6.67E+10	1305.912	.000	.982
GROUP#	1157885.8	1	1157885.8	.023	.882	.001
Error	1.23E+09	24	51084277			

APPENDIX E

2 (Group) X 2 (Time) ANOVA with Repeated Measures

for Lower Body Bone Mineral free Lean Tissue Mass

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	3531803.6	1	3531803.6	42.151	.000
	Greenhouse-Geisser	3531803.6	1.000	3531803.6	42.151	.000
	Huynh-Feldt	3531803.6	1.000	3531803.6	42.151	.000
	Lower-bound	3531803.6	1.000	3531803.6	42.151	.000
TIME * GROUP#	Sphericity Assumed	249804.40	1	249804.40	2.981	.097
	Greenhouse-Geisser	249804.40	1.000	249804.40	2.981	.097
	Huynh-Feldt	249804.40	1.000	249804.40	2.981	.097
	Lower-bound	249804.40	1.000	249804.40	2.981	.097
Error(TIME)	Sphericity Assumed	2010954.4	24	83789.765		
	Greenhouse-Geisser	2010954.4	24.000	83789.765		
	Huynh-Feldt	2010954.4	24.000	83789.765		
	Lower-bound	2010954.4	24.000	83789.765		

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
TIME	Pillai's Trace	.637	42.151[b]	1.000	24.000	.000
	Wilks' Lambda	.363	42.151[b]	1.000	24.000	.000
	Hotelling's Trace	1.756	42.151[b]	1.000	24.000	.000
	Roy's Largest Root	1.756	42.151[b]	1.000	24.000	.000
TIME * GROUP#	Pillai's Trace	.110	2.981[b]	1.000	24.000	.097
	Wilks' Lambda	.890	2.981[b]	1.000	24.000	.097
	Hotelling's Trace	.124	2.981[b]	1.000	24.000	.097
	Roy's Largest Root	.124	2.981[b]	1.000	24.000	.097

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP#
Within Subjects Design: TIME

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TIME	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
TIME	Linear	3531803.6	1	3531803.6	42.151	.000	.637
TIME * GROUP#	Linear	249804.40	1	249804.40	2.981	.097	.110
Error(TIME)	Linear	2010954.4	24	83789.765			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Intercept	7.31E+09	1	7.31E+09	928.848	.000	.975
GROUP#	70138.600	1	70138.600	.009	.926	.000
Error	1.89E+08	24	7866836.4			

APPENDIX F

2 (Group) X 2 (Time) ANOVA with Repeated Measures

for Upper Body Bone Mineral free Lean Tissue Mass

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
TIME	Sphericity Assumed	9421919.5	1	9421919.5	15.294	.001
	Greenhouse-Geisser	9421919.5	1.000	9421919.5	15.294	.001
	Huynh-Feldt	9421919.5	1.000	9421919.5	15.294	.001
	Lower-bound	9421919.5	1.000	9421919.5	15.294	.001
TIME * GROUP#	Sphericity Assumed	762.541	1	762.541	.001	.972
	Greenhouse-Geisser	762.541	1.000	762.541	.001	.972
	Huynh-Feldt	762.541	1.000	762.541	.001	.972
	Lower-bound	762.541	1.000	762.541	.001	.972
Error(TIME)	Sphericity Assumed	14785339	24	616055.77		
	Greenhouse-Geisser	14785339	24.000	616055.77		
	Huynh-Feldt	14785339	24.000	616055.77		
	Lower-bound	14785339	24.000	616055.77		

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
TIME	Pillai's Trace	.389	15.294[b]	1.000	24.000	.001
	Wilks' Lambda	.611	15.294[b]	1.000	24.000	.001
	Hotelling's Trace	.637	15.294[b]	1.000	24.000	.001
	Roy's Largest Root	.637	15.294[b]	1.000	24.000	.001
TIME * GROUP#	Pillai's Trace	.000	.001[b]	1.000	24.000	.972
	Wilks' Lambda	1.000	.001[b]	1.000	24.000	.972
	Hotelling's Trace	.000	.001[b]	1.000	24.000	.972
	Roy's Largest Root	.000	.001[b]	1.000	24.000	.972

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+GROUP#
Within Subjects Design: TIME

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TIME	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
TIME	Linear	9421919.5	1	9421919.5	15.294	.001	.389
TIME * GROUP#	Linear	762.541	1	762.541	.001	.972	.000
Error(TIME)	Linear	14785339	24	616055.77			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Intercept	2.99E+10	1	2.99E+10	1478.773	.000	.984
GROUP#	658130.79	1	658130.79	.033	.858	.001
Error	4.85E+08	24	20193308			

APPENDIX G

Training Log Sheet

Date: ____________________

	Set #1		Set #2	
	Weight	Repetitions	Weight	Repetitions
Leg Press				
Chest Press				
"Lat" Pulldown				
Shoulder Press				
Leg Extension				
Leg Curl				
Biceps Curl				
Back Extension				
Hip Flexion				
Hip Extension				
Hip Adduction				
Hip Abduction				

Leg Press seat setting: ____________

Back Extension: Feet: ____________ Seat: ____________
Back: ____________ Top: ____________

Hip Machine Arm Length: ____________

APPENDIX H

Consent Form

CONSENT FORM

Title of Study: Post-Menopausal Osteoporosis in Saskatchewan: Prevention with Exercise and Bisphosphate Therapy

Principal Researcher: Dr. Philip Chilibeck
College of Physical Education
University of Saskatchewan
Saskatoon SK
S7N 1M3
Phone: (306) 966-6469

Purpose:
The purpose of this study is to compare the effectiveness of exercise (weight-training) and a drug therapy (bisphosphonates) or both exercise and drug therapy combined for preventing loss of bone in post-menopausal women.

Possible Benefits of the Study:
A possible benefit of the study is that your bone mineral content may increase as a result of bisphosphonate treatment or exercise. This benefit is not guaranteed.

Procedures:
Initially, you will be given a questionnaire that assesses whether you have medical problems that may effect your bones or prevent you from participating in an exercise program. Your blood pressure will also be measured.

You will also be required to fill out a 3-day food diary, in which you will have to record all the food you eat for three successive days.

You will be randomly assigned to one of four groups. One group will take part in a weight-training exercise program three times a week for 12 months. A second group will receive a drug called bisphosphonate (cyclical etidronate), which slows down the rate of bone loss in post-menopausal women. If in this group, you will be required to orally take this drug at a dose of 400 mg/day for 14 days, followed by 76 days of calcium carbonate supplement (500 mg/day). This cycle will be repeated four times over twelve months. A third group will combine weight-training exercise and drug therapy. A fourth group will act as Acontrol≅ and will receive a placebo pill.

Your bone mineral will be measured initially, six months into the study and at the conclusion of the study (12 months). Measurements will be made with a machine called a dual energy x-ray absorptiometer.

Your muscular strength will be tested for eight different exercises. This involves measuring the maximal amount of weight you can lift once. Strength will be measured before the study, at six months and at 12 months. During these strength measurements, electrode Astickers≅ will be applied to your skin over the muscle to measure electrical activity in the muscle.

Risks:

There is some radiation exposure during the bone measurement with the dual energy x-ray apparatus, but it is small. The amount of radiation you will be exposed to is equivalent to the amount of radiation you would be exposed to during a return flight to Toronto at 30,000 feet and is about 10 times lower than a mammogram and twice as low as a chest x-ray.

Side effects of the drug (bisposphonate) treatment may include upset stomach, changes in taste and development of rashes.

There may be unforeseen risks during the project or after it is completed.

You are free to withdraw for the study at anytime and this withdrawal will not affect your access to services at the university or at the hospital.

All the information collected during the study will be stored either on computer disk or in files, both of which will be locked in filing cabinets at the College of Physical Education. The data collected during this study may appear in a graduate student thesis and in journal publications, but only aggregate data will be reported.

If you have any questions regarding the research project, you can call:
Dr. Philip Chilibeck at 966-6469 or or Shawn Davison at 966-6769 or

If you have any questions regarding possible side effects of the drug therapy, you can call Dr. Paul Peloso, who will be prescribing the drug and overseeing follow-up potential adverse effects, at 966-8262.

We will advise you of any new information that will have a bearing on your decision to continue in the study.

We will inform you of your individual results throughout the study.

I acknowledge that the study and contents of the consent have been explained to me and that I understand the contents and that I have received a copy of the consent for my own records.

Date

Signature of subject:

Signature of researcher or agent:

Witness:

University of Saskatchewan
Advisory Committee on Ethics in Human Experimentation

April 22, 1998

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	EC #
P. Chilibeck	Physical Education	98-64

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT

CO-INVESTIGATORS

SPONSORING AGENCIES

Grant Application to HSURC

TITLE:

Post-Menopausal Osteoporosis in Saskatchewan: Prevention with Exercise and Bisphosphonate Therapy

APPROVAL DATE	TERM (YEARS)	AMENDED:	MODIFICATION OF:
April 22, 1998	3	April 21, 1998	Consent Form

CERTIFICATION:

The protocol and consent form for the above-named project have been reviewed by the Committee and the experimental procedures were found to be acceptable on ethical grounds for research involving human subjects.

APPROVED.

H.E. Emson MA MD FRCPC
Chair
University Advisory Committee on
Ethics in Human Experimentation

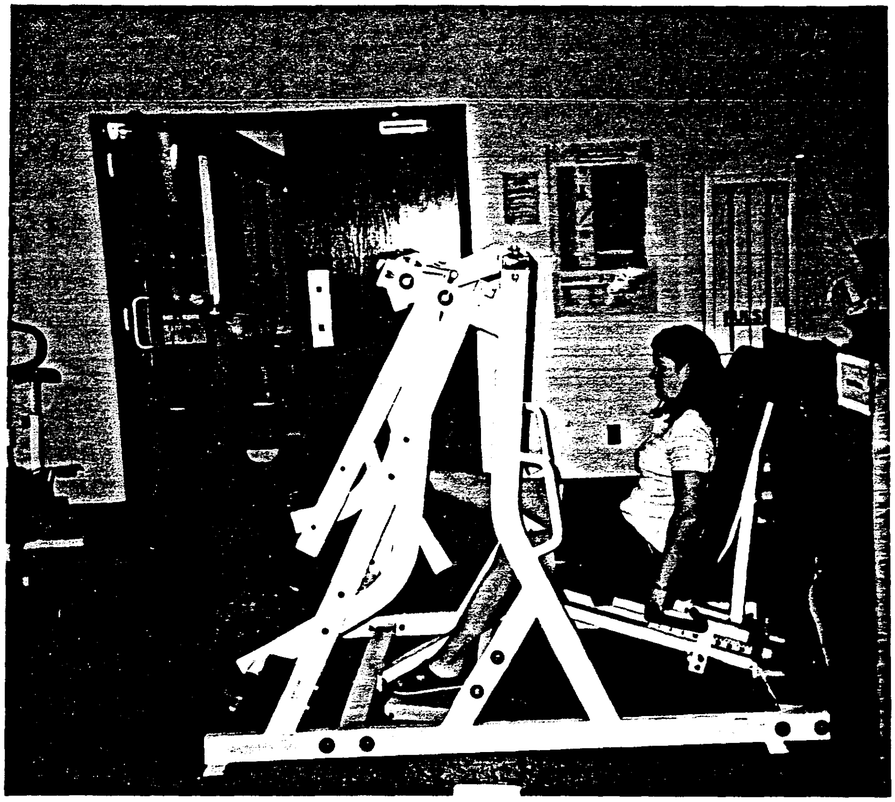
This Certificate of Approval is valid for the above term provided there is no change in the experimental procedures, subject to annual reapproval.

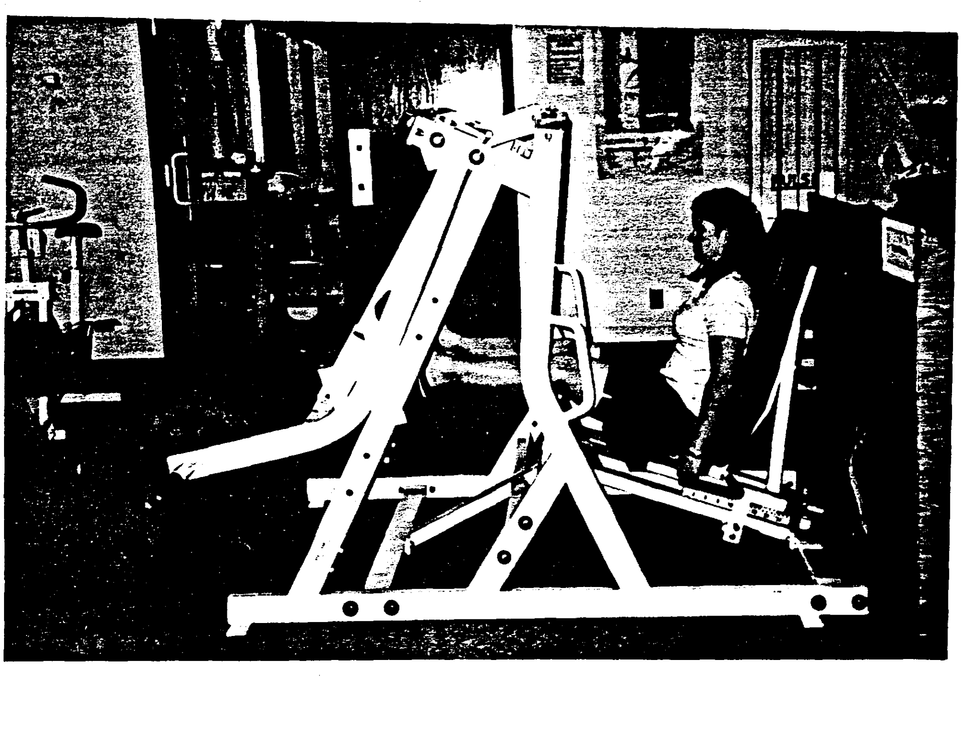
Please send all correspondence to:

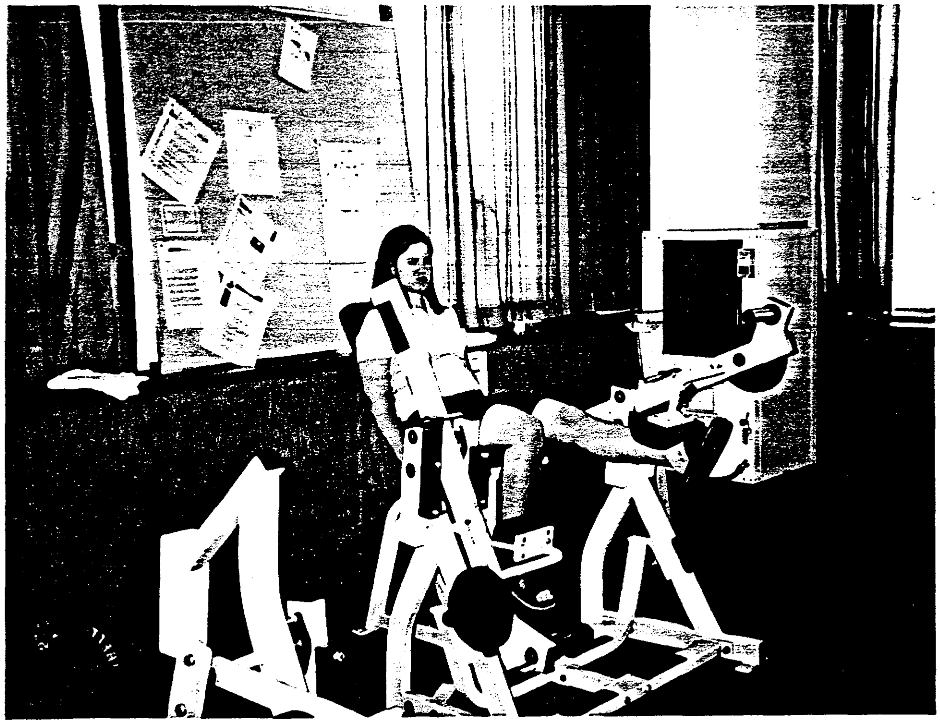
Office of Research Services
University of Saskatchewan
Room 210 Kirk Hall, 117 Science Place
Saskatoon, SK S7N 5C8

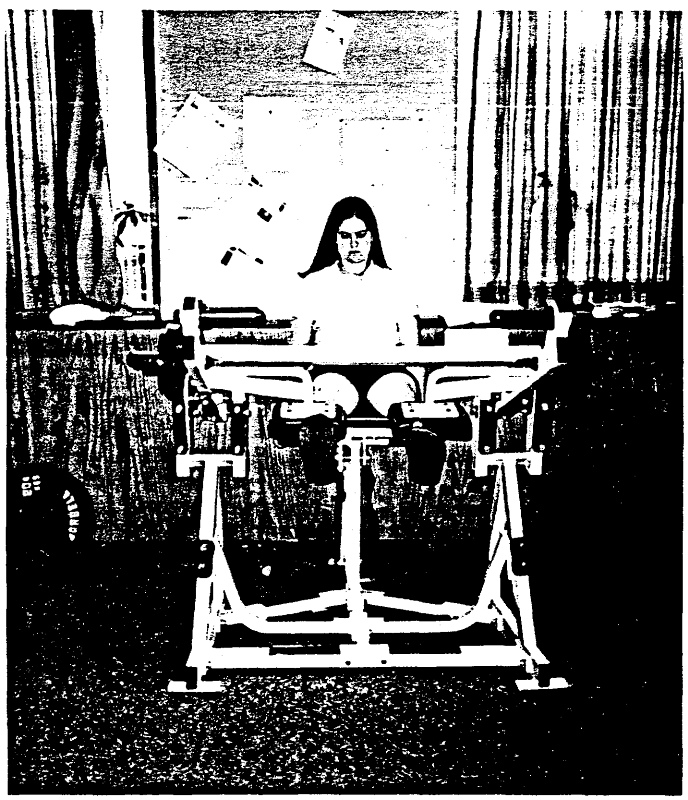
APPENDIX I

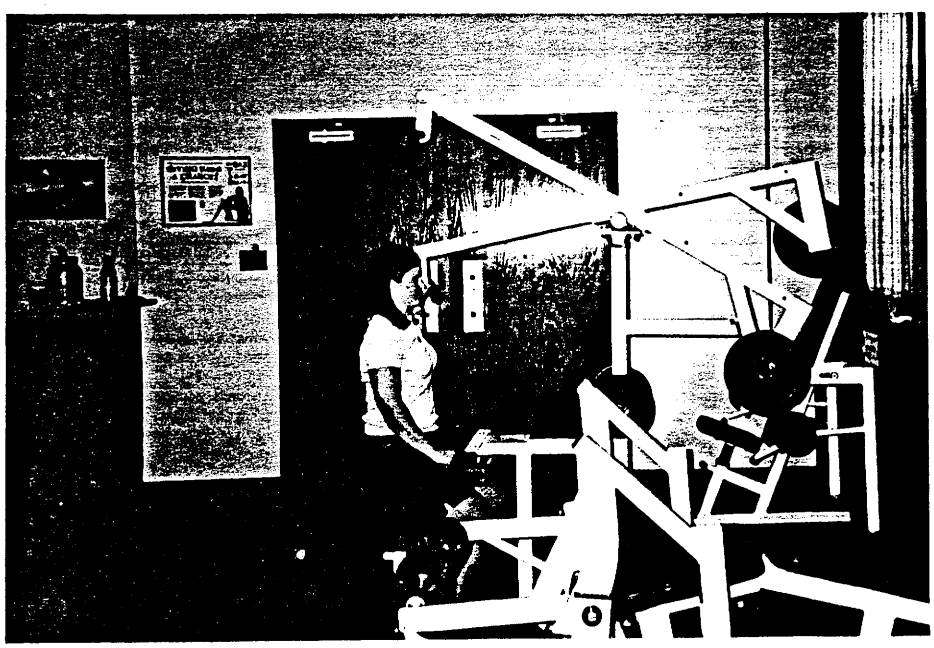
Photographs for Test (1-RM) Machines











APPENDIX J

Glossary of Abbreviations

1-RM = one repetition maximum

ANOVA = analysis of variance

BI = bilateral index

BL = bilateral

BLD = bilateral deficit

BLF = bilateral facilitation

CNS = central nervous system

CSA = cross-sectional area

CT = computed tomography

DEXA = dual energy x-ray absorptiometry

EMG = electromyogram

HW = hydrostatic weighing

KE = knee extension

LAT = lat pulldown

LP = leg press

UL = unilateral