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LOWER LIMB DOMINANCE AND VOLUME IN HEALTHY INDIVIDUALS

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ABSTRACT

Upper limb dominance is associated with increased limb volume, however there is a paucity of evidence if this is true for the lower limbs. This study investigated if there is a normative volume difference between the dominant and nondominant leg. Healthy volunteers between the ages of 18-40 years were recruited. Exclusion criteria included previous lower limb surgery, BMI >30, or pregnancy. An experienced lymphedema nurse specialist measured the circumference of each limb at 4 cm intervals from the malleolus to the groin. Measurements were used to calculate volume of each limb in milliliters. 100 (52 male, 48 female) participants met our inclusion criteria. 86% were right leg dominant and 14% left leg dominant. 93% demonstrated an average increased volume of 349 ml (4.5%) in the dominant leg which is statistically significant (p<0.001). Age, sports, and gender did not affect lower limb volumes. This is the first study to show a normative variance in leg volume in healthy individuals, with a greater volume in the dominant leg. This should be taken into consideration when managing and measuring outcomes for patients with conditions resulting in enlarged lower limbs.

Keywords: Limb dominance, limb volume, lower limb, lymphedema

It is well established that the general population have a dominant upper limb, with greater strength (1) and volume in the dominant arm (2,3). In contrast, there has been little research on lower limb dominance and its effect on volume. Hunter et al (3) reported greater muscle strength in dominant lower limbs in a cohort of Australian women and attributed this to greater habitual use of the dominant muscle groups, but they made no assessments on volume. Ditroilo M et al (4) investigated the effects of dominance on muscle function in upper and lower limbs finding greater strength in dominant limbs, but they also made no comment on volume. Eckstein F et al (5), aiming to better understand joint disease in unilateral osteoarthritis, performed a magnetic resonance imaging (MRI) based study assessing leg dominance and its effect on cartilage loss. 15 healthy individuals were recruited and this study showed trends (not statistically significant) towards larger muscle transverse cross-sections of the thigh and calf on the dominant lower limb. Dominance was not associated with significant differences of the knee joint cartilage. While this study alludes to a greater volume in a dominant lower limb, this conclusion is reliant on a single transverse MRI image, which may not be a true representation of the entire limb volume.

At the time of this study, there has been no published literature analyzing lower limb dominance and its effect on limb volume. Information on normative leg volumes and its relationship with leg dominance is important particularly in the context of treating patients with conditions such as lymphedema. Our hypothesis is that lower limb dominance is associated with a greater volume. As secondary outcomes, we wanted to identify if and how gender, sports, and upper limb dominance affected lower limb dominance and volume.

METHODS

Sampling Frame

Following approval from the local ethics committee, healthy volunteers between the ages of 18-40 years were recruited through local advertisement. Inclusion criteria were independent mobility and agreement to participation. Exclusion criteria included: prior surgery of any kind of the lower limb; Body Mass Index (BMI) >30; cardiac failure, renal failure, or liver failure; pregnancy; malnutrition, or any active lower limb conditions such as varicose veins or pre-existing lymphedema. Malnutrition Universal Screening Tool (MUST) was used to estimate the volunteers' nutritional status. Written informed consent to participate in the study was obtained from all volunteers.

Data collected included age, past medical history, upper and lower limb dominance, and participation in sports (defined as greater than 2 hours of activity per week). Dominance was established independently for the upper and lower limbs.

Upper limb dominance was ascertained by direct questioning of which hand they normally use for daily activities and writing (6). Lower limb dominance was determined firstly by asking which leg participants thought was their dominant leg, secondly by giving participants a ball to kick towards a target, and lastly with a gentle push to determine the leg which was used to break their fall.

Volume Measurement

An experienced lymphedema nurse specialist measured the circumference of each limb at 4cm intervals from the malleolus to the groin. Measurements were entered into a validated software program that calculated each limb volume in milliliters. This formula utilizes truncated-cone measurements and the volume between two adjacent measurements is calculated by this formula:

$$V = 4/12\,\pi\,(C_1^2 + C_1C_2 + C_2^2)$$

where V is the volume between two segments, C_1 and C_2 are the measured adjacent circumferences. This entire limb volume is calculated by adding up all the segmental volumes.

Statistical Analysis

Statistical analysis was performed using statistical software (IBM SPSS Inc.). The Gaussian distribution of the parameters was tested using Kolmogory-Smirnov normality test. A p-value of 0.01 or less was considered statistically significant.

RESULTS

100 (52 male, 48 female) participants met our inclusion criteria. Through our three point assessment of lower limb dominance, we identified 86% to be right leg dominant and 14% to be left leg dominant. It was found that all participants were aware of their leg dominance, which was confirmed by the ball and push test. There was complete concordance of all three test items in all participants and no individual claimed to be ambidextrous.

75% answered yes to participation of greater than 2 hours of sports per week, and 92% informed us that they were right hand dominant.

The vast majority (93 out of 100) demonstrated an increased volume in the dominant leg with an average discrepancy of 349 ml. This means that on average, each person's dominant leg is 4.5% bigger than their non-dominant leg. The difference was found to be statistically significant ($p<0.001$) (*Table 1*).

TABLE 1
Comparing Dominant and Non-dominant Leg Volumes

	Mean Volume (ml)	Std. Deviation (ml)
Dominant	8041.78	1738.41
Non-dominant	7693.24	1798.90
Mean difference	349 ml (4.5%)	
Paired t-test p-value	<0.001	
One way ANOVA p-value	<0.001	

TABLE 2
Volumes of Dominant Right and Left Legs

	Mean Volume (ml)	Std. Deviation (ml)
Right leg dominant n=86)	8023.17	1810.84
Left leg dominant (n-14)	8156.07	1247.89
Mean difference	132 + 386.47	
Independent t-test p-value	0.453	
One way NOVA p-value	0.792	

We performed a separate analysis on the 7 subjects (4 males and 3 females) whose dominant leg was smaller than the non-dominant leg. The mean and median age of these subjects are 24 years. Five of the 7 subjects (71.43%) are active in sports. Four subjects (57.14%) are right leg dominant. The mean dominant leg volume is 7637.29 ± 1154.34 ml and the mean non-dominant leg volume is 7807.29 ± 1387.55 ml. The mean difference was not statistically significant (170 ± 299.13 ml, p=0.183).

There was no difference between the dominant legs of those who were right legged and left leg dominant (*Table 2*).

Analyzing gender, the mean volume in the female dominant leg is 7704 ml and 8353 ml for the male dominant leg. The difference in the mean volumes between males and females was not found to be statistically significant (*Table 3*).

We also found that sports did not affect limb volume (independent t-test p=0.214, one way ANOVA p=0.758). The majority of right handed individuals were right leg dominant. Of the eight left handed individuals, four were right leg dominant (50%) and the other half were left leg dominant (*Table 4*). There was no upper or lower limb ambidexterity identified in any participants.

A significantly higher percentage of left-handers than right-handers showed crossed lateral preference (odds ratio 8.2; p<0.001), that is, for preference of the opposite-side foot.

DISCUSSION

The concept of limb dominance is stemmed from the premise that the two hemispheres of the brain function differently and there is a preferential use of either the right or left limb, eye, ear, and other bodily functions. The hemisphere of speech is the stronger hemisphere, and the majority of humans have a dominant left cerebral hemisphere. Upper limb dominance is fairly easy to establish, with most people knowing which hand they use for activities such as writing, tooth brushing, and sports. Dominance in the lower limb, however, is less discernable and there was substantial debate as to what defined a dominant leg. It was only in 1987, that Chapman et al (7) developed a reliable (alpha=0.89) 11-item behavioral inventory of foot preferences which are shown in *Fig. 1.* This landmark study laid down scientific validated parameters to establish lower limb dominance. Rosado in 2006 examined the effect of unanticipated jump landing on leg dominance, and found that the dominant leg is used for stability, is stronger, and accommodates more force than the non-dominant leg (8).

Most clinicians analyzing lower limb

TABLE 3
Leg Volumes in Females and Males

	Female Mean volume/ standard deviation (ml)	Male Mean volume/ standard deviation (ml)
Dominant	7704.02 ± 1311.25	8353.56 ± 2018.75
Non-dominant	7437.67 ± 1171.63	7929.15 ± 2213.25
Mean difference	266.35 ± 239.42	424.41 ± 1305.29
Independent t-test p-value	0.171	
One way ANOVA p-value	0.411	

TABLE 4
Association of Upper and Lower Limb Dominance

	Right leg dominance	Left leg dominance
Right hand dominance (n=92)	82 (89.13%)	10 (10.87%)
Left hand dominance (n=8)	4 (50%)	4 (50%)

dominance utilize one or two of the Chapman inventory items in clinical studies, in particular standing on one foot and kicking a ball for ease and simplicity (9-12). We chose to ask participants about leg dominance to establish if people were leg dominant aware, and in particular to identify any lower limb ambidextrous individuals which would deserve subgroup analysis. There were none in this group. Item 2 from the Chapman in 'to kick a ball' was utilized as this has a high (0.66) correlation of identification of dominance when all 11 inventory items are used. In addition, we elected to affirm our findings with a gentle non-lateralized push from the back to ascertain which leg was used to break their fall as per Rosado's study to identify the dominant leg. It was interesting to note that all participants had confidently correctly identified their leg dominance which was confirmed by the subsequent two tests.

Despite the myriad of papers on dominant legs and strength, to date there have been no publications on volume. This decision has implications on treatment for conditions such as lymphedema, lipedema, and proteus syndrome to name a few. Results for volume reducing treatments such as decongestive therapy or surgery need to be measured and monitored accurately. Often in unilateral disease, the contralateral leg is used as a gold standard towards which treatment of the affected leg is targeted towards. Knowledge of leg volumes in a healthy population and the extent of variance between the dominant and nondominant leg are important factors to consider when treating such patients. We have found that there is a normative discrepancy in leg volume in healthy individuals, with an average of 4.6% larger dominant leg compared to the nondominant leg ($p<0.001$). This discrepancy has implications in treatment of patients receiving lower limb volume reducing treatment.

There are many methods to measure lower limb volumes. Laser plethysmography (13), perometry, computer-aided design, photometrics, MRIs, and hand scanners are some of the contemporary methods for limb volume measurement (14). Numerous studies

1. Stand on one foot
2. Kick a ball
3. Stamp a tin
4. Push a golf ball through a maze
5. Write name in sand
6. Smooth sand
7. Arrange pebbles
8. Balance rod
9. Push a golf ball around a circle
10. Step on a stool
11. Kick as high as possible

Fig. 1. Chapman et al 11-item behavioral inventory of foot preference (7).

have been published on the various approaches to volume measurement, all of which are as valid and reliable as the other (15). The water displacement method of immersing the entire limb and calculating the volume of displaced fluid is based on the Archimedes Principle, which is considered by most authors as the gold standard. Water displacement is an accurate method of volume assessment but has practical limitations with regards to equipment set-up, transport, and patient factors. Girth measurement with a measuring tape is simple, quick, cost effective, and acceptable to most patient. Karges et al (16) compared water displacement and girth measurement and found both methods to be reliable and accurate. We have used girth measurements and truncated volumes for 10 years at our lymphedema service and have found this method clinically reliable and hence suitable for the purposes of this study.

We have found that right handed individuals are 8.2 times more likely to have ipsilateral leg dominance compared to left handed people who exhibit less predictability of lower limb dominance. In this cohort, 89.13% of right handed participants were also right legged, while 50% of the left handed were left legged. This finding is consistent with other studies. Shugaba et al (17) studied hand and foot preferences in 50 footballers, and found that 85% of right handed footballers were also right footed. Kang T et al (18) similarly found that a higher percentage of left handers showed crossed lateral preference of the foot compared to right handers. This consistent phenomenon suggests that right handed/legged are more lateralized than the left handed/legged (19).

It would appear logical that sports may increase muscle mass and hence volume in the dominant leg; however, we did not find this association to be statistically significant. McCreesh et al (20) performed ultrasound measurement of the size of the anterior tibial muscle group in a cohort of 10 Gaelic footballers and found that muscle thickness was significantly larger in the dominant leg. Our criteria of two hours of sports a week does not discriminate lateralising sports such as football or tennis from non-lateralising exercise such as jogging. Perhaps our findings would be different with more defined questioning.

There are limitations to this study. We have ascertained leg dominance with only 3 tasks. The Chapman's 11 item inventory is ideal however we had felt our three items were sufficient and its simplicity would improve volunteer participation. The study number is small, and each task was only performed once. Volunteers may be aware of which leg they have used to kick the ball, hence consciously or subconsciously determining the leg which would be used for the stabilizing task. This flaw is unfortunately inherent to all studies utilizing dominance tasks on the same day, or on a time scale that permits memory. There were no participants who were found to be ambidextrous. It is well known that a small proportion of people are ambidextrous and increasing our study size to include this subgroup for analysis would be valuable. To minimize measurement variability, all measurements were performed by a skilled lymphedema nurse with 10 years of experience in measuring limbs.

This study is the first to show that the dominant leg is associated with greater volume. This finding is important to consider when treating patients with lower limb disease undergoing volume reducing treatment. We aim in the future to increase our participation numbers and perform subgroup analyses to better understand leg dominance and its relationship with leg volume.

CONFLICT OF INTEREST AND DISCLOSURE

All authors declare that no competing financial interests exist.

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