ANATOMICAL INVESTIGATION OF THE TENSOR VASTUS INTERMEDIUS IN THE QUADRICEPS MUSCLE GROUP

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Past anatomical research has shown examples of fusion of the quadriceps muscle group. Researchers have seen examples of this muscle group exhibiting extra muscle bellies or multiple small flaps. A recent study has confirmed a consistent variation to this muscle group, that could qualify as a new muscle, the tensor vastus intermedius (TVI). This study investigates the presence and type of TVI muscle found in 70 cadavers, with additional focus on the arterial supply to the lateral aspect of the quadriceps muscle group and the variations associated with these vessels. To further understand the function and clinical implications of this new muscle, a large cumulative sample size is necessary to investigate its tendencies and variations. These data lend strong support to the existence of this new muscle, the TVI.

ANATOMICAL INVESTIGATION OF THE TENSOR VASTUS INTERMEDIUS

IN THE QUADRICEPS MUSCLE GROUP

THESIS REPORT

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Warmest Regards,

Christopher T. Collins

"If I have been able to see farther than others, it is because I stood on the shoulders of giants"

- Sir Isaac Newton

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CHAPTER I

INTRODUCTION

By all definitions of and images presented in anatomy textbooks, the quadriceps muscle group is defined as four distinct muscle bellies: rectus femoris (RF), vastus lateralis (VL), vastus intermedius (VI) and vastus medialis (VM). However, current research has portrayed this description to be inadequate, specifically with regards to an additional muscle belly, the tensor vastus intermedius (TVI), found between the VI and VL muscles. Until last year, any mention of this extra belly was attributed to the VL muscle (Willan et al., 1990; Willan et al., 2002; Becker et al., 2009; Becker et al., 2010). Now this muscular contribution is considered a separate entity based on its proximity to VI and the contradicting neurovascular supply with VI/VL (Grob et al., 2016; Grob et al., 2016; Rajasekaran et al., 2016). Recently, clinical cases have been described where the TVI muscle and its tendon have specifically become problematic. In one case, a nine-year-old girl presents with unusual limitations during knee flexion secondary to an accessory quinticeps tendon (Labbe et al., 2001). The other case reported a rupture of the TVI muscle causing pain and dysfunction in a 62-year-old female patient (Grob et al., 2016). As the foundation of evidence for the TVI muscle accumulates, additional research must be conducted to understand the prevalence of this new muscle among populations. If we can accurately quantify prevalence of the TVI we will be one step closer to understanding how this muscle and tendon contributes to the quadriceps muscle group.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

Multiple studies have investigated variations of the quadriceps muscle group, and more specifically the VL (Willan et al., 1990; Engstrom et al., 1991; Willan et al., 2002; Bevilaqua-Grossi et al., 2004; Becker et al., 2009; Waligora et al., 2009; Becker et al., 2010; Toia et al., 2015). An additional (fifth) muscle head was observed in about one third of the thighs (36% in 75 thighs) by Willan et al. (1990). Distally, this muscle belly was usually replaced by a tendinous lamina which contributed to the quadriceps tendon, but occasionally it fused directly with VI or VL. This study also noted that fusion between VI and VL varied from being almost completely fused to less than one third of the interface between the muscles, (Willan et al. 1990).

Over a decade later, a journal review article that described the variability in the quadriceps gave an alternative explanation for the new muscle (Willan et al., 2002). They concluded that even though the results of the previous studies confirm the prevalence of fused vasti in human populations, it is noteworthy that the concept of separation of the bellies of the quadriceps is of greater biological interest, because this follows both an evolutionary and development trend. The bellies of the anterior thigh muscles seem to have evolved with greater separation and specialization.

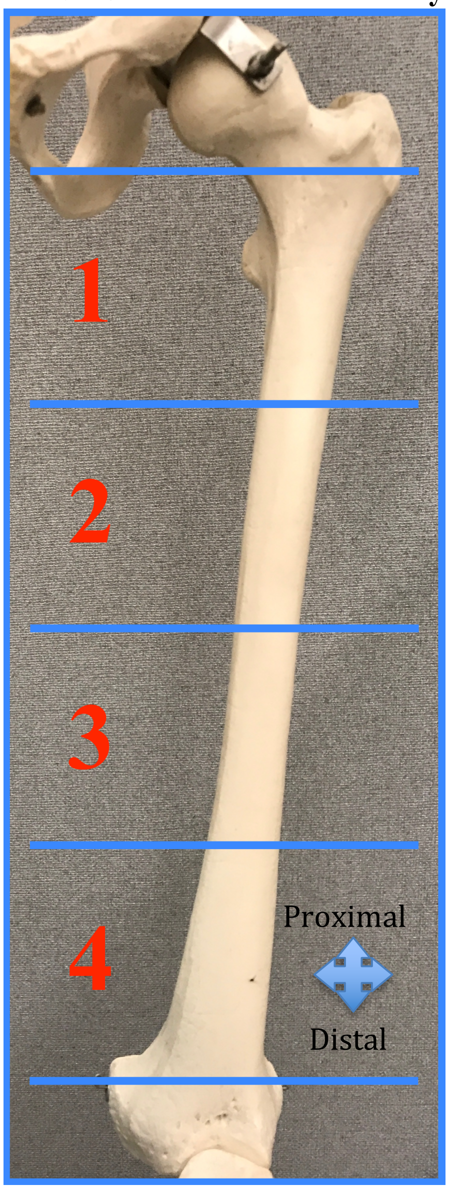
The fifth muscle head of the quadriceps was reported to be its own muscle, and was so named the tensor of the vastus intermedius for its similarity to the tensor fascia latae (TFL) muscle and the tensing force it appears to assert on the VI (Grob et al., 2016). This study showed separate innervation of the TVI muscle belly in all 26 thigh dissections, with only 4 out of 26 thighs being unable to clearly separate the proximal belly and 5 out of 26 having multiple proximal bellies. Along with the TVI muscle belly presence, there is variation among its contribution to the quadriceps tendon, which is classified based on the muscle it fuses with: VI-type, VL-type, common type (both VI/VL), or independent type (Neither VI/VL).

The contributions of the quadriceps muscles to the quadriceps tendon has been discussed in multiple journals and has even been updated with the recent discovery of the TVI. Andrikoula et al. (2006) showed that the extensor mechanism consisted of four distinct quadriceps bellies that shared a common insertion. The quadriceps tendon was tri-laminar (i.e., composed of three layers) in all 10 cases, with the anterior layer formed by rectus femoris (RF), the intermediate layer formed by vastus medialis (VM) and VL, and the deepest layer formed by the tendon of the VI. Waligora et al. (2009) found similar results in 11 out of 20 cases, while the remaining cases had either a bi-laminar formation or tetra-laminar formation in 6 out of 20 and 3 out of 20 cases respectively. With the discovery of the TVI, Grob et al. (2016) has found that the quadriceps tendon can be described by six components forming a tri-laminar structure with a sub-divided intermediate layer. The superficial layer is comprised of the RF tendon and the VM, which contributes to all the layers; the superficial intermediate layer is formed by the superficial medial portion of VI and the VL; the deep intermediate layer is formed by the deep medial portion of VI and the TVI; while the deepest layer is formed by lateral layer of VI. Based on the type of TVI (VI-Type, VL-Type or Independent), the VI or VL portions can be considered one with the TVI portion, forming a true tri-laminar structure without a sub-divided intermediate layer.

Typically, there is one femoral nerve branch to the VL with a primary proximal & distal branch, which further divide into secondary branches and muscular branches as they innervate the muscles (Patil et al., 2007; Revenaugh et al., 2012). This innervation covers the VI and TVI as well. Essentially all the VI and TVI studies mention the same innervation pattern of this femoral nerve branch with similar variations in the amount of primary and secondary branches (Willan et al., 1990; Willan et al., 2002; Becker et al., 2009; Becker et al., 2010; Toia et al., 2015; Grob et al., 2016). The arterial supply in question is consistently defined by all studies as being the lateral circumflex femoral artery (LCFA), the transverse branch of LCFA gives rise to branches for VI and TVI (if mentioned) while the descending LCFA is responsible for the VL (Willan et al., 1990; Willan et al., 2002; Becker et al., 2009; Becker et al., 2010; Toia et al., 2015; Grob et al., 2016). There are other studies that focus specifically on the origin/orientation of profunda femoris artery (PFA) and LCFA that could possibly explain quadriceps muscle variations (Dixit et al., 2011; Phalgunan et al., 2013; Nasr et al., 2014; Goel et al., 2015; Singh et al., 2016). One study concluded that the development of the vasculature of the lower limb precedes the morphological and molecular changes that occur in the limb mesenchyme, hence vascular variations are more of a rule than an exception (Dixit et al., 2011). This early vascular development indicates that the arterial supply will likely dictate muscular development. Anomalous patterns of vascular system may be due to: (1) divergence in the mode and proximo-distal level of branching; (2) presence of unusual compound arterial segments; (3) aberrant vessels that connect with the principle vessels, arcades or plexuses; (4) vessels occupying exceptional tissue planes and having unsuspected neural, myological or osteo-ligamentous relationships.

Toia et al. (2015) described the functioning segmental anatomy of the VL to be composed of two aponeuroses and three anatomical partitions: superficial, intermediate & deep. These functional units pertain to anterolateral free flap procedures, however, the neurovascular supplies to each partition are the same as mentioned in all the VI/TVI research as well as the specific nerve and artery journals (Willan et al., 1990; Willan et al., 2002; Patil et al., 2007; Becker et al., 2009; Becker et al., 2010; Dixit et al., 2011; Revenaugh et al., 2012; Phalgunan et al., 2013; Nasr et al., 2014; Goel et al., 2015; Toia et al., 2015; Grob et al., 2016; Singh et al., 2016).

FIGURE 1: Four Regions of Femur for Describing Aberrant Patterns of Vasti Fusion in TVI Cases – Picture Taken by Author in UNTHSC Anatomy Lab



SPECIFIC AIMS

The aim of this practicum study is to investigate the presence of the tensor vastus intermedius (TVI) in 70 femoral anterior thigh dissections. With respect to the TVI, VI & VL muscles, understanding the neurovascular supply and variations that correspond with the morphology is also of significant importance. In preliminary dissections performed on 49 thighs, the focus was specifically on TVI presence, tendinous properties and nerve innervation; while both arteries and veins were removed after the relevant femoral nerve branches were traced to the muscles. This preliminary investigation showed the TVI muscle was present in at least 37% of donors. I predict that this number is an under-representation of the true presence of this structure.

Preliminary dissections were conducted on dissected specimens with varying degrees of preservation and structural integrity. Based on these dissections, I predict the actual presence of TVI, however, will fall between 37-60% in complete well-preserved specimen. Given the lack of description for TVI type classification, developing a set of regions to describe where the fusion or separation occurs could help properly assign each TVI muscle to the appropriate type (Figure 1). The four regions shown in Figure 1 are rough guidelines used to describe the TVI tendon in cases that did not follow a consistent fusion pattern distally. Ideally, this study will find a correlation between variations of the FA, PFA and LCFA with the presence and or type of TVI muscles found in cadaver dissections. If any variation correlates with increased TVI muscle presence, it will likely be a more proximal origin for PFA and LCFA.

SIGNIFICANCE

Documenting the frequency of the TVI muscle in humans is necessary for three major reasons: (1) to better understand the biomechanical limitations of this muscle; (2) to define the implications on surgical approaches of the hip and thigh; and (3) to discover how this muscle can be utilized in surgical procedures such as facial reconstruction, breast reconstruction, and heart bypass surgery. The first known clinical case reported the TVI muscle and tendon causing problems by limiting knee flexion in a nine-year-old girl (Labbe et al., 2011). Another case specifically reported a TVI muscle rupture, causing pain and loss of normal function in a 62-year-old female (Grob et al., 2016). Regarding implications of surgical approaches, Omakobia et al. (2016) reported a case of aberrant quadriceps muscle fusion that prevented a successful anterolateral thigh flap harvest (ALTf) on one side; however, the contralateral thigh had normal anatomy which allowed successful completion of the procedure. Another surgical study investigated a direct anterior approach to the hip, which is commonly performed in total hip replacement surgery (Grob et al., 2015). While attempting to distally extend the procedure, the results showed increased risk of causing damage to an important neurovascular bundle in the lateral thigh. The most relevant clinical procedure to this research practicum is the ALTf harvest. During this procedure, a portion of the VL and its vasculature can be used as a graft for facial reconstructive surgery (Rozen et al., 2009; Toia et al., 2015; Grob et al., 2016; Omakobia et al., 2016), breast reconstruction after mastectomy (Dixit et al., 2011; Goel et al., 2015), and in coronary bypass surgery (Goel et al., 2015).

MATERIALS AND METHODS

The entirety of this research was conducted on donated human cadavers from the UNTHSC willed body program. These cadavers were recently dissected for the medical school anatomy course and were in varying degrees of preservation. Specimens that were excessively atrophied were not included (e.g., wheelchair-bound or ALS). The sample size includes 36 cadavers, 19 females and 17 males. All specimens were formalin embalmed. The dissection began with cutting the distal origin and proximally reflecting of the rectus femoris (RF) and sartorius (SA) muscles. The reflection of these muscles also allowed for a glance at the distal insertions into the quadriceps tendon which can reveal the TVI tendon upon first examination in most cases. Identification of the neurovascular branches for the two superficial muscles, RF and SA, were followed back to the femoral nerve bundle and the femoral artery. After tracing the femoral nerve branches from the reflected muscles, the femoral nerve was dissected to specific

VL/VI branches. Finding these specific nerve branches allowed for the most direct identification of a TVI proximal belly. While dissecting the femoral nerve, the PFA could be exposed from its FA origin and the branches of LCFA could be traced to their destinations. With all important neurovascular supplies identified, the venous structures were removed for a less obstructed view to finish dissecting the muscle bellies up to the origin near the intertrochanteric line of the femur, which was the final step to determine the TVI type. After completing each thigh dissection, we specified whether the proximal TVI muscle belly was present and, if so, what type of muscle variation was seen: independent, common, VI-type, VL-type or multiple belly. If necessary, to understand the level of fusion between the quadriceps, a 4-region system was used to explain the tendinous patterns in more detail (Figure 1). The layers of the quadriceps tendon were also observed as they converge at the distal thigh. During the preliminary work and extensive research on the topic, the innervation of the femoral region seemed to be quite consistent so the focus shifted toward arterial variation instead. Most notably, we investigated the PFA as it originates from the FA, as well as the origin of the LCFA from either the PFA or FA (posterior, posterolateral, lateral, etc.) and the distance between the two origins. The further branching of LFCA and any shared trunks amongst the three branches were also observed. Lastly, the donor profile was included (Table 1) with measures of central tendency for the age of death (AOD) and gender ratios (M: F). Table 2 summarizes the areas of interest for this practicum study.

TABLE 1: Donor Population Data

Male: Female Ratio	**17:19**
AOD Mean	**82**
AOD Mode	**85**
AOD Range	**60-99**

Abbreviation: AOD – Age of Death

TABLE 2: Practicum Focus for TVI Muscle Presence & Arterial Variation

TVI Data Collection	**Arterial Variation Data Collections**
TVI Muscle Presence (Yes/No)	PFA & LCFA – Source and Position of Origin
TVI Type (Ind, Com, VI, VL, MB, or Non)	Distance from Midpoint IL – PFA Origin
Gender/Bilateral Variation – Fisher Exact Test	Distance from PFA Origin – LCFA Origin

Abbreviations: TVI – tensor vastus intermedius; Ind – independent type; Com – common type; VI – vastus intermedius type; VL – vastus lateralis type; MB – multiple belly; Non – no TVI; PFA – profunda femoris artery; LCFA – lateral circumflex artery; IL – inguinal ligament

RESULTS AND DISCUSSION

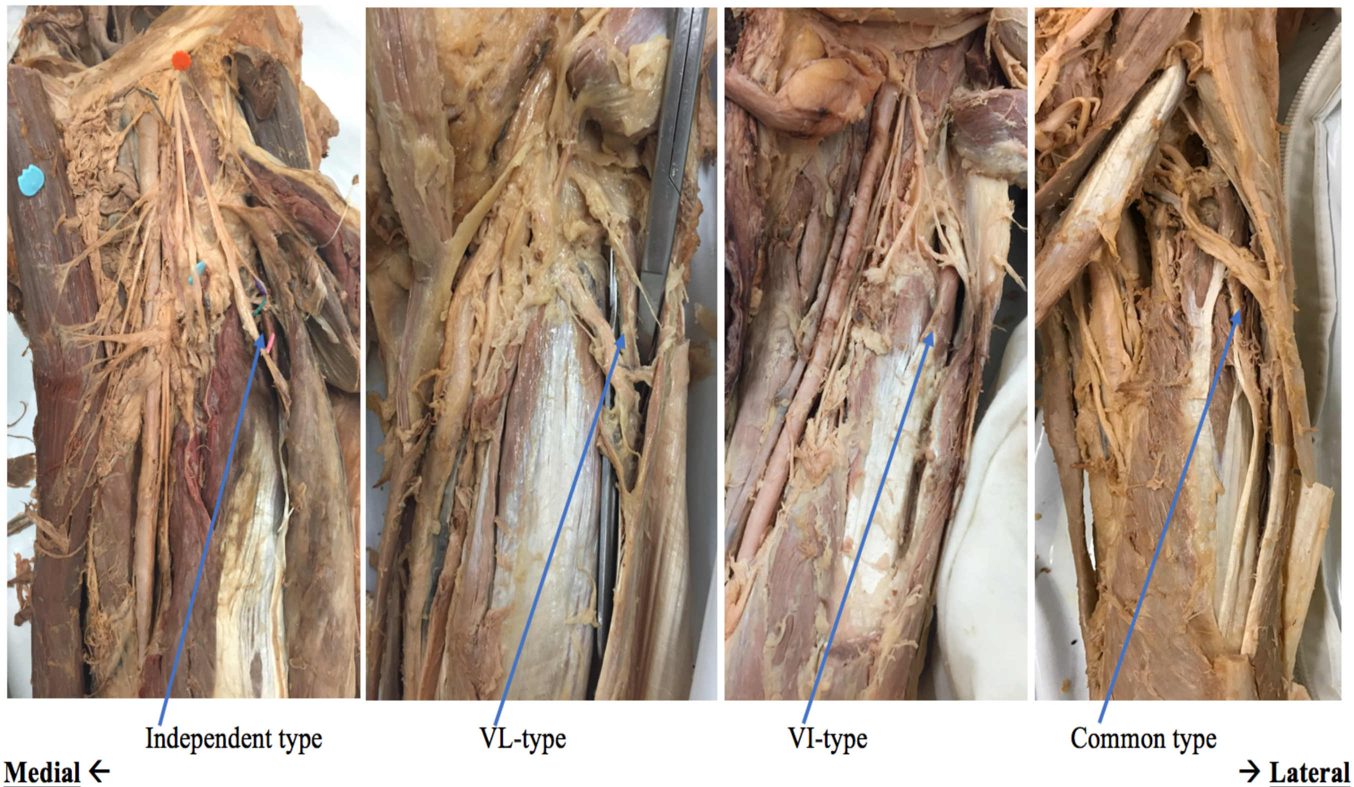
The TVI muscle was clearly identified in 51 of the 70 thighs (72.86%). Among the 36 female thigh dissections, 30 had the TVI Muscle (83.33%), but for the males, only 21 out of 34 thighs (61.76%) had the TVI muscle. After performing a Fisher Exact Test, the gender difference regarding presence of the TVI muscle was not statistically significant (P=0.06). As for the types of TVI muscles found, there were five independent type muscles among the females but none in the male population. There were nine total common type muscles, three of which were found in males and the remaining six were found in females. The VI-type muscle was found in 11 total thighs, six males and five females. The VL-type muscle was the most common variation seen in this study, with a total of 23 thighs, 10 males and 13 females. There were three cases where multiple bellies were found in the proximal thigh, two males and one female. As for bilateral comparisons in the paired samples, 17 of the 35 donors or 48.57% had different TVI muscle types in each thigh; for the males, this was observed in 5 out of 17 donors (29.41%) and females had 12 out of 18 donors (66.67%) with bilateral variation. In the original TVI muscle study, Grob et al., (2016) reported bilateral differences in six of the ten paired samples, which is relatively close to 48.57% given the difference in paired sample size. Table 3 and Figure 2 show prevalence of TVI types and dissection images of the four primary types, respectively.

TABLE 3: TVI Muscle Type Prevalence

TVI Type	M	F	Totals	Type %
Non - TVI	13	6	19	27.14%
Independent Type	0	5	5	7.14%
Common Type	3	6	9	12.86%
VI - Type	6	5	11	15.71%
VL - Type	10	13	23	17.14%
Multiple Bellies	2	1	3	4.29%
Total	34	36	70	
TVI %	61.76%	83.33%	72.86%	

Abbreviations: TVI – tensor vastus intermedius; VI – vastus intermedius; VL – vastus lateralis; Non – no TVI; M – male; F – female; % - percent of TVI presence

Figure 2 – TVI Muscle Types – Blue Arrow Indicates TVI Muscle Belly



Abbreviations: TVI – tensor vastus intermedius; VI – vastus intermedius; VL – vastus lateralis

The secondary portion of this anatomical investigation focused on the arterial variations of the PFA and LCFA in the thigh, for which the results of this practicum study along with the similar publications have been listed in Table 4 for comparison. In this study, the PFA originated from the posterior aspect of the FA in 45 out of 72 thighs (62.50%), the posterior-lateral aspect of the FA in 16 out of 72 thighs (22.22%), the lateral aspect of the FA in 10 out of 72 thighs (13.89%), and in one thigh, the PFA originated from the posterior-medial aspect of the FA (0.01%). The LCFA origin was also recorded in this study, with 12 out of 70 thighs (17.14%) originating directly from the FA and the remaining 58 thighs (82.86%) originated from the PFA as expected. The two most common sites of origin for the LCFA were the posterior-lateral aspect of PFA (14 out of 70) and the lateral aspect of PFA (35 out of 70). Other sites of LCFA origin can also be seen in Table 4, see next page.

The distance from the mid-point of the inguinal ligament to the origin of the PFA (IL-PFA) was measured and then the average value was calculated based on the side of the body and the gender. For females, the average IL-PFA distance in the left leg was 32.3 mm, and the right leg was 32.92 mm. As for the males, the average IL-PFA distance in the left leg was 42.29 mm, whereas the right leg was 45.04 mm. Lastly, the distance between the PFA origin and the LCFA origin (PFA-LCFA) was measured and recorded in the same format as the IL-PFA measurements. For the females, the left and right distances averaged 19.1 mm and 18.03 mm respectively. For the males, the left and right measurements of PFA-LCFA distance averaged 22.68 mm and 23.27 mm respectively. All outliers have been removed to prevent the averages from being skewed negatively. These outliers refer to measurements of 0 mm and negative values, where the LCFA originates at the same level as the PFA or prior to the PFA origin, respectively. There was only one case where the LCFA origin was proximal to the PFA origin (Figure 3). Table 5 shows results from the variation studies that measured the distances of origin for the PFA and LCFA.

TABLE 4: Comparing Origins for the PFA and LCFA to Similar Variation Studies

Note: All results have been converted to percentages for relevant comparison

Author/Year	Collins	Anwer	Choi	Dixit*	Dixit**	Nasr	Prakash	Rajani	Samarawickrama
Country	USA	India	Korea	India	India	Egypt/S.A.	India	India	Galle
PFA Origin	n=72	n=60	n=38	n=48	n=228	n=90	n=64	n=66	n=26
Post - FA	62.50%	-	-	31.25%	29.82%	25.56%	46.88%	-	46.15%
Post/Lat - FA	22.22%	-	-	35.42%	42.11%	42.22%	50.00%	53.03%	30.77%
Post/Md - FA	0.01%	-	-	-	-	12.22%	-	13.64%	-
Lat - FA	13.89%	-	-	-	18.86%	20.00%	-	18.18%	23.08%
Med - FA	-	-	-	-	12.72%	-	3.13%	3.03%	-
LCFA Origin	n=70	n=60	n=38	n=48	n=228	n=90	n=64	n=66	n=26
PFA-CT	-	R:1.67%; L:0%	-	R:8.34%; L:4.17%	R:8.75%; L:7.45%	14.40%	-	10.61%	7.69%
Post - PFA	1.43%	-	-	-	-	-	-	-	-
PFA	82.86%	R:41.67%; L:41.67%	86.84%	R:37.5%; L:45.84%	R:36.4%; L:38.6%	-	81.25%	-	92.31%
Post/Lat - PFA	20.00%	-	-	-	-	-	-	-	-
Lat - PFA	50.00%	-	-	-	-	70%	-	-	-
Ant/Lat - PFA	7.14%	-	-	-	-	-	-	-	-
Post/Lat - FA	12.86%	-	-	-	-	-	-	-	-
FA	17.14%	R:6.67%; L:8.33%	13.16%	R:4.17%; L:0%	R:3.9%; L:3.9%	15.56%	18.75%	-	-
Lat - FA	1.43%	-	-	-	-	-	-	-	-

Abbreviations: PFA – profunda femoris artery; FA – femoral artery; LCFA – lateral circumflex femoral artery; CT – common trunk – (Choi et al., 2007; Dixit et al., 2001; Samarawickrama et al., 2009; Prakash et al., 2010; Dixit et al., 2011; Anwer et al., 2013; Nasr et al., 2014; Rajani et al., 2015)

TABLE 5: PFA and LCFA Origin Measurements from Similar Variation Studies

Author	Anwer	Dixit*	Dixit**	Nasr	Prakash	Rajani	Samarawickrama
Country	India	India	India	Egypt/S.A.	India	India	Galle
	n=60	n=48	n=228	n=90	n=64	n=66	n=26
IL - PFA	37.12 mm	R:41-52 mm; L:46-54 mm	R:31-40 mm; L:41-50 mm	R:49.8 mm; L:49.3 mm	42 mm	R:21-40mm; L:11-40mm	R:55 mm; L:45mm
PFA - LCFA	21.2 mm	23-34 mm	21-30 mm	21-30mm	25 mm	-	1-40 mm

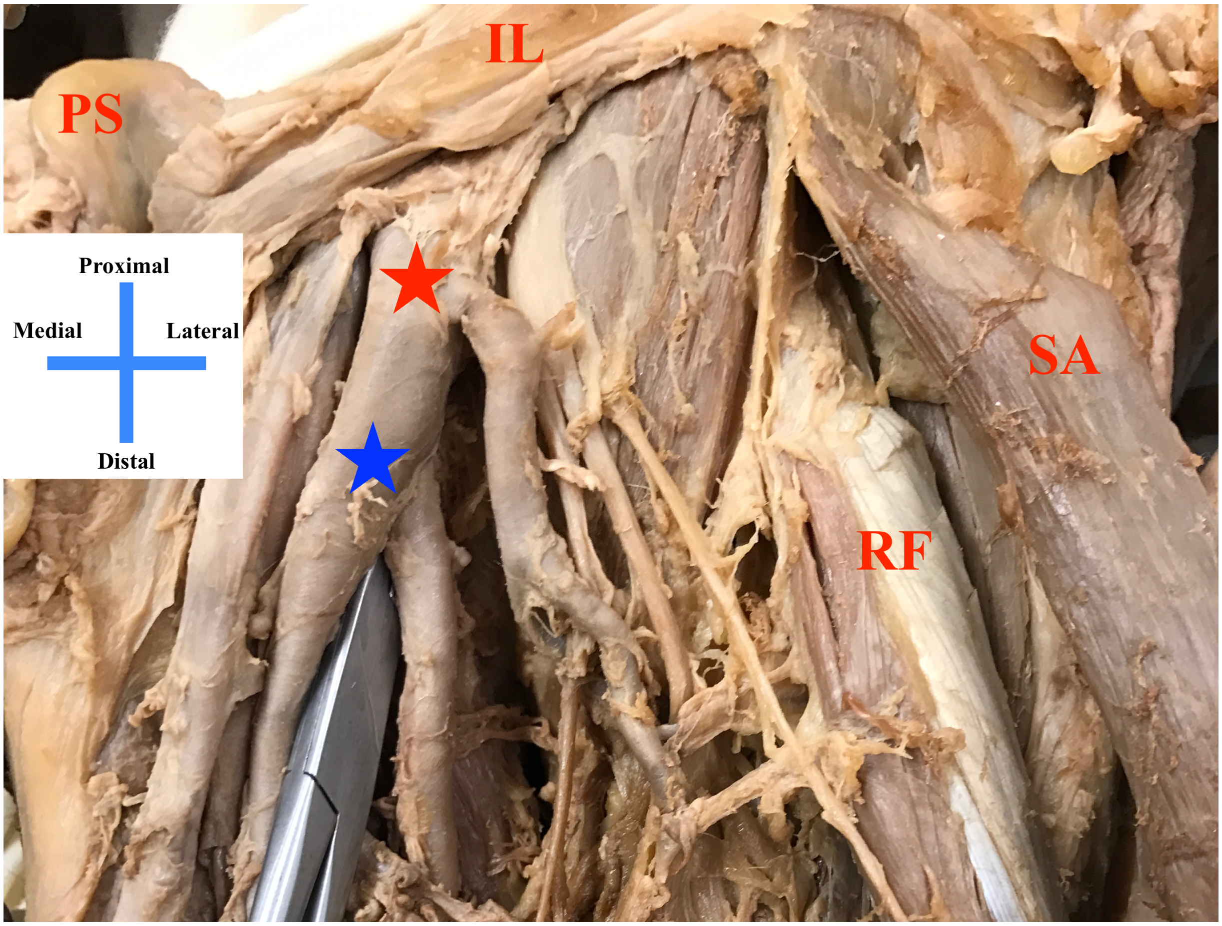
Abbreviations: IL-PFA – inguinal ligament to profunda femoris artery; PFA-LCFA – origin of PFA to origin of the lateral circumflex femoral artery – (Dixit et al., 2001; Samarawickrama et al., 2009; Prakash et al., 2010; Dixit et al., 2011; Anwer et al., 2013; Nasr et al., 2014; Rajani et al., 2015)

Table 6: Average Distances Between IL-PFA & PFA- LCFA by L/R; M/F; Non-TVI

AA Measure	Avg mm	StDv mm	MF Avg	NonTVI
F Left IL-PFA	32.30	13.81	37.29	-
F Right IL-PFA	32.92	10.61	40.08	43.811
M Left IL-PFA	42.29	12.91	-	-
M Right IL-PFA	45.04	6.12	-	-
F Left PFA-LCFA	19.09	10.90	20.89	-
F Right PFA-LCFA	18.03	14.43	20.65	18.813
M Left PFA-LCFA	22.68	12.75	-	-
M Right PFA-LCFA	23.27	10.66	-	-

Abbreviations: AA – arterial measure; Avg mm – average distance in mm; StDv mm – standard deviation for averages; MF – combined male/female average; Non-TVI – averages for samples without TVI muscle present; IL-PFA – inguinal ligament to profunda femoris artery; PFA-LCFA – origin of PFA to origin of the lateral circumflex femoral artery

FIGURE 3: Example of the LCFA Originating Proximal to the PFA



Abbreviations: Red Star: lateral circumflex femoral artery; Blue Star: profunda femoris artery; PS: pubic symphysis; IL: inguinal ligament; RF: rectus femoris muscle; SA: sartorius muscle

SUMMARY AND CONCLUSIONS

The intention for investigating arterial variation along with the TVI muscle was to find statistically significant differences by comparing the arterial values measured among donors with a present TVI muscle or even a specific TVI muscle type. There were no observable patterns when the TVI muscle groups were compared based on arterial data. However, the average distance from IL-PFA for thighs without a TVI muscle is greater than the average for thighs with a TVI muscle. This supports the hypothesis that TVI muscle presence would relate to more proximal origins of the PFA & LCFA.

The lack of significant differences does not disprove the idea that the development of vascular supply potentially leads to changes of muscle morphology in the lower limb mesenchyme (Dixit et al., 2011). The arterial variations observed in this practicum study have at least provided a better understanding of the femoral triangle, but data regarding the PFA and LCFA origins might be too far upstream regarding blood flow; with numerous muscular branches arising from the three divisions of the LCFA (ascending, transverse, descending), it is unlikely that the precise locations of the PFA and LCFA origins would play a role in muscular variations such as the TVI.

We found the TVI muscle to be present more often in female specimen, which was contradictory to the preliminary research findings, however many females were dismissed early in that specific sample. If females do indeed have increased TVI prevalence compared to males, possibly due to the differences in gait, this could potentially lead to increased incidence of knee injury among females, such as anterior cruciate ligament tears or other ligament damage.

In just over a year since the TVI muscle was formally described, it can now be found in five major journal articles (Grob et al., 2016; Grob et al., 2016; Grob et al., 2016; Grob et al., 2017; Rajasekaran et al., 2016). Although the groups of researchers responsible for our current knowledge of the TVI muscle may be few in numbers, they have made substantial progress towards understanding the presence and variations of the TVI. However, the big question regarding function and the contribution to the quadriceps muscle group remains unanswered;

what is the purpose of this separate muscle belly and why do these different variations occur? The answer is still unclear, primarily because there have only been 26 thigh dissections aimed specifically towards investigating the TVI muscle. Between the present study and preliminary research, 119 thighs have been investigated, which is almost five times more than the current published sample (Grob et al., 2016). Even with such large sample sizes being added, it is still not enough to fully understand the function of this new muscle.

Limitations

The most obvious of limitation for this practicum study is the average age of death among the donor population studied and the varying levels of muscle atrophy. In a quantitative study/review, Willan et al. (2002) cited multiple authors commenting on the prominence of connective tissue, fatty areas, and wasting in patients with neuromuscular disorders or malnutrition. It should also be noted that all donors used in the preliminary and current study had already been dissected for the medical school anatomy course. However, the area of interest was undisturbed as it remains deep to the usual structures of academic context and should not have had any effect on the research outcome. Between those two limitations, there were only two donors excluded from the TVI sample because of atrophy, plus two additional thighs with the LCFA torn from its origin.

Future Research

As previously mentioned, the small sample size continues to be a limiting factor in TVI research. Future research should be focused on examining as many thighs as possible while trying to find correlations with other relevant factors, or testing novel imaging and biomechanical techniques. One of the major accomplishments of this study was the large sample size acquired through the *Willed Body Program* at the UNT Health Science Center. Without the high turnaround of cadavers in medical school dissections, performing over 100 thigh dissections would be a much more difficult task. Although the present study did not utilize novel imaging or any biomechanical aspects, the resources are available if more research is conducted with the next medical school dissection. On that note, I would encourage any student or faculty with access to cadavers from a dissection course to consider this research topic, especially those who are on or near a medical campus. Beyond the need for gaining sample size and functional testing of the TVI, working backwards with a retrospective clinical study could be quite beneficial by studying patients with reoccurring knee problems and using sonographic imaging to determine whether the TVI is present.

REFERENCES CITED

Andrikoula, S., A. Tokis, H. S. Vasiliadis, and A. Georgoulis. 2006. 'The extensor mechanism of the knee joint: an anatomical study', *Knee Surg Sports Traumatol Arthrosc*, 14: 214-20.

Anwer, D., Karmalkar, A., Humbarawadi, R. 2013. 'A Study of Variation in Origin of Profunda Femoris Artery and its Branches', *International Journal of Biomedical and Advance Research*: 3.

Becker, I., G. D. Baxter, and S. J. Woodley. 2010. 'The vastus lateralis muscle: an anatomical investigation', *Clin Anat*, 23: 575-85.

Becker, I., S. J. Woodley, and G. D. Baxter. 2009. 'Gross morphology of the vastus lateralis muscle: An anatomical review', *Clin Anat*, 22: 436-50.

Bevilaqua-Grossi, D., Monteiro-Pedro, V., Sousa, G., Silva, Z., Berzin, F. 2004. 'Conrtibution to the Anatomical Study of the Oblique Portion of the Vastus Lateralis Muscle', *Brazilian Journal of Morphological Sciences*, 21: 6.

Choi, S. W., J. Y. Park, M. S. Hur, H. D. Park, H. J. Kang, K. S. Hu, and H. J. Kim. 2007. 'An anatomic assessment on perforators of the lateral circumflex femoral artery for anterolateral thigh flap', *J Craniofac Surg*, 18: 866-71.

Dixit, D., Mehta, L., Kothari, M. 2001. 'Variations in the Origin and Course of Profunda Femoris', *Journal of the Anatomy Society of India*, 50: 3.

Dixit, Daksha, Dharati M Kubavat, Sureshbhai P Rathod, Mital M Patel, and Tulsibhai C Singel. 2011. 'A study of variations in the origin of profunda femoris artery and its circumflex branches', *Int J Biol Med Res*, 2: 1084-89.

Engstrom, C. M., G. E. Loeb, J. G. Reid, W. J. Forrest, and L. Avruch. 1991. 'Morphometry of the human thigh muscles. A comparison between anatomical sections and computer tomographic and magnetic resonance images', *J Anat*, 176: 139-56.

Goel, S., J. Arora, V. Mehta, M. Sharma, R. K. Suri, and G. Rath. 2015. 'Unusual disposition of lateral circumflex femoral artery: Anatomical description and clinical implications', *World J Clin Cases*, 3: 85-8.

Grob, K, CH Fretz, MS Kuster, H Gilbey, and T Ackland. 2016. 'Knee Pain Associated with Rupture of Tensor Vastus Intermedius, a Newly Discovered Muscle: A Case Report', *J Clin Case Rep*, 6: 2.

Grob, K., T. Ackland, M. S. Kuster, M. Manestar, and L. Filgueira. 2016. 'A newly discovered muscle: The tensor of the vastus intermedius', *Clin Anat*, 29: 256-63.

Grob, K., M. Manestar, L. Filgueira, T. Ackland, H. Gilbey, and M. S. Kuster. 2016. 'New insight in the architecture of the quadriceps tendon', *J Exp Orthop*, 3: 32.

Grob, K., R. Monahan, H. Gilbey, T. Ackland, and M. S. Kuster. 2015. 'Limitations of the Vastus Lateralis Muscle as a Substitute for Lost Abductor Muscle Function: An Anatomical Study', *J Arthroplasty*, 30: 2338-42.

Grob, K., R. Monahan, H. Gilbey, F. Yap, L. Filgueira, and M. Kuster. 2015. 'Distal extension of the direct anterior approach to the hip poses risk to neurovascular structures: an anatomical study', *J Bone Joint Surg Am*, 97: 126-32.

Labbe, J. L., O. Peres, O. Leclair, R. Goulon, P. Scemama, F. Jourdel, and B. Duparc. 2011. 'Progressive limitation of knee flexion secondary to an accessory quinticeps femoris muscle in a child: a case report and literature review', *J Bone Joint Surg Br*, 93: 1568-70.

Nasr, A. Y., M. H. Badawoud, A. A. Al-Hayani, and A. M. Hussein. 2014. 'Origin of profunda femoris artery and its circumflex femoral branches: anatomical variations and clinical significance', *Folia Morphol (Warsz)*, 73: 58-67.

Omakobia, Eugene, Colin Liew, Natasha Berridge, and Stefano Cotrufo. 2016. 'A rare case of aberrant quadriceps muscle anatomy preventing anterolateral thigh flap harvest', *JPRAS Open*, 7: 19-22.

Patil, S., P. Grigoris, J. Shaw-Dunn, and A. T. Reece. 2007. 'Innervation of vastus lateralis muscle', *Clin Anat*, 20: 556-9.

Phalgunan, Vijisha, and Baskaran Srinivasan. 2013. 'Variations of lateral circumflex femoral artery and profunda femoris artery–', *Int J Anat Var (IJAV)*, 6: 213-15.

Prakash, Kumari, J., Bhardwaj, A., Jose, B., Yadav, S., Singh, G. 2010. 'Variations in the Origins of the Profunda Femoris, Medial and Lateral Femoral Circumflex Arteries: A Cadaver Study in the Indian Population', *Romanian Journal of Morphology and Embryology*, 51: 4.

Rajani, S. J., M. K. Ravat, J. K. Rajani, and A. N. Bhedi. 2015. 'Cadaveric Study of Profunda Femoris Artery with Some Unique Variations', *J Clin Diagn Res*, 9: Ac01-3.

Rajasekaran, S., and M. M. Hall. 2016. 'Sonographic Appearance of the Tensor of the Vastus Intermedius', *Pm r*, 8: 1020-23.

Revenaugh, P. C., D. Knott, J. M. McBride, and M. A. Fritz. 2012. 'Motor nerve to the vastus lateralis', *Arch Facial Plast Surg*, 14: 365-8.

Rozen, W. M., C. M. le Roux, M. W. Ashton, and D. Grinsell. 2009. 'The unfavorable anatomy of vastus lateralis motor nerves: a cause of donor-site morbidity after anterolateral thigh flap harvest', *Plast Reconstr Surg*, 123: 1505-9.

Samarawickrama, M., Nanayakkara, B., Wimalagunarathna, K., Nishantha, D., Walawage, U. 2009. 'Branching Pattern of the Femoral Artery at the Femoral Triangle: A Cadaver Study', *Galle Medical Journal*, 14: 4.

Singh, R., Wadhwan, M. 2016. 'Aberrant Configuration and Branching Pattern of Circumflex Femoris Arteries', *Basic Sciences of Medicine*, 5: 3.

Toia, F., S. D'Arpa, E. Brenner, C. Melloni, F. Moschella, and A. Cordova. 2015. 'Segmental anatomy of the vastus lateralis: guidelines for muscle-sparing flap harvest', *Plast Reconstr Surg*, 135: 185e-98e.

Waligora, A. C., N. A. Johanson, and B. E. Hirsch. 2009. 'Clinical anatomy of the quadriceps femoris and extensor apparatus of the knee', *Clin Orthop Relat Res*, 467: 3297-306.

Willan, P. L., M. Mahon, and J. A. Golland. 1990. 'Morphological variations of the human vastus lateralis muscle', *J Anat*, 168: 235-9.

Willan, P. L., J. A. Ransome, and M. Mahon. 2002. 'Variability in human quadriceps muscles: quantitative study and review of clinical literature', *Clin Anat*, 15: 116-28.

APPENDIX A

COMPLETE DATA COLLECTION TABLE

T#	L/R	SAB#	Sex	AOD	TVI	Type	PFA Org	IL-PFA	LCFA Org	PFA-LCFA
1	L	65395	M	81	1	VI	Post - Fem A	47.23	Lat - PFA	16.49
1	R	^	M	^	0	Non	Post - Fem A	42.44	Ant/Lat - PFA	24.92
2	L	65467	F	92	1	VL	Post - Fem A	29.26	Ant/Lat - PFA	10.11
2	R	^	F	^	1	VL	Post - Fem A	34.23	Ant/Lat - PFA	7.64
3	L	65372	F	63	0	Non	Post - Fem A	14.94	Lat - PFA	9.71
3	R	^	F	^	0	Non	Post - Fem A	32.79	Lat - PFA	15.87
4	L	65356	M	68	1	VL	Post/Lat - Fem A	47.89	Lat - PFA	43.24
4	R	^	M	^	1	Com	Post - Fem A	34.23	Lat - PFA	23.28
5	L	65373	M	60	0	Non	Post - Fem A	49.72	Lat - PFA	5.33
5	R	^	M	^	0	Non	Post - Fem A	50.22	Lat - PFA	15.75
6	L	65457	F	84	0	Non	Post/Lat - Fem A	45.4	Lat - PFA	16.85
6	R	^	F	^	1	VL	Post/Med - Fem A	48.24	Post/Lat - Fem A	0mm
7	L	65389	F	88	1	VI	Post - Fem A	48.4	Post/Lat - Fem A	< 1mm
7	R	^	F	^	0	Non	Post - Fem A	54.06	Lat/Ant - PFA	20.07
8	L	65458	M	85	1	VI	Post - Fem A	22.38	Lat/Ant - PFA	14.92
8	R	^	M	^	1	VI	Post/Lat - Fem A	53.73	Post/Lat - Fem A	0mm
9	L	65386	M	86	0	Non	Post - Fem A	25.32 IL-LCFA	Lat - Fem A	-14.02mm
9	R	^	M	^	1	Com	Post/Lat - Fem A	38.19	Post/Lat - PFA	26.19
10	L	65364	F	78		Atroph	Post - Fem A	29.5	Lat - PFA	26.75
10	R	^	F	^		Atroph	Post/Lat - Fem A	29.04	Lat - PFA	5.09
11	L	65392	F	88	1	VL	Post/Lat - Fem A	51.84	Lat - PFA	16.52
11	R	^	F	^	1	Ind	Post/Lat - Fem A	43.73	Lat - PFA	10.07
12	L	65445	M	94	1	VL	Post - Fem A	41.44	Lat - PFA	28.18
12	R	^	M	^	1	VL	Post - Fem A	42.75	Lat - PFA	29.81
13	L	65393	M	76	0	Non	Post/Lat - Fem A	64.64	Post/Lat - PFA	22.09
13	R	^	M	^	0	Non	Post - Fem A	48.79	Lat - PFA	29.87
14	L	65377	F	85	1	Com	Post - Fem A	43.94	Post - Fem A	20.25
14	R	^	F	^	1	Com	Lat - Fem A	24.25	Lat - PFA	42.48
16	L	65442	M	88	1	VL	Post/Lat - Fem A	22.02	Post/Lat - PFA	26.83
16	R	^	M	^	0	Non	Post/Lat - Fem A	44.26	Post/Lat - PFA	17.83
17	L	65406	M	84	0	Non	Post - Fem A	39.9	Post/Lat - Fem A	0mm
17	R	^	M	^	0	Non	Post - Fem A	41.45	Post/Lat - Fem A	0mm
18	L	65421	F	75	1	VL	Post - Fem A	33.09	Post/Lat - PFA	23.77
18	R	^	F	^	1	Ind	Post - Fem A	39.67	Post/Lat - PFA	10.49
19	L	65384	F	94	1	Com	Post - Fem A	28.02	Post/Lat - Fem A	0mm
19	R	^	F	^	1	VI	Lat - Fem A	19.27	Lat - PFA	56.21
20	L	65413	M	85	0	Non	Post - Fem A	36.94	Lat - PFA	51.35
20	R	^	M	^	0	Non	Post - Fem A	X Torn X	X Torn X	X Torn X
21	L	65439	M	68	1	MB	Post - Fem A	40.6	Post/Lat - PFA	13.44
21	R	^	M	^	1	MB	Post - Fem A	46.45	Post - PFA	31.27

T#	L/R	SAB#	Sex	AOD	TVI	Type	PFA Org	IL-PFA	LCFA Org	PFA-LCFA
22	L	65419	F	78	1	Com	Post - Fem A	16.38	Post/Lat - Fem A	0mm
22	R	^	F	^	1	VL	Post - Fem A	19.27	Lat - PFA	12.47
23	L	65453	F	99	0	Non	Lat - Fem A	27.62	Lat - PFA	6.65
23	R	^	F	^	0	Non	Lat - Fem A	X TORN X	X TORN X	X TORN X
24	L	65414	M	80	1	VL	Post - Fem A	30.3	Post/Lat - Fem A	0mm
24	R	^	M	^	1	VL	Post - Fem A	45.32	Lat - PFA	13.22
25	L	65394	M	72	1	VL	Post - Fem A	34.28	Lat - PFA	19.29
25	R	^	M	^	1	VL	Post - Fem A	45.76	D:A.PFA;TA:L.PFA	14.88
26	L	65412	F	79	1	MB	Post - Fem A	34.34	Lat - PFA	7.73
26	R	^	F	^	1	VL	Post - Fem A	33.6	Lat - PFA	9.4
27	L	65405	F	85	1	VL	Lat - Fem A	16.56	Post/Lat - PFA	44.01
27	R	^	F	^	1	Com	Lat - Fem A	23.1	Post/Lat - PFA	35.71
28	L	65430	M	87	1	VI	Post - Fem A	50.94	Lat - PFA	17.53
28	R	^	M	^	1	Com	Post/Lat - Fem A	41.72	Lat - PFA	49.51
29	L	65403	M	74	0	Non	Post - Fem A	53.15	Post - Fem A	0mm
29	R	^	M	^	0	*Med	Post/Lat - Fem A	59.13	Post/Lat - PFA	8.28
30	L	65452	F	77	1	Com	Post - Fem A	30.53	Post/Lat - PFA	23.7
30	R	^	F	^	1	VL	Post - Fem A	40.61	Post/Lat, Lat - PFA	19.99
31	L	65417	F	85	1	Ind	Lat - Fem A	0mm	Lat - PFA	36.11
31	R	^	F	^	1	VL	Lat - Fem A	30.91	Lat - PFA	11.17
33	L	65449	M	90	1	VI	Post/Lat - Fem A	67.92	Lat - PFA	11.22
33	R	^	M	^	1	VI	Post - Fem A	38.81	Post/Lat - Fem A	< 1mm
34	L	65434	F	86	1	VL	Lat - Fem A	13.15	Lat - PFA	19.57
34	R	^	F	^	1	VL	Post - Fem A	22.81	Lat - PFA	11.47
35	L	65451	F	88	1	Ind	Post/Lat - Fem A	15.42	Lat - PFA	19.19
35	R	^	F	^	1	VL	Lat - Fem A	18.69	D:L.PFA;TA:PL.PFA	D:6.99;TA:32.72
38	L	65380	F	84	1	VI	Post - Fem A	47.11	Lat - PFA	5.5
38	R	^	F	^	1	Ind	Post - Fem A	44.7	Lat - PFA	6.48
39	L	65424	M	91	1	VL	Post/Lat - Fem A	30.27	Post/Lat - PFA	24.93
39	R	^	M	^	1	VL	Post/Lat - Fem A	47.37	Lat - PFA	17.69
40	L	65455	F	84	1	VI	Post - Fem A	55.85	Post/Lat - PFA	0mm
40	R	^	F	^	1	VI	Post - Fem A	33.51	Post/Lat - PFA	13.89
T#	L/R	16(32)	Sex	AOD	TVI	Type	PFA	IL-PFA	LCFA	PFA-LCFA
72	36	Total	avg	82	51					
70	35	TVI	md	85						

Key		
Interesting	1	IND
Take Picture	2	COM
Torn/Atrophy	3	VI
Needs Work	4	VL
	5	MB

APPENDIX B

DATA TABLE FOR REPEATED MEASUREMENTS

Tank 7	1	2	3	Measure	Average
L	48.19	47.44	49.57	IL - PFA	48.40
R	54.05	53.4	54.73	IL - PFA	54.06
L	LCFA 1mm tops after PFA almost trunk			PFA - LCFA	>1mm
R	19.27	20.62	20.33	PFA - LCFA	20.07
Tank 10	1	2	3	Measure	Average
L	28.6	28.52	31.38	IL - PFA	29.50
R	27.98	30.72	28.41	IL - PFA	29.04
L	27.19	26.39	26.68	PFA - LCFA	26.75
R	5.32	4.86	5.09	PFA - LCFA	5.09
Tank 5	1	2	3	Measure	Average
L	47.29	51.7	50.16	IL - PFA	49.72
R	50.12	51.23	49.31	IL - PFA	50.22
L	4.55	5.39	6.06	PFA - LCFA	5.33
R	16.15	16.09	15	PFA - LCFA	15.75
Tank 6	1	2	3	Measure	Average
L	46.32	43.64	46.25	IL - PFA	45.40
R	46.86	48.39	49.48	IL - PFA	48.24
L	18.06	16.12	16.37	PFA - LCFA	16.85
R	0	0	0	PFA - LCFA	0.00
Tank 9	1	2	3	Measure	Average
L	26.06	24.97	24.93	IL - LCFA*	25.32
R	38.72	38.6	37.25	IL - PFA	38.19
L	14.18	14.68	13.21	LCFA - PFA*	14.02
R	25.07	26.11	27.4	PFA - LCFA	26.19
Tank 11	1	2	3	Measure	Average
L	51.35	52.11	52.07	IL - PFA	51.84
R	43.82	43.37	44.01	IL - PFA	43.73
L	17.02	16.27	16.26	PFA - LCFA	16.52
R	9.31	10.31	10.58	PFA - LCFA	10.07
Tank 1	1	2	3	Measure	Average
L	48.1	47.15	46.45	IL - PFA	47.23
R	43.15	42.02	42.16	IL - PFA	42.44
L	16.99	16.03	16.46	PFA - LCFA	16.49
R	25.9	24.98	23.88	PFA - LCFA	24.92

	Tank 8	1	2	3	Measure	Average
	L	23.37	20.76	23.02	IL - PFA	22.38
	R	55.35	53.95	51.88	IL - PFA	53.73
	L	15.15	14.95	14.67	PFA - LCFA	14.92
	R	0	0	0	PFA - LCFA	0.00
	Tank 16	1	2	3	Measure	Average
	L	21.99	22.17	21.91	IL - PFA	22.02
	R	45.53	44.24	43.02	IL - PFA	44.26
	L	26.09	27.31	27.09	PFA - LCFA	26.83
	R	18.05	17.57	17.87	PFA - LCFA	17.83
	Tank 4	1	2	3	Measure	Average
	L	49.48	47.1	47.09	IL - PFA	47.89
	R	34.78	34.46	33.45	IL - PFA	34.23
	L	43.63	42.97	43.13	PFA - LCFA	43.24
	R	23.59	23.94	22.31	PFA - LCFA	23.28
	Tank 3	1	2	3	Measure	Average
	L	15.3	14.47	15.06	IL - PFA	14.94
	R	32.34	32.79	33.25	IL - PFA	32.79
	L	9.69	10.24	9.21	PFA - LCFA	9.71
	R	16.27	15.43	15.9	PFA - LCFA	15.87
	Tank 30	1	2	3	Measure	Average
	L	30.3	31.17	30.11	IL - PFA	30.53
	R	40.77	40.11	40.95	IL - PFA	40.61
	L	23.78	24.13	23.2	PFA - LCFA	23.70
	R	20.7	19.37	19.91	PFA - LCFA	19.99
	Tank 28	1	2	3	Measure	Average
	L	51.49	50.69	50.65	IL - PFA	50.94
	R	42.5	41.73	40.93	IL - PFA	41.72
	L	17	17.95	17.65	PFA - LCFA	17.53
	R	48.97	49.86	49.69	PFA - LCFA	49.51
	Tank 20	1	2	3	Measure	Average
	L	37.19	37.01	36.62	IL - PFA	36.94
Torn*	R				IL - PFA	#DIV/0!
	L	51.59	50.35	52.12	PFA - LCFA	51.35
Torn*	R				PFA - LCFA	#DIV/0!

	Tank 29	1	2	3	Measure	Average
	L	53.53	52.7	53.22	IL - PFA	53.15
	R	58.6	59.67	59.13	IL - PFA	59.13
	L	0			PFA - LCFA	0.00
	R	7.68	9.47	7.69	PFA - LCFA	8.28
	Tank 14	1	2	3	Measure	Average
**	L	44.09	43.79	43.94	IL - PFA	43.94
	R	24.81	23.22	24.72	IL - PFA	24.25
	L	19.71	21.63	19.4	IL - CFT	20.25
	R	41.63	42.69	43.13	PFA - LCFA	42.48
	Tank 21	1	2	3	Measure	Average
	L	40.66	40.16	40.97	IL - PFA	40.60
	R	45.47	46.06	47.83	IL - PFA	46.45
	L	13.42	13.01	13.88	PFA - LCFA	13.44
	R	31.09	31.5	31.22	PFA - LCFA	31.27
	Tank 18	1	2	3	Measure	Average
	L	32.74	33.95	32.59	IL - PFA	33.09
	R	39.51	39.6	39.89	IL - PFA	39.67
	L	23.86	24.31	23.15	PFA - LCFA	23.77
	R	11.44	9.11	10.93	PFA - LCFA	10.49
	R	13.44	12.3	11.01	D - A/T	12.25
	Tank 2	1	2	3	Measure	Average
	L	29.29	29.33	29.17	IL - PFA	29.26
	R	34.04	33.74	34.91	IL - PFA	34.23
	L	9.6	10.51	10.21	PFA - LCFA	10.11
	R	8.08	7.08	7.75	PFA - LCFA	7.64
	Tank 13	1	2	3	Measure	Average
	L	63.78	64.72	65.41	IL - PFA	64.64
	R	48.81	49.08	48.47	IL - PFA	48.79
	L	22.6	21.81	21.85	PFA - LCFA	22.09
	R	29.02	30.78	29.8	PFA - LCFA	29.87
	Tank 19	1	2	3	Measure	Average
	L	28.01	27.89	28.16	IL - PFA	28.02
	R	19.2	19.62	19	IL - PFA	19.27
	L	0	0	0	PFA - LCFA	0.00
	R	55.99	54.7	54.95	PFA - LCFA	55.21

	Tank 12	1	2	3	Measure	Average
	L	42.33	40.67	41.33	IL - PFA	41.44
	R	42.52	43.07	42.66	IL - PFA	42.75
	L	27.86	27.9	28.78	PFA - LCFA	28.18
	R	29.94	31.21	28.28	PFA - LCFA	29.81
	Tank 17	1	2	3	Measure	Average
	L	39.86	39.34	40.5	IL - PFA	39.90
	R	41.81	41.37	41.16	IL - PFA	41.45
	L	0	0	0	PFA - LCFA	0.00
	R	0	0	0	PFA - LCFA	0.00
	Tank 35	1	2	3	Measure	Average
	L	15.73	15.45	15.09	IL - PFA	15.42
	R	18.6	19.14	18.33	IL - PFA	18.69
	L	19.3	18.29	19.99	PFA - LCFA	19.19
	R	32.96	32.97	32.23	PFA - T/A	32.72
	R	6.74	7.28	6.96	PFA - D	6.99
	Tank 33	1	2	3	Measure	Average
	L	68	67.53	68.24	IL - PFA	67.92
	R	38.54	38.4	39.48	IL - PFA	38.81
	L	11.16	11.18	11.33	PFA - LCFA	11.22
	R	<1mm			PFA - LCFA	#DIV/0!
	Tank 24	1	2	3	Measure	Average
	L	29.6	30.16	31.14	IL - PFA	30.30
	R	45.39	45.04	45.52	IL - PFA	45.32
	L	0			PFA - LCFA	0.00
	R	12.85	13.84	12.98	PFA - LCFA	13.22
	Tank 23	1	2	3	Measure	Average
	L	28.2	27.21	27.44	IL - PFA	27.62
Torn*	R				IL - PFA	#DIV/0!
	L	6.34	7.05	6.56	PFA - LCFA	6.65
Torn*	R				PFA - LCFA	#DIV/0!
	Tank 26	1	2	3	Measure	Average
	L	33.75	34.93	34.33	IL - PFA	34.34
	R	33.46	33.81	33.54	IL - PFA	33.60
	L	7.21	7.64	8.33	PFA - LCFA	7.73
	R	9.29	9.15	9.75	PFA - LCFA	9.40

	Tank 25	1	2	3	Measure	Average
	L	33.98	34.57	34.28	IL - PFA	34.28
	R	45.47	46.05	45.76	IL - PFA	45.76
	L	19.19	19.66	19.02	PFA - LCFA	19.29
	R	14.95	14.88	14.8	PFA - LCFA	14.88
	Tank 27	1	2	3	Measure	Average
	L	16.72	16.29	16.68	IL - PFA	16.56
	R	22.98	23.58	22.73	IL - PFA	23.10
	L	43.78	43.45	44.8	PFA - LCFA	44.01
	R	35.7	35.89	35.55	PFA - LCFA	35.71
	Tank 40	1	2	3	Measure	Average
	L	56.77	55.44	55.34	IL - PFA	55.85
	R	33.64	33.55	33.33	IL - PFA	33.51
	L	0	0	0	PFA - LCFA	0.00
	R	14.05	13.73	13.9	PFA - LCFA	13.89
	Tank 22	1	2	3	Measure	Average
	L	16.7	16.1	16.34	IL - PFA	16.38
	R	19.76	18.94	19.1	IL - PFA	19.27
	L	0	0	0	PFA - LCFA	0.00
	R	11.99	12.69	12.72	PFA - LCFA	12.47
	Tank 31	1	2	3	Measure	Average
	L	0	0	0	IL - PFA	0.00
	R	30.81	31.42	30.5	IL - PFA	30.91
	L	35.39	36.25	36.7	PFA - LCFA	36.11
	R	10.9	11.25	11.36	PFA - LCFA	11.17
	Tank 38	1	2	3	Measure	Average
	L	47.48	46.99	46.87	IL - PFA	47.11
	R	44.43	45.13	44.53	IL - PFA	44.70
	L	5.71	5.68	5.1	PFA - LCFA	5.50
	R	6.5	6.18	6.76	PFA - LCFA	6.48
	Tank 34	1	2	3	Measure	Average
	L	12.93	13.21	13.3	IL - PFA	13.15
	R	22.47	23.28	22.69	IL - PFA	22.81
	L	19.57	19.32	19.82	PFA - LCFA	19.57
	R	11.94	11.75	10.72	PFA - LCFA	11.47

	Tank 39	1	2	3	Measure	Average
	L	30.05	30.66	30.11	IL - PFA	30.27
	R	47.23	47.26	47.63	IL - PFA	47.37
	L	25.12	24.36	25.32	PFA - LCFA	24.93
	R	17.51	17.86	18.17	PFA - LCFA	17.85

APPENDIX C

ABBREVIATIONS KEY

ABBREVIATION KEY

- TVI – Tensor Vastus Intermedius Muscle
- Types = Ind – Independent; Com – Common; VI-Type/VL-Type; MB – Multiple Bellies
- TFL – Tensor Fascia Latae Muscle
- SA – Sartorius Muscle
- RF – Rectus Femoris Muscle
- VL – Vastus Lateralis Muscle
- VI – Vastus Intermedius Muscle
- VM – Vastus Medialis Muscle
- FA – Femoral Artery
- PFA – Profunda Femoris Artery
- LCFA – Lateral Circumflex Femoral Artery
- aLCFA – Ascending Branch of LCFA
- tLCFA – Transverse Branch of LCFA
- dLCFA – Descending Branch of LCFA
- IL – PFA = Distance from Midpoint of Inguinal Ligament to Origin of PFA
- PFA – LCFA = Distance from Origin of PFA to Origin of LCFA
- ALTf Harvest – Anterolateral Thigh Flap Harvest