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Ultrasound Identification of the deep band of the lateral plantar aponeurosis

Research Thesis

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Abstract

Research Question: In a convenience sample of cadaveric feet, can ultrasonography (US) provide accurate identification of the deep band of the lateral plantar aponeurosis as confirmed by direct anatomic evidence of the structure?

Background, Significance, and Rationale: While anatomy textbooks generally portray the human body fairly consistently, in reality there are numerous anatomical variations of those portrayals. These variations may or may not be clinically relevant. In 2018, Drs. Cara Fisher and Cameron Beck described in detail, for the first time, an anatomical variation of the plantar aponeurosis (PA). This variation, a fascial band that dives deep into the foot instead of staying superficial, crosses over a branch of the lateral plantar nerve which could lead to compression of the nerve. In future studies, we hope to investigate the potential clinical significance of this variation. In this research project, our goal is to determine if the fascial band can be identified noninvasively using US.

Materials and Methods: Under the direction of my SPT mentor, Dr. Fisher, I assisted in testing 15 pairs of fresh-frozen cadaveric feet (n = 30) for the presence of the deep band of the lateral PA. We assessed the feet using US. If the fascial band variation appeared to be present, we used US to guide an injection of a small bead of latex at that site. We then dissected the foot to the latex to verify its presence. Our findings were recorded at the end of each dissection.

Results and Conclusions: In a sample of 30 feet, the prevalence of the deep band of the lateral PA was 36.7%. Our results suggest that US is not a reliable screening tool to detect the deep band of the lateral PA with a sensitivity of only 36.4% and a specificity of 73.7%. The positive predictive value (PPV) was 44.4%, which is only 7.7% higher than the prevalence of the band in our sample of feet. Despite these negative results, we believe a repeat study that addresses certain limitations would be needed to confidently conclude that US cannot detect the deep band of the lateral PA in cadaveric feet.

Research Question

The **overall hypothesis** guiding this research is that ultrasonography, a noninvasive, commonly used medical procedure, can positively identify the deep band of the lateral plantar aponeurosis. We will test this hypothesis by executing the following Specific Aims (SA):

SA1: We will use US to identify the deep band of the lateral plantar aponeurosis. This will be accomplished using clinical ultrasound equipment on 15 pairs of cadaveric feet.

SA2: Upon identification of the deep band of the lateral plantar aponeurosis, we will inject a latex bead into the structure identified. The latex bead will serve as a physical "marker" of the potential anatomical variation under study.

SA3: Anatomic dissection of each foot will be performed to determine, based upon the position of the latex bead, if the deep band of the lateral plantar aponeurosis is indeed present. This will enable us to examine the accuracy and precision of ultrasonography examination and potentially, validate the test as a diagnostic biomarker of a human anatomical variant.

Introduction, Significance, and Rationale

The plantar aponeurosis is a thick fascial band on the plantar surface of the foot. It attaches proximally to the medial process of the tuberosity of the calcaneus and divides distally into five slips that insert onto the skin and fibrous tendon sheaths of the toes. The PA itself can be divided into three main longitudinal bands: a thicker central band and two thinner lateral and medial bands.[1] The PA assists local muscles and ligaments to support the longitudinal arches of the foot and distribute stress forces throughout the gait cycle.[2] A common pathology arising from inflammation of the PA is plantar fasciitis.[3]

In 2019, Beck et al. discovered an atypical fascial band arising from the medial aspect of the lateral plantar aponeurosis.[4] Similar to the lateral PA, the band is proximally located superficial to the abductor digiti minimi muscle.[4] However, it then deviates from the lateral PA by diving deep into the forefoot and crossing over the lateral plantar nerve, artery, and vein in a medial direction.[4] Its course continues anteromedially, passing deep to the central PA and tendons of the flexor digitorum brevis and longus muscles before inserting on the plantar plates of the third and fourth metatarsophalangeal joints.[4] Beck et al. hypothesized that this newly described deep band of the lateral PA may have clinical significance due to its close association with the lateral plantar nerve (Baxter's nerve).[4]

Arbab D et al. describes the procedure for plantar fascia release and decompression in a 2021 study. When more conservative measures for managing plantar fasciitis fail, an incision is made at the medial plantar fascia, preserving the lateral plantar aponeurosis. The goal of this procedure is to decompress the first branch of the lateral plantar nerve. However, results of this study found that 18.8% of patients continued to report similar or worse pain 6 weeks post-operatively.[9] Lateral column foot pain following fasciotomy could be related to the increased need of the lateral PA for support.[7] It would be interesting to investigate the presence of the deep band of the lateral PA in those patients reporting refractory post-operative pain, as its close association with the lateral plantar nerve could explain the continued pain.

A review of the literature strongly supports the ability of ultrasonography to identify the plantar fascia, which is critical to the success of this study. Draghi et al. includes many clear images of the PA using plain radiography, ultrasound, and magnetic resonance imaging. These imaging modalities could all potentially be used to identify the deep band of the lateral PA. The potential challenge in this study is whether our chosen imaging tool is powerful enough to differentiate the central PA from the deep band of the lateral PA, which is often a thin fascia band when present. Based on current literature, ultrasonography should be sufficient to identify the deep band of the lateral PA.[5]

After 100 cadaveric foot dissections, Beck et al. identified the fascial band variation in 38% of the feet.[4] If we assume this percentage can be applied to the general population, that means a significant number of people have the deep band of the lateral PA. This fascial band may have no clinical significance but, given its close association with the lateral plantar nerve, we believe

a thorough investigation should be conducted to rule out that possibility. While it is well established that both magnetic resonance imaging (MRI) and ultrasonography (US) can be used to view the plantar fascia[5], it is important to verify that the deep band of the lateral PA can be differentiated from typical PA anatomy using one of these imaging methods. Thus, this study was designed as a follow-up to the discoveries made by Beck et al. with the goal of confirming US as a suitable tool to identify the deep band of the lateral PA.[4] US was chosen over MRI due to its ease of use, low cost, and wide availability in the clinical setting.

Materials and Methods

Preliminary Information

In 2019, Beck et al. describes the deep band of the lateral plantar aponeurosis as well as the superficial dissection used to visualize it.[4] The same dissection technique and landmarks are utilized in this study to confirm the presence of the deep band of the lateral PA following ultrasound-guided injection of latex at the site. The figure below was published by my mentor, Dr. Fisher, and illustrates this dissection from superficial to deep.[4]

First, the skin and superficial fascia of the plantar surface of the foot is removed down to the plantar aponeurosis.[4] Next, the tuberosity of the base of the fifth metatarsal is used as a landmark to determine if the deep band of the lateral PA is present.[4] If it is, its course is followed to ensure it dives deep to the central PA, the flexor digitorum brevis tendon, and the flexor digitorum longus tendon and inserts on the plantar plates of the third and fourth metatarsophalangeal joints.[4]

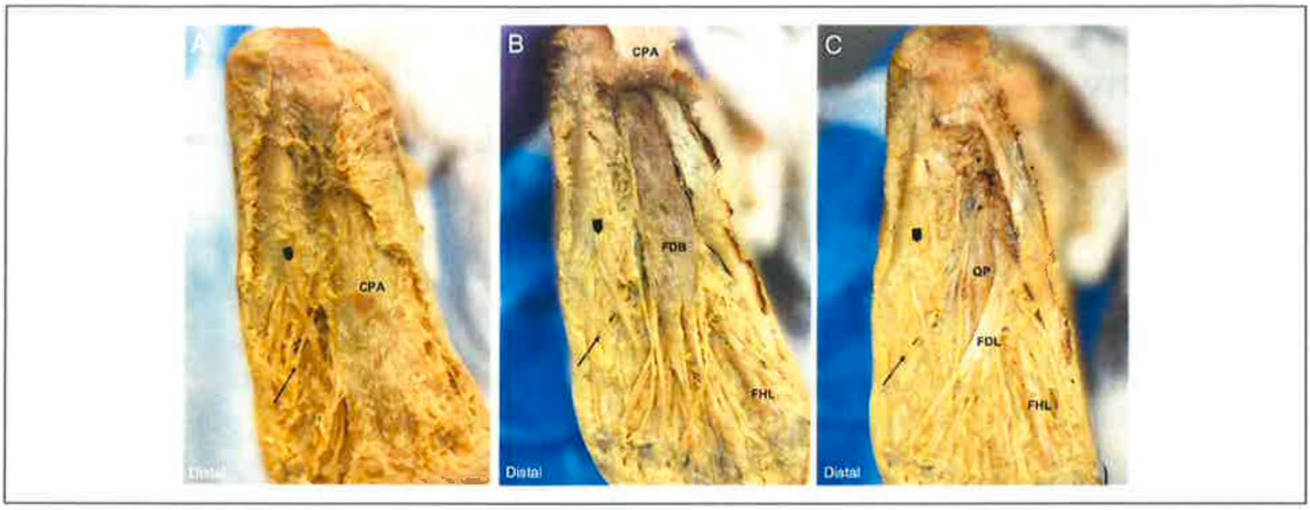

Figure 1. Images depict the progression of a dissection, from superficial to deep, of the plantar foot containing the deep band of the lateral plantar aponeurosis (black arrowhead) crossing over the lateral plantar nerve (black arrow). (A) The deep band of the lateral plantar aponeurosis passing deep to and not receiving any contributions from the central plantar aponeurosis (CPA). (B) The deep band of the lateral plantar aponeurosis passing deep to the tendons of the flexor digitorum brevis (FDB) muscle with the CPA reflected and the flexor hallucis longus (FHL) tendon exposed. (C) The deep band of the lateral plantar aponeurosis passing deep to the tendons of the flexor digitorum longus (FDL) muscle with the FHL tendon and quadratus plantae (QP) muscle exposed.

Materials

TCU School of Medicine embalmed cadaveric feet (n=20) for dissection technique practice *
Fresh-frozen cadaveric feet (n=30) *

Butterfly iQ+ Portable Ultrasound device **
Liquid blue latex
Syringe
Scalpel

*The cadaveric feet required for this project are being provided by the Willed Body Program at the University of North Texas Health Science Center at Fort Worth (UNTHSC). All cadaveric work for this project will be completed at the UNTHSC campus in the Research and Education Building: 1055 Montgomery St., Fort Worth, TX 76107.

**Ultrasound analysis of each specimen was facilitated by Dr. Kristopher Aten, who generously provided his personal Butterfly iQ+ portable ultrasound device and expertise for this project.

Methods

Prior to starting data collection, I practiced the foot dissection described by Beck et al. on the TCU School of Medicine cadaver feet, which are not typically utilized by the students. I was able to perform the dissection on 20 feet with guidance from Dr. Fisher prior to starting data collection for this study.

We utilized a convenience sample of 15 pairs of fresh cadaveric feet (n = 30) and performed US examination of them to locate the deep band of the lateral plantar aponeurosis (PA). During US examination, we first locate the tuberosity of the base of the fifth metatarsal, which is used as a landmark to locate the deep band of the lateral PA, if present.[4] If we identified a potential deep band of the lateral PA, a small bead of latex was injected into the foot, under US guidance, to mark that location. Then, to verify its presence, we then dissected down to the latex using the dissection technique described by Beck et al. above.

For data collection, we recorded whether the deep band of the lateral PA appeared to be present on US (positive vs. negative) as well as whether the band was present following dissection (present vs. absent). Certain foot donor information (sex, age, race) is included, if available. Qualitative comments were made on select specimens.

Statistical Analyses

One method of organizing the data obtained from this study is a simple 2 x 2 table comparing the accuracy and precision of US vs. anatomical dissection in the identification of the deep band of the lateral PA. The table below, published by Richardson R et al., depicts an example of a 2 x 2 table, with the “screening measure” being US and the “gold standard diagnosis” being anatomical dissection.[8] The four cells (a, b, c, d) represent the four possible relationships between the results of US and anatomical dissection. Sensitivity, or the proportion of feet with the deep band of the lateral PA that are positive on US examination, will be calculated as

a/(a+c).[8] Specificity, or the proportion of feet without the deep band of the lateral PA that are negative on US examination, will be calculated as d/(b+d).[8] The level of statistical significance accepted for all analyses will be alpha = 0.05. A statistician will be consulted to determine which additional statistical methods should be included to accurately show the sensitivity and specificity of US as a diagnostic test to identify the deep band of the lateral PA.

A 2 × 2 table for summarising test accuracy

Screening measure	**Gold standard diagnosis**	
	+	–
+	True positive (a)	False positive (b)
–	False negative (c)	True negative (d)

Results

Specimen #	SAB#	Side	US Band Prediction	Band Present post-dissection	Sex	Age (years)	Race	Notes
1	84606	Right	Positive	Absent	Male	68	White	
2	84606	Left	Positive	Absent	Male	68	White	
3	84605	Right	Negative	Absent	Female			
4	84605	Left	Negative	Absent	Female			
5	83238	Right	Negative	Present	Female	86		small, unsubstantial band
6	83238	Left	Negative	Absent	Female	86		
7	83263	Right	Negative	Absent	Male	60	White	
8	83263	Left	Positive	Present	Male	60	White	substantial band
9	83253	Right	Positive	Present	Female	74	White	thin band; bifurcation to 3rd metatarsal not seen
10	83253	Left	Positive	Present	Female	74	White	
11	80783	Right	Negative	Absent	Male	45	White	
12	80783	Left	Negative	Absent	Male	45	White	
13	85253	Right	Negative	Present	Male	80	White	
14	85253	Left	Negative	Present	Male	80	White	substantial band
15	85247	Right	Negative	Absent	Male	68	White	
16	85247	Left	Negative	Absent	Male	68	White	
17	85804	Right	Positive	Present	Male	74	Hispanic	
18	85804	Left	Negative	Present	Male	74	Hispanic	
19	85289	Right	Positive	Absent	Male	62	White	
20	85289	Left	Negative	Absent	Male	62	White	
21	85287	Right	Negative	Present	Female	86	White	
22	85287	Left	Negative	Absent	Female	86	White	
23	83403	Right	Positive	Absent				
24	83403	Left	Positive	Absent				
25	83639	Right	Negative	Present				
26	83639	Left	Negative	Present				
27	80490	Right	Negative	Absent				
28	80490	Left	Negative	Absent				
29	80492	Right	Negative	Absent				
30	80492	Left	Negative	Absent				

Table 1. Raw data collected from 30 cadaveric foot specimens.

Images of Select Cadaveric Dissections

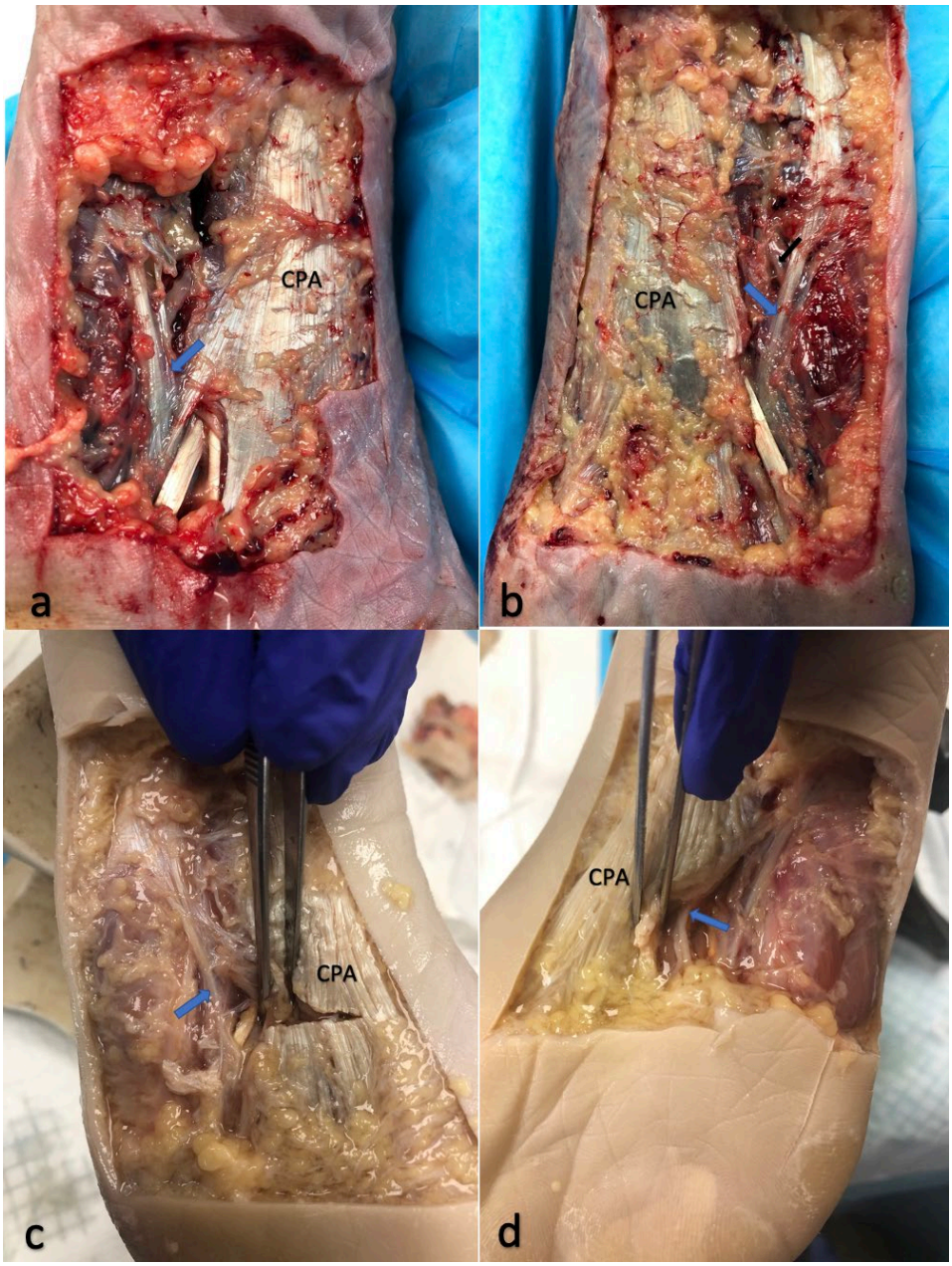

Figure 1. Image "a" is the left foot of SAB #85253, which was noted to have a substantial deep band of the lateral PA (blue arrow). Image "b" is the right foot of SAB #85287. The deep band of the lateral PA (blue arrow) and lateral plantar nerve (black arrow) are both seen. Images "c" and "d" are the left and right feet, respectively, of SAB #83639. The deep band of the lateral PA (blue arrow) is visualized. The central plantar aponeurosis (CPA) is labeled in all feet for reference.

2x2 Table Analysis of Ultrasound vs. Anatomical Dissection

US Screen	Dissection Results		
	Band Present	**Band Absent**	
Positive	4	5	PPV = TP/(TP+FP) = 0.444
Negative	7	14	NPV = TN/(TN+FN) = 0.667
	Sensitivity = TP/(TP+FN) = 0.364	Specificity = TN/(TN+FP) = 0.737	Prevalence = (TP+FN)/(TP+FN+FP+TN) = 0.367

Table 2. The 2x2 table above displays the numbers of true positives (TP), false positives (FP), false negatives (FN), and true negatives (TN) regarding ultrasound screening vs anatomical dissection. From these data, the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and prevalence were calculated.

Likelihood ratio:

$LR^{+} = \frac{sensitivity}{1-specificity} =$ 1.384

$LR^{-} = \frac{1-sensitivity}{specificity} = 0.863$

Discussion

While ultrasonography (US) has been shown to be an effective tool for visualizing the PA, it has not yet been used to differentiate between typical plantar fascia anatomy and the deep band of the lateral PA variation.[6] By proving the capability of US to identify patients with this anatomic variation, we hoped to lay the groundwork for future studies to investigate the potential clinical significance of the deep band of the lateral PA. If we were unable to accurately confirm the presence of the deep band of the lateral PA with US, we could consider other imaging techniques instead, such as magnetic resonance imaging (MRI). It is already well established that MRI can be used to accurately identify plantar fascia, such as in the diagnosis of plantar fasciitis.[5] However, it would present an additional challenge in future studies if MRI was the only option to identify the deep band of the lateral PA, considering the increased cost and limited availability compared to US.

Unfortunately, the results above suggest that US is not a reliable method of identifying the deep band of the lateral PA in cadaveric feet. In this study, we utilized US like a screening test, with the deep band of the lateral PA acting as the "condition" we were trying to detect. A reliable screening test should have high sensitivity, which translates to a low false-negative rate. Our results demonstrated a sensitivity of 36.4%, which is far too low to use with confidence. The specificity, or true-negative rate, is also low at 73.7%.

An LR^+ value greater than 10 indicates a highly specific test, while an LR^- value less than 0.1 indicates a highly sensitive test. Because our LR^+ and LR^- values are both very close to 1, we can infer minimal impact of our results. Our LR^+ value of 1.384 indicates minimal increase for the likelihood of disease when US analysis was "positive." Our LR^- value of 0.863 indicates minimal decrease for the likelihood of the disease when US analysis was "negative." The post-test probability for a positive test (PPV) was 44.4%. The post-test probability for a negative test (NPV) was 66.7%.

The prevalence of the deep band of the lateral PA was found to be 36.7% in our sample of 30 feet. While our sample size was low, this number is further supported by Beck et al., who recorded a prevalence of 38% in his sample of 100 feet. If we compare this overall prevalence to our PPV, then a positive US test increases the probability of having the deep band of the lateral PA from 36.7% to 44.4%. This is an absolute increase of only 7.7%.

We identified several factors that may have led to our negative results. First, the lack of expertise of our team likely contributed to many of our challenges with dissection and US identification. I, a medical student, had virtually no US experience at the start of this project and very little dissection experience. The 20 dissections on embalmed cadaver feet I performed prior to starting data collection gave me enough practice to continue the dissections during data collection, but only with supervision from my PI, Dr. Fisher. Our US "expert" was proficient with basic US technique considering he was a fourth-year medical student at the time, but he was often uncertain of whether the deep band of the lateral PA was present. We agree this

study may have benefitted from an US technician who is more experienced in soft tissue identification. In addition, the handheld butterfly US device may not have had a high enough resolution to differentiate the different fascia layers of the foot to the degree our study required. Finally, we acknowledge that our low sample size limits the power of our results. Our original plan was to analyze a sample of 100 feet, but several factors led to only 30 feet being analyzed.

With the above limitations in mind, there are many ways our study design could be improved. While our results suggest that the deep band of the lateral PA cannot be reliably identified via US, we are not convinced that the results themselves are reliable. There are many study modifications that could be made, assuming we had the resources to repeat this study, that could change our initial findings. First, we could attempt the study again using the same point-of-care handheld butterfly device, but have a more experienced US technician guiding the US. Ideally, this would be an expert in foot pathologies who is already familiar with viewing the plantar fascia via ultrasound and knows how to adjust the settings for what we are trying to see. If we were still unsuccessful, we could try using a more powerful US device with better resolution, as we found it difficult to differentiate between the fine layers of fascia in the foot. If US was still found to be unreliable, we could consider other imaging modalities such as MRI. However, MRI is not as easily accessible as US and may not be feasible for our cadaveric study. In the future, it would be preferable to have both US images and gross photographs of every specimen, so an US device with image-saving capabilities should be used. Finally, our sample size was very low for what we were trying to show. A sample of 100 feet, like originally planned, would greatly increase the power of our study results.

Future Directions

A future study design to improve upon our results could be similar to what we did with a few key changes. First, our sample size should be increased to 50 pairs of cadaveric feet (n=100) to increase the power of our study results. If we still have negative results with a larger sample size, we can be more confident in the validity of those results. One idea to reduce US operator bias is to bring in a small panel of US technicians instead of relying on one person to analyze the feet. Each technician would have a set of feet to analyze, and the results could then be compared to see if accurate identification is US operator dependent. If all our panel members continue to struggle with identification of the deep band of the lateral PA, we can be more confident in those negative results. Finally, it would be interesting to repeat US analysis using different brands and models of ultrasounds. It is possible that accurate identification of the target fascia band was too difficult with the smaller handheld butterfly device we used. Comparison with higher powered US devices could show if this was another limiting factor in our study. While MRI analysis could be attempted in a follow-up study, we want to be mindful of the increased cost and difficulty in accessing this imaging modality. This is especially relevant if we were to design future studies looking at the potential clinical significance of the deep band of the lateral PA. We would want a quick and easy way to determine if a patient has this fascia band variation, and US achieves this more practically than MRI.

If the deep band of the lateral PA does have clinical significance, it is likely related to its association with the lateral plantar nerve which could lead to nerve compression. By taking careful measurements of where the deep band of the lateral PA crosses over the lateral plantar nerve, Beck et al. was able to establish a target zone for which to focus follow-up studies on.[4] They proposed a handful of foot pathologies that should be included in future investigations, including plantar fasciitis, metatarsalgia, neuritis, and neuromas.

Plantar fasciitis that is resistant to nonoperative therapies may require surgical treatment.[3] However, some patients report lateral column pain even after release of the medial one-third to one-half of the central PA. While the exact mechanism for this is not known, Anderson DJ et al. hypothesized that the lateral PA, as well as several ligaments, may become strained following the plantar fascial release surgery.[7] Since the deep band of the lateral PA arises from the lateral plantar fascia, it is possible that excessive strain is also put on the deep band of the lateral PA in patients with the variation.[4] This increased strain could be a mechanism for the compression of the lateral plantar nerve. Of course, future clinical studies will be necessary to investigate the potential link between the deep band of the lateral PA and the foot pathologies we've discussed.

Conclusions

There are few conclusions that can reasonably be made based on the results of this study. I feel most confident in reporting the prevalence of the deep band of the lateral plantar aponeurosis in the general population as being close to our value of 36.7%, as this is further supported by Dr. Beck's prior study showing a prevalence of 38% in his sample of 100 feet.[4] Our initial hypothesis postulated that ultrasonography could positively identify the deep band of the lateral PA. Our actual results suggest that US is not a reliable screening test to positively identify this fascia band variation due to a low sensitivity and specificity. A positive US test increased the probability of a foot having the deep band of the lateral PA by only 7.7%. However, I do not believe our results are reliable enough to confidently conclude that US is not able to positively identify the deep band of the lateral PA. This study had several limitations that weakened the validity of our results, including low sample size, a lower resolution US device, and limited experience in both US analysis and dissection technique. The implication of these results is that a repeat study that addresses our limitations would have to be conducted to confidently conclude whether US is able to detect the presence of the deep band of the lateral PA.

Compliance

This research study does not require IRB approval. I completed the lab safety training required to work in the UNTHSC cadaver lab and all required CITI training.

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