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Proximal Plantar Plate of Lesser Toe Metatarsophalangeal Joint Vascular Supply

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Abstract

Background: The plantar plate is a major stabilizing structure of the MTP joint with instability frequently occurring after a tear or attenuation of this structure. Commonly, a McGlamry elevator is used to strip the plantar plate from the plantar surface of the metatarsal to improve exposure of the MTP joint. The anatomy of the proximal plantar plate and vascular consequence of stripping the plantar plate from the metatarsal is not yet well understood. The purpose of this study is to describe the proximal attachment of the plantar plate anatomically and quantify the relative contribution of blood supply to the proximal plantar plate from both the metatarsal and the plantar fascia.

Methods: For anatomic evaluation, six lower extremity cadaver specimens without any gross evidence of foot and ankle deformity were utilized. For imaging analysis, sixteen fresh-frozen human adult cadaveric lower extremity specimens were utilized for this study, resulting in 35 MTP joints without deformity and 11 lesser MTP joints with cockup and/or crossover deformities. The specimens were prepared as described previously by Finney et al.[5]

Results: From gross anatomic dissection, the plantar plate origin consists of a stout fibrous pedicle distinct from the surrounding synovial-type tissue that firmly anchors the plantar plate to the metatarsal. Based on nano-CT imaging, an average of 63.5% of the vascular supply to the proximal portion of the plantar plate entered from the metatarsal pedicle. The remaining 36.5% of the vascular supply entered from the plantar fascia.

Conclusion: The proximal attachment of the plantar plate includes a stout fibrous pedicle anchoring the proximal portion of the plantar plate to the notch between the medial and lateral

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Level of Evidence:
Level III-Retrospective Comparative Study

Ethical Approval:
Ethical approval was not sought for the present study because it does not meet the criteria for research requiring IRB review since cadavers are not considered human subjects according to 45 CFR 46.102(e)(1) and our study was for scholarly/journalistic activity according to 45 CFR 46.102(l)(1).

plantar condyles of the metatarsal head. The vascular supply of the proximal plantar plate is supplied from both the metatarsal pedicle and plantar fascia.

Keywords

Plantar plate; Nano-CT; Metatarsalgia; Forefoot disorders; Hammertoes

INTRODUCTION:

Instability of the lesser metatarsophalangeal (MTP) joints has been implicated in metatarsalgia as well as a number of common toe deformities.[2] A growing body of research has supported the concept that the plantar plate functions as the principal static stabilizer of the MTP joint, resisting tensile loads in the sagittal plane and preventing dorsal displacement of the proximal phalanx.[1, 4] Dysfunction of the plantar plate and/or collateral ligaments, which often occurs in the setting of a tear or attenuation, can therefore compromise the stability of the MTP joint. When the MTP joint static stabilizers become dysfunctional, the imbalanced vectors from the toe flexors and extensors leads to coronal and sagittal plane deformities such as hammertoes and crossover toes.[2, 14]

The proximal plantar plate has two components to its origin. Previous literature describes one component of the proximal plantar plate as a "delicate," "thin," "synovial" attachment to the metatarsal bone and the other is described as a blending of fibers to the MTP collateral ligaments and plantar fascia.[3, 8] The proximal origin of the plantar plate loosely attaches to the periosteum of the metatarsal shaft. Distally, the plantar plate firmly and directly inserts into bone on the plantar surface of the proximal phalanx.[11] The microvasculature of the plantar plate has been described as a network extending from surrounding soft tissues at the attachment to the metatarsal and proximal phalanx. The vascular density is highest at the proximal and distal attachments of the plantar plate.[5]

Previous studies have demonstrated that the vasculature to the proximal plantar plate is supplied by both the plantar fascia as well as the metatarsal attachment.[5,15] Surgical procedures addressing MTP instability often include stripping the metatarsal attachment of the plantar plate using a degloving "Mcglamry" elevator to gain adequate exposure of the plantar plate.[12] This maneuver intentionally separates the attachment from the metatarsal to the plantar plate; the consequence of this disruption on local vessels is unknown. The purpose of this study is two-fold, 1) describe the gross anatomy of the proximal attachment of the plantar plate, and 2) quantify the relative contribution of blood supply to the proximal plantar plate from both the metatarsal and the plantar fascia.

MATERIALS AND METHODS:

Specimen Preparation for Anatomic Study:

Six lower extremity cadaver specimens without any gross evidence of foot and ankle deformity were utilized for anatomic dissection. Specimens were kept frozen at −20°C, then thawed at room temperature for 24 hours. The skin and subcutaneous tissue were removed from the plantar aspect of the foot. The flexor tendons were then carefully excised and the plantar plate was exposed on the second, third, and fourth MTP joints. The collateral ligaments were divided, and the plantar plate was detached from the proximal phalanx. The origin of the plantar plate was then isolated and measured using digital calipers (Mitutoyo Corp., Kawasaki, Japan).

Specimen Preparation for Imaging:

Sixteen fresh-frozen human adult cadaver lower extremity specimens were utilized for this study, resulting in 35 MTP joints without deformity and 11 lesser MTP joints with cockup and/or crossover deformity. All specimens were between the ages of 34 and 82 years and had no history of diabetes, peripheral vascular disease, or connective tissue disorders. Specimens with a history of trauma to the foot or ankle or prior foot or ankle surgery upon inspection were excluded.

The specimens were prepared as described previously by Finney et al.[5] A 16-gauge blunt-tip needle was used to cannulate the anterior and posterior tibial arteries. Next, the arteries were flushed under constant pressure with 5% PI 3N1 Pre-Injection Embalming Fluid (Trinity Fluids, Inc., Lapeer, MI) in distilled water until venous return was free of blood clots. One hundred twenty milliliters of radio-opaque contrast composed of 15% barium sulfate suspension in 10% neutral buffered formalin (Thermo Fisher, Kalamazoo, MI) was injected into each artery. The processed specimens were refrigerated for 24 hours and then amputated at the proximal metatarsals.

Prior to counterstaining, the skin on the toes was removed. The soft tissues of each foot were counterstained with phosphomolybdic acid (PMA) (Sigma-Aldrich, St. Louis, MO). The counterstain was done to enhance x-ray attenuation of soft tissues. Specimens were soaked for a minimum of 9 days in a 3-L bath of 10 g/L PMA solution and kept agitated on a shaker table. The PMA solutions were replaced every 3 days until counterstaining was complete.

CT Image Analysis:

The second, third, and fourth toe MTP joints were scanned at a resolution of 14 μm (GE Nanotom S nano-CT scanner, GE Measurements, Wunstorf, Germany). The three-dimensional and two-dimensional CT images of the plantar plate were utilized for analysis of the volume of vasculature along the metatarsal pedicle and plantar fascia of the proximal plantar plate (Dragonfly v3.1, Object Research Systems, Inc., Montreal, QC, Canada).

Three-dimensional reconstruction, as well as the two-dimensional images in the XY, YZ, and XZ planes, were created. A region of interest (ROI) was first created for the entire length of the plantar plate. Due to the curvilinear 3D structure of the plantar plate and software capability limited to linear analysis, the longitudinal axis of the plantar plate was estimated as previously described in the literature.[5] This estimation was calculated by finding the midpoint between the plantar and dorsal aspects of the plantar plate at its proximal and distal attachments and carrying out a linear analysis along this axis. Window leveling parameters were adjusted to capture all vessels in the frames. A second ROI of the vessels was added. Overlayed on the 1st ROI of the plantar plate, two additional ROIs were created for the proximal portion of the plantar plate entering from the metatarsal pedicle and the plantar fascia. The ROIs of the proximal portions of the plantar plate were intersected with the ROI of the vasculature to identify the volume of vasculature in each portion. Vessel volume was computed based on the voxel size and the number of segmented voxels in a 3D space. Vascular density was defined as vessel volume over tissue volume (VV/TV) and calculated for the proximal portion of the plantar plate from the metatarsal pedicle and the plantar fascia.

RESULTS:

Anatomic Study of the Plantar Plate Origin:

There is a synovial portion of the plantar plate origin that is broad and fragile, as previously described.[7, 11, 13] Within this areolar tissue, there is a stout fibrous pedicle anchoring the proximal portion of the plantar plate to the notch between the medial and lateral plantar condyles of the metatarsal head (Figure 1). All six specimens had this pedicle in the second and fourth metatarsals. This structure was present in 5 of 6 third metatarsals.

For all MTP joints, the average length (proximal to distal) and width (medial to lateral) of the plantar plate pedicle measured 2.01 mm (range, 1.35–3.27 mm) and 2.08 mm (range, 0.92–3.7 mm) respectively. The average length and width of the plantar plate pedicle in the second metatarsal was 2.08 mm (range, 1.46–2.71 mm) by 2.27 mm (range, 1.53–3.38mm). The average length and width in the third metatarsal was 2.05 mm (range, 1.35–2.94 mm) by 2.16 mm (range, 0.92–3.7 mm). The average length and width in the fourth metatarsal specimens was 1.90 mm (range, 1.42–3.27 mm) by 1.86 mm (range, 1.21–2.59 mm).

Nano-CT Imaging Evaluation

A total of 35 lesser toes from 10 human cadaveric specimens were included in the image analysis. One specimen was excluded due to clinical deformities of the second and third toes and poor-quality scan of the fourth toe. Another fourth toe sample was excluded due to a poor-quality scan. The plantar plate of the specimens that we included for analysis were not stripped from the metatarsal pedicle using a degloving elevator. The final dataset of toe samples included the following: 12 second toes, 12 third toes, and 11 fourth toes. The average age of the samples included was 50.3 years. Of the 35 lesser toes, 15 specimens were from a female cadaver and 20 were from a male cadaver. The final sample included 17 right-sided lesser toes and 18 left-sided lesser toes.

The plantar plate specimen demonstrated similar microvascular infiltration at the proximal attachments of the metatarsal neck, interosseous muscles, periosteum, and plantar fascia (Figure 2). A single vessel could not be identified as the primary vasculature of the proximal plantar plate. An average of 63.5% (range, 20.0%−88.2%) of the vascular supply to the proximal portion of the plantar plate entered from the metatarsal pedicle in 35 lesser toe specimens analyzed. The remaining 36.5% (range, 11.8%−80.0%) of the vascular supply entered from the plantar fascia. The second toes, third toes, and fourth toes had an average of 64.7% (range, 42.6%−80.2%), 59.0% (range, 28.6%−84.4%), and 67.1% (range, 50.0% −88.2%) of vasculature supply from the metatarsal pedicle, respectively (Figure 3). The average volume of vasculature from the metatarsal pedicle to the proximal plantar plate was

0.38 mm^3 (range, 1×10^{-10} – 1.3 mm) while the average volume of vasculature from the plantar fascia to the proximal plantar plate was 0.19 mm^3 (range, 4×10^{-11} − 0.74 mm).

DISCUSSION:

We found the proximal attachment of the plantar plate is stout and fibrous, and not as delicate as previously described in literature.[3,8] Previous papers showed that the blood supply to the plantar plate arises from the metatarsal pedicle and plantar fascia but the relative contribution of blood supply to the proximal plantar plate from both the metatarsal and the plantar fascia has not been described in literature.[5,15] Our paper shows that the dominant tributary of proximal plantar plate perfusion arises from the metatarsal pedicle.

Understanding the proximal attachment of the plantar plate from a vascular and anatomic perspective is critical for adequately treating lesser MTP instability. Contemporary surgical procedures addressing MTP instability often include the release of the metatarsal origin of the plantar plate and with a degloving elevator in order to gain adequate exposure of the plantar plate through a dorsal approach.[10, 13] Using the degloving elevator to strip the plantar plate from the metatarsal leads to a greater improvement in plantar plate exposure than releasing the plantar plate from the proximal phalanx.[10] Destabilizing the MTP joint by stripping the proximal attachment of the plantar plate from the metatarsal may contribute to the floating toe deformity and residual MTP instability that have been reported following plantar plate repair.[9,12]

For these reasons, the anatomic region of the proximal plantar plate has become an increasing relevant factor in optimizing postoperative digital stability. Recent studies suggest preservative techniques that leave the plantar plate metatarsal attachments intact during reconstruction may reduce rates of residual instability.[6,7] Based on our results, we suspect that placement of a degloving elevator for exposure of the MTP joint during plantar plate repair disrupts the dominant tributary for proximal plantar plate perfusion. Although we did not directly test the effects of using a degloving elevator, our findings show that the attachment of the proximal plantar plate to the metatarsal pedicle appears to be an important blood supply to the proximal plantar plate. The most vascular regions of the plantar plate are at the proximal and distal ends, with a relatively hypovascular midsubstance.[5] Given the possible disruption of the dominant perfusion, a degloving elevator should be used with caution during plantar plate repair from a dorsal approach.

Limitations of this study include the use of a cadaveric model which restricts the generalizability of the results. Variability in the size of the proximal plantar plate between cadavers represents a potentially confounding variable. A greater number of specimens may be necessary before declaring the current findings as the ‘normal’ anatomy. In addition, the quality of plantar plate tissue in this model may not directly represent the in vivo environment. The ability to visualize small blood vessels may have been limited by the use of frozen cadaveric tissue and the resolution of the nano-CT images.

Future studies to elucidate the characteristics of the proximal plantar plate can include biomechanical strength testing of the plantar plate pedicle and its quantitative contribution to the stability of the lesser MTP joint. Image analysis of vasculature to the proximal plantar plate in torn or injured samples may help expand knowledge of potential revascularization of the proximal plantar plate.

CONCLUSION:

The proximal attachment of the plantar plate includes a stout fibrous pedicle anchoring the proximal portion of the plantar plate to the notch between the medial and lateral plantar condyles of the metatarsal head. The vascular supply of the proximal plantar plate is supplied from both the metatarsal pedicle and plantar fascia.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Declaration of Conflicting Interests:

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References:

1. Akoh CC, Phisitkul P. Plantar Plate Injury and Angular Toe Deformity. Foot Ankle Clin 2018;23(4):703–713. doi: 10.1016/j.fcl.2018.07.010. [PubMed: 30414662]
2. Coughlin MJ. Crossover second toe deformity. Foot Ankle 1987;8(1):29–39. doi: 10.1177/107110078700800108. [PubMed: 3623359]
3. Deland JT, Lee KT, Sobel M, DiCarlo EF. Anatomy of the plantar plate and its attachments in the lesser metatarsal phalangeal joint. Foot Ankle Int. 1995;16(8):480–486. doi:10.1177/107110079501600804 [PubMed: 8520660]
4. Dinoá V, von Ranke F, Costa F, Marchiori E. Evaluation of lesser metatarsophalangeal joint plantar plate tears with contrast-enhanced and fat-suppressed MRI. Skeletal Radiology 2016;45(5):635–644. doi: 10.1007/s00256-016-2349-z. [PubMed: 26887801]
5. Finney FT, McPheters A, Singer NV, et al. Microvasculature of the Plantar Plate Using Nano-Computed Tomography. Foot Ankle Int. 2019;40(4):457–464. doi:10.1177/1071100718816292. [PubMed: 30565497]
6. Flint WW, Macias DM, Jastifer JR, Doty JF, Hirose CB, Coughlin MJ. Plantar Plate Repair for Lesser Metatarsophalangeal Joint Instability. Foot Ankle Int 2017;38(3):234–242. doi: 10.1177/1071100716679110. [PubMed: 27852647]
7. Gazdag A, Cracchiolo A 3rd. Surgical treatment of patients with painful instability of the second metatarsophalangeal joint. Foot Ankle Int 1998;19(3):137–43. doi: 10.1177/107110079801900304. [PubMed: 9542983]
8. Gregg J, Silberstein M, Clark C, Schneider T. Plantar plate repair and Weil osteotomy for metatarsophalangeal joint instability. Foot and Ankle Surgery 2007;13:116–121. doi: 10.1016/j.fas.2007.01.001.
9. Hofstaetter SG, Hofstaetter JG, Petroutsas JA, Gruber F, Ritschl P, Trnka HJ. The Weil osteotomy: a seven-year follow-up. J Bone Joint Surg Br 2005;87(11):1507–11. doi: 10.1302/0301-620x.87b11.16590. [PubMed: 16260668]
10. Jastifer JR, Coughlin MJ. Exposure via Sequential Release of the Metatarsophalangeal Joint for Plantar Plate Repair Through a Dorsal Approach Without an Intraarticular Osteotomy. Foot & Ankle International 2015;36(3):335–338. doi: 10.1177/1071100714553791. [PubMed: 25288329]

11. Johnston RB 3rd, Smith J, Daniels T. The plantar plate of the lesser toes: an anatomical study in human cadavers. Foot Ankle Int 1994;15(5):276–82. doi: 10.1177/107110079401500508. [PubMed: 7951967]

12. Nery C, Coughlin MJ, Baumfeld D, Mann TS. Lesser metatarsophalangeal joint instability: prospective evaluation and repair of plantar plate and capsular insufficiency. Foot Ankle Int 2012;33(4):301–11. doi: 10.3113/fai.2012.0301. [PubMed: 22735202]

13. Nery C, Coughlin MJ, Baumfeld D, et al. Lesser metatarsal phalangeal joint arthroscopy: anatomic description and comparative dissection. Arthroscopy 2014;30(8):971–9. doi: 10.1016/j.arthro.2014.03.018. [PubMed: 24835840]

14. Shirzad K, Kiesau CD, DeOrio JK, Parekh SG. Lesser toe deformities. J Am Acad Orthop Surg 2011;19(8):505–14. doi: 10.5435/00124635-201108000-00006. [PubMed: 21807918]

15. Singer NV, Saunders NE, Holmes JR, et al. Presence of Neovascularization in Torn Plantar Plates of the Lesser Metatarsophalangeal Joints. Foot Ankle Int. 2021;42(7):944–951. doi:10.1177/1071100721990038. [PubMed: 33563043]

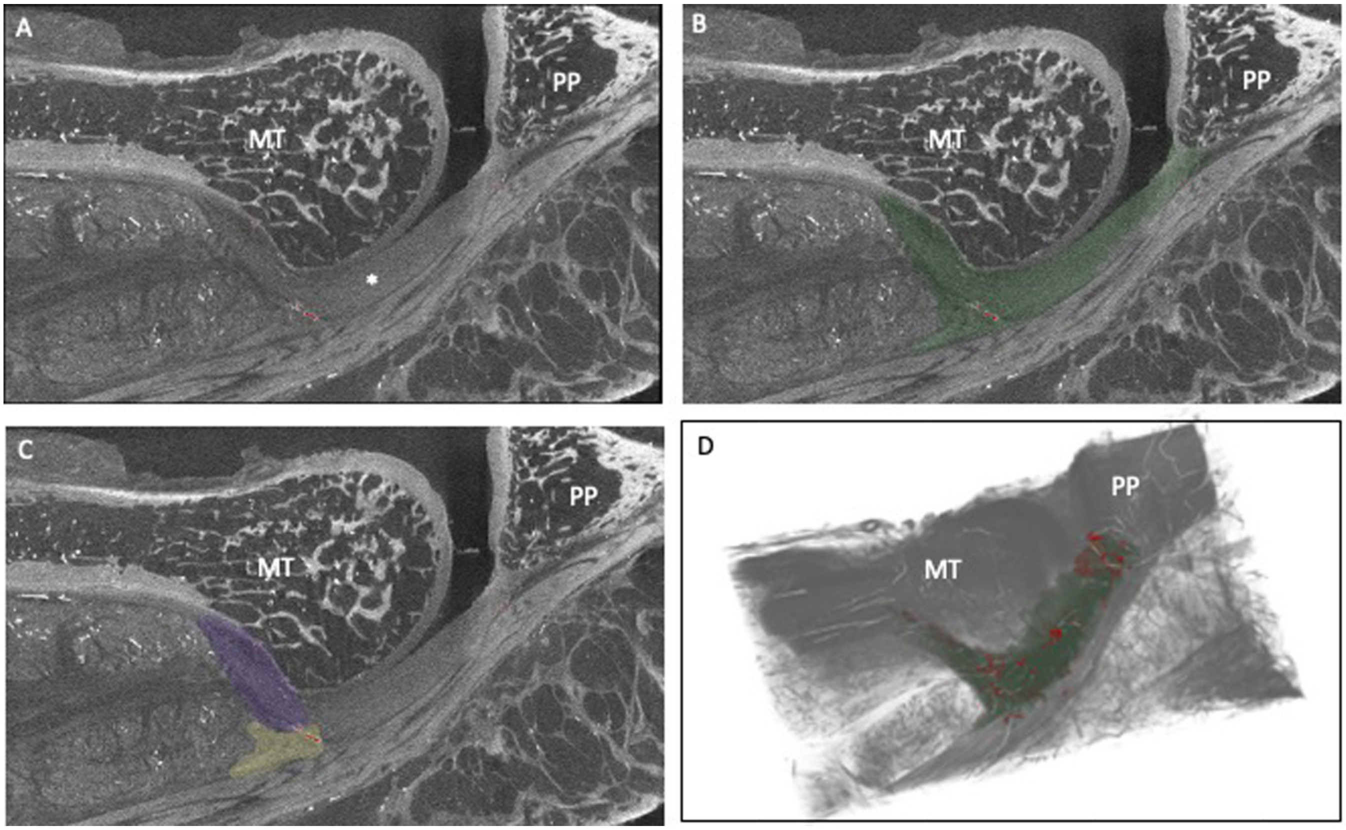

Figure 1.

(A-C) 2D sagittal nano-CT slice and (D) 3D reconstruction of lesser MTP joint nano-CT scan. (A) Representative sagittal cut of 2D analysis. The barium-infused vasculature appears as bright white in nano-CT images. The vasculature within the plantar plate was pseudocolored red for visualization. (B) Sagittal cut of 2D analysis with the plantar plate highlighted in green and semitranslucent with the vasculature colored red. (C) Sagittal cut of 2D analysis with the regions of interest of the metatarsal pedicle of the proximal plantar plate highlighted blue and plantar fascia of the proximal plantar plate highlighted yellow. Vasculature supply of the plantar plate is highlighted in red. (D) Sagittal view of a 3D reconstruction of a lesser toe MTP joint with lateral bone and soft tissues surrounding the plantar plate removed. The metatarsal head (MT), proximal phalanx (PP) are labeled for reference.

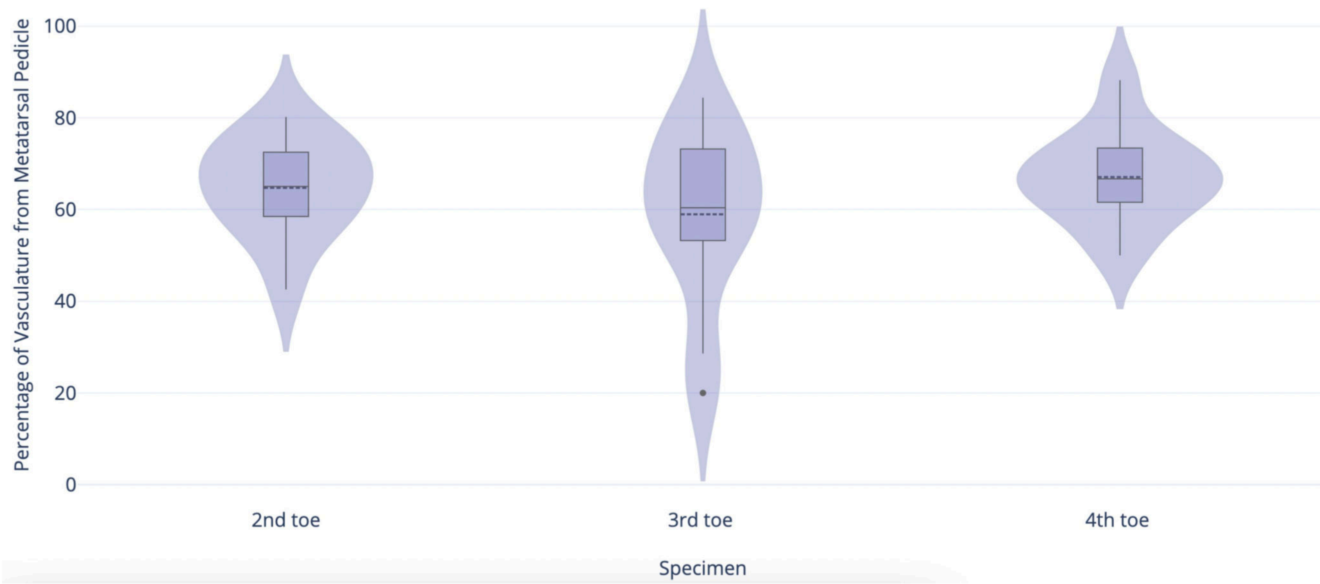

Figure 2.

Violin plot for percentage of vasculature supply to the proximal plantar plate from the metatarsal pedicle in lesser toes. Percentages were calculated from vasculature volume (mm^3). The violin plot includes a box and whisker plot overlayed with a kernel density estimation of the distribution of the percentage of vasculature supply to the proximal plantar plate from the metatarsal pedicle. Wider sections of the plot represent a higher probability that the lesser toe specimen will have a particular percentage of vasculature from the metatarsal. The dot at 20% for the 3rd toe is an outlier. The dotted horizontal line is the mean. The solid horizontal line is the median.

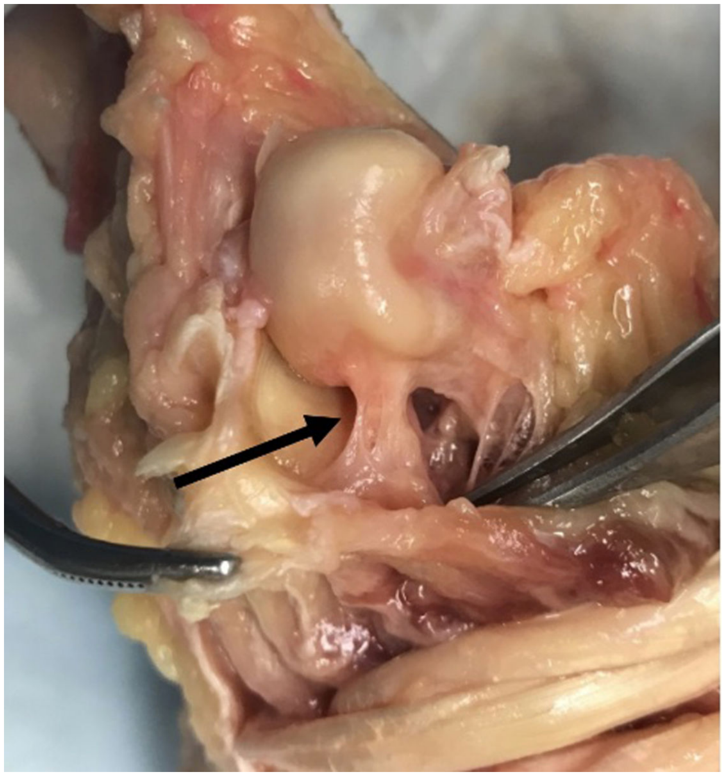

Figure 3.

Photograph of metatarsal head with plantar plate reflected toward bottom left and proximal plantar plate attachment visible with notable invagination of articular surface at insertion site with pedicle labeled with black arrow.