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Vascular Supply of the Tendon of the Equine Deep Digital Flexor Muscle Within the Digital Sheath

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The vascular and microvascular anatomy of the equine deep digital flexor tendon (DDFT) within the digital sheath was studied by injecting the vasculature with either colored latex or barium sulphate for radiographic, microangiographic, histologic, and computed tomographic (CT) evaluation. Consecutive 4-mm thick two-dimensional CT slice data were reconstructed to 3-dimensional volumetric images to enhance spatial evaluation of the blood supply. Gross dissection and angiographic studies identified three major vascular sources. Above the fetlock, the DDFT was supplied by either a branch of the medial palmar artery (Arteriae digitalis palmaris communis II) or a branch of the medial palmar digital artery (A. digitalis [palmaris propria III] medialis). Below the fetlock, the DDFT was supplied by branches from the lateral and medial palmar branches to the proximal phalanx (Ramus palmaris phalangis proximalis). The most distal aspect of the tendon received small branches from the medial and lateral palmar digital arteries. Using histology and microangiography we observed an extensive and uniform intratendinous vascular network above and below the fetlock, with a relatively avascular region of tendon palmar to the fetlock. The most distal 2.0 to 2.5 cm of the tendon within the sheath was heavily infiltrated with fibrocartilage along its dorsal aspect.
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INJURIES TO the tendon of the deep digital flexor muscle (DDFT) are common and often occur adjacent to or below the fetlock where the tendon is enclosed within the digital synovial sheath. These injuries have a poor prognosis for future soundness, because of predisposition to infection, formation of restrictive adhesions, poor healing capabilities of sheathed tendons, and a precarious blood supply.[1-4]

Despite the frequency and often devastating consequences of these injuries, little information is available about the normal blood supply and histological appearance of that segment of the DDFT within the digital sheath of the horse. Webbon suggested that the DDFT received its extrinsic vascular supply proximally from the common digital artery and distally by a vinculum.[5] Within the digital sheath, the dorsal one fourth of the DDFT is composed of fibrocartilage.[6] From a microangiographic study, the intrinsic blood supply of the DDFT in the region of the fetlock joint seemed to be confined to the palmar surface of the tendon.[7] These findings suggest that there are regional differences in tendon morphology that may contribute to differences in regional blood supply to the DDFT within the digital sheath.

The objective of this study was to fully characterize the intrinsic and extrinsic blood supply of the seg-

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ment of the DDFT contained within the digital sheath. We hypothesized that the vascular pattern would be similar to that observed in the tendons of other species. Specifically, that the DDFT of the horse should be relatively avascular adjacent to the palmar aspect of the fetlock joint;[8-14] that the normal dense connective tissue characteristic of tendon would be replaced with fibrocartilage in areas of increased frictional and compressive forces[15,16]; and that regions within the body of the tendon composed of fibrocartilage correspond to regions of avascularity.[13,17] In addition to traditional methods of gross anatomic dissection, microangiography, and histology, we developed and used a new technique for studying vascular anatomy by 3-dimensional (3-D) volumetric reconstruction of the vessels from 2-dimensional (2-D) computed tomography (CT) data sets.

MATERIALS AND METHODS

Eighteen forelimbs were obtained from nine horses euthanatized for reasons other than vascular or forelimb orthopedic disease. Horses were administered acetylpromazine (0.02 mg/kg, intravenously [IV]) (Promace, Fort Dodge Labs Inc, Fort Dodge, IA) and heparin sodium (200 IU/kg, IV) (Heparin Sodium, Schein Pharmaceutical Inc, Port Washington, NY) 10 minutes before being killed with pentobarbital sodium (Socumb, Butler Co, Columbus, OH). Immediately after death, the forelimbs were severed in the middle of the antebrachium and the median artery was cannulated with a 10-gauge polypropylene catheter (Medicut Cannula, Sherwood Medical, St. Louis, MO).

One forelimb randomly chosen from each horse was injected manually with 60 to 120 mL of colored latex (Blue Vinyl, Carolina Biological Co, Burlington, NC) and then used for anatomic dissection. The contralateral limb was placed in a water bath at 37°C and the vessels were injected with 525 mL of barium sulphate (50% weight by volume) (Micropaque contrast, Picker International, Canton, MA) and water suspension. Seventy-five mL of 10% buffered formalin was added to the last half of the injection medium. Compressed air and a manometer were used to maintain injection pressure at 100 mm Hg. Injection of specimens was considered complete when flow of barium suspension from cut ends of collateral arteries slowed to an almost imperceptible rate. The injection process took 3 to 5 hours to complete, then the limbs were refrigerated for at least 12 hours to allow the injection medium to cure.

Dorsopalmar and lateromedial radiographs (70 kVp, 200 mA, .017 s) were taken of the limb specimens to document satisfactory filling of the digital vasculature. Then the limbs were imaged using CT (120 kVp, 50 mA, 8 s, 12 cm field diameter) (Technicare 2010 CT scanner, Ohio Nuclear [GE Medical Systems], Philadelphia, PA). Transverse 4-mm contiguous CT images were taken, starting 2 cm proximal to the bifurcation of the medial palmar artery and extending 2 cm distal to the termination of the digital sheath.

Then the DDFT was dissected free of surrounding tissues and a dorsal to palmar microangiogram (23 kVp, 50 mA, 20 s) of the sheathed portion of the DDFT was obtained on high detail film (Kodak Min-R film, E.M. Parker, Brookline, MA) with a Kodak Min-R screen, using a Faxitron cabinet (Faxitron cabinet, Hewlett Packard, OR). The tendon was then cut into 4-mm thick transverse sections and sequential microangiograms of tendon cross-sections were taken (20 kVp, 50 mA, 20 s). Tendon sections were placed in 10% formalin and later were embedded in paraffin, cut to 10 μm and stained with hematoxylin and eosin.

CT data was transcribed to data sets of 2-D bit map files (256 $\times$ 256 pixels of 8-bit data). Geometric information and measures from the CT scanner also were transcribed and all files were transferred to a computer work station (240 GTX, Silicon Graphics Inc, Mountain View, CA) designed for graphic manipulations. These 2-D files were reconstructed volumetrically by stacking sequential CT files using commercially available software (Voxelview, Vital Images Inc, Fairfield, IA).

The 3-D volumetric reconstructions were rendered by changing opacity, color or grey scale according to voxel values. Mean $\pm$ 2 *SD* voxel value bands for different tissue types were calculated from 100 voxels chosen from areas of tendon, bone, injected vessels, and skin. An animation was created where each of these tissue types were enhanced by increasing the opacity values of the related voxel value bands. A lighting algorithm was applied to the rendering. Each enhanced rendering was rotated 360 degrees in 10 degree increments around the long axis of the limb, as this was a small enough increment of rotation to allow a smooth animation.

RESULTS

Anatomic dissection revealed three major divisions from the palmar digital arteries to the DDFT: proximal to the fetlock below the fetlock, and at the distal extent of the digital sheath (Fig 1). Proximal to the fetlock the tendon received a branch from the medial palmar artery (A. digitalis palmaris communis II) in 7 horses and a branch from the medial palmar digital artery (A. digitalis [palmaris propria III] medialis) in two horses. These branches were

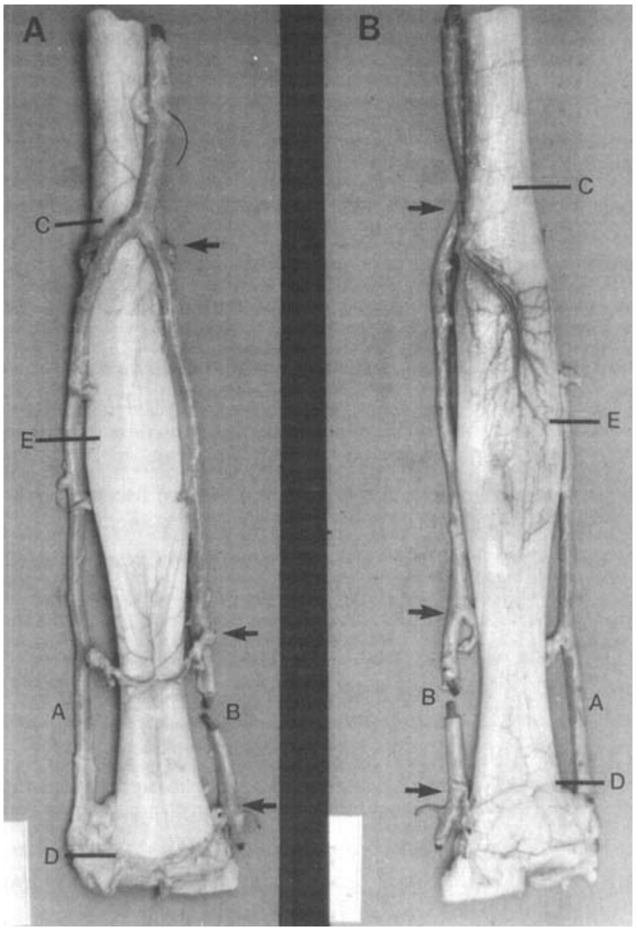


Fig 1. Dorsal (A) and palmar (B) aspects of the DDFT within the digital sheath. Vessels in the specimen have been injected with latex. Three major vascular divisions (arrows) to the tendon are evident: above the fetlock (proximal), below the fetlock (middle) and distal to the digital sheath (distal). (A) lateral and (B) medial palmar digital arteries, (C) proximal and (D) distal extents of the digital sheath, and (E) denotes the approximate level of the fetlock joint space.

located 7.0 to 7.6 cm proximal to the fetlock joint space at the proximal reflection of the digital synovial sheath. The vessel penetrated the sheath on the medial aspect of the proximal sheath reflection, was carried in a condensation of areolar connective tissue (vinculum) and inserted on the palmar aspect of the DDFT (Fig 1). The vessel radiated branches as it coursed distally. In several horses, one or two small branches from the lateral palmar digital or medial palmar arteries accompanied the larger branch. However, these small vessels supplied only a relatively small section of the tendon within the sheath.

In four horses, the middle blood supply was derived from a single branch from the palmar branch to the proximal phalanx of the lateral palmar digital artery (Ramus palmaris phalangis proximalis), whereas in five horses there were two branches; one each from the palmar branches to the proximal phalanx of the lateral and medial palmar digital arteries to the proximal phalanx (Fig 2). The palmar branches to the proximal phalanx originated from the lateral and medial palmar digital arteries approximately 5 cm distal to the fetlock joint space. This corresponded approximately to the middle of the proximal phalanx. These branches to the DDFT penetrated the digital sheath of the tendon and were

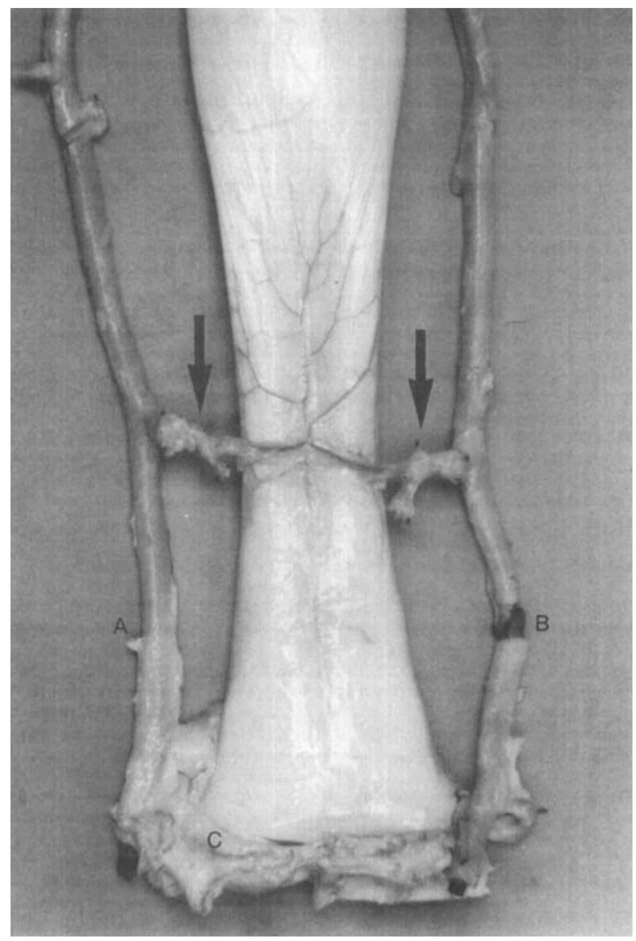


Fig 2. Dorsal aspect of the DDFT distal to the fetlock. Blood supply in this region originates from branches (arrows) from the palmar branches to the proximal phalanx of the palmar digital arteries. Four horses only had a branch from the palmar branch to the proximal phalanx of the lateral palmar digital artery. The vessels originate at about the level of the middle of the proximal phalanx and are carried in a condensation of areolar connective tissue (vinculum) as they course from the tendon sheath to the tendon. (A) lateral and (B) medial palmar digital arteries and (C) dorsal distal reflection of the digital sheath.

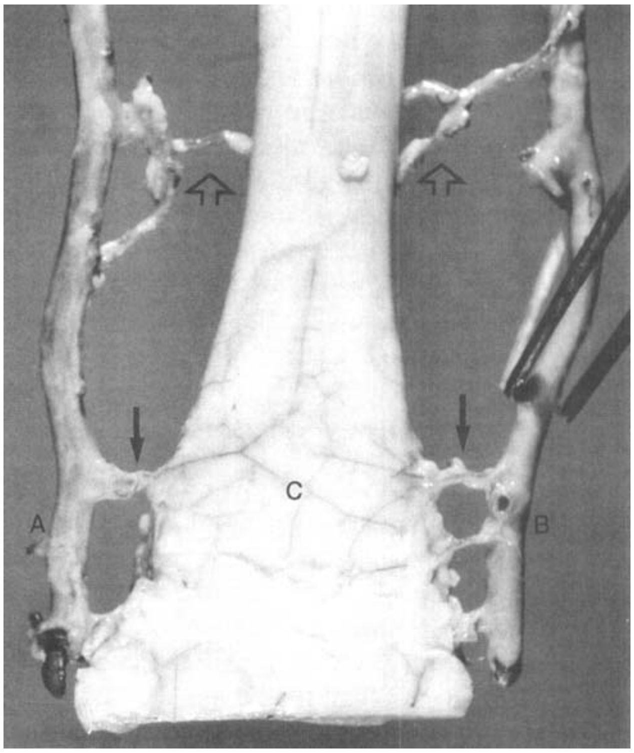


Fig 3. Palmar aspect of the distal DDFT within the digital sheath. The distal blood supply is provided by branches (arrows), from the lateral (A) and medial (B) palmar digital arteries. Branches (open arrows) of the palmar branches to the proximal phalanx of the lateral and medial palmar digital arteries pass to the dorsal aspect of the tendon. (C) Denotes the level of the palmar distal reflection of the digital sheath.

carried in a condensation of areolar connective tissue (vinculum), and inserted onto the dorsal aspect of the tendon (Fig 2). These vessels and vincula were located at the same level as the vincula tendinum which are the fibrous bands extending from the DDFT to the straight sesmoidean ligament.[18,19] In contrast to the proximal blood supply, these vessels coursed both proximally and distally along the dorsal surface of the tendon.

Distally, the tendon received two small branches, one each from the medial and lateral palmar digital arteries (Fig 3). These branches originated about 10 cm distal to the fetlock joint space. They inserted onto the palmarolateral and palmaromedial aspects of the DDFT at or just below the palmar distal reflection of the tendon sheath and penetrated proximally into the sheathed portion of the tendon. Immediately distal to these branches were two vessels, also from the lateral and medial palmar digital arteries, that were carried within the dorsal distal reflection of the tendon sheath (Fig 4), anastomosed with each other but did not seem to penetrate the tendon. On the palmar aspect, the tendon sheath ended 1.75 to 2.0 cm proximal to the dorsal reflection of the tendon sheath. The dorsal reflection of the tendon sheath was located immediately proximal to the navicular bone.

Dorsal to palmar microangiograms showed an extensive vascular network within the tendon. Intratendinous vessels from the nonsheathed portion of the DDFT seemed to penetrate the most proximal 2.0 to 2.5 cm of the sheathed portion of the tendon. The major vessels, after entering the tendon, were

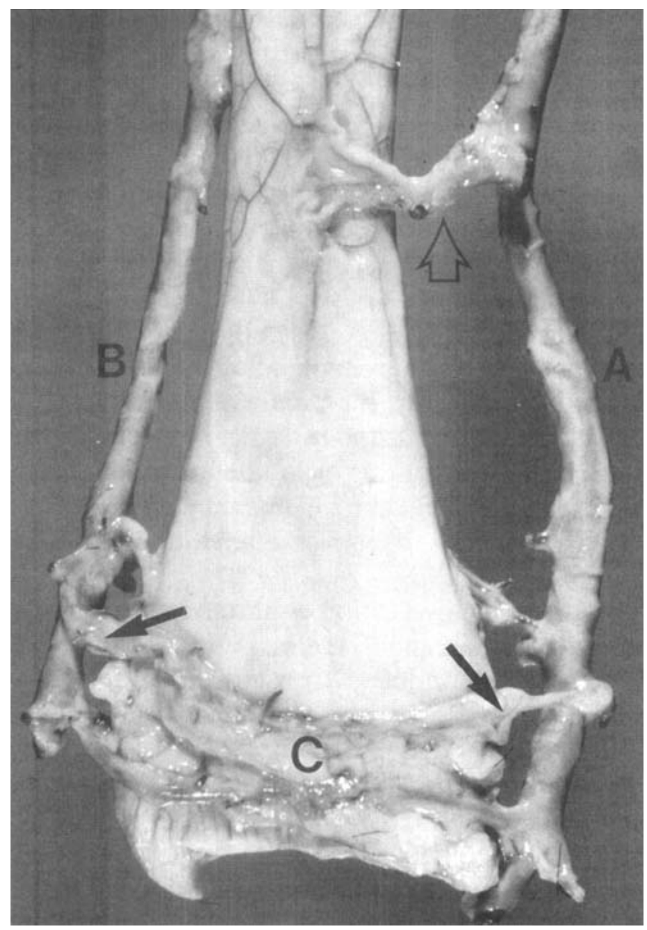


Fig 4. Dorsal distal aspect of the DDFT within the sheath. Small branches (arrows) from the lateral (A) and medial (B) palmar digital arteries are carried within the distal dorsal reflection of the digital sheath (C) but do not penetrate the tendon. The middle blood supply (open arrows) in this specimen is supplied by one vessel; a branch of the palmar branch to the proximal phalanx of the lateral palmar digital artery. The white areolar connective tissue surrounding the vessel is a condensation of mesotenon called the vinculum.

oriented in a longitudinal direction and connected by transversely oriented branches. There was a distinct region at the level of the fetlock joint space where the intratendinous vessels arising from the proximal and middle extrinsic vessels appeared to meet. Numerous anastamoses were evident between the two blood supplies. However, many vessels were observed to end before anastomosis, especially those located on the lateral and medial aspects of the tendon. A similar but much less distinct region was observed distally between the intratendinous vessels arising from the middle and distal extrinsic blood supplies (Fig 5). There did not seem to be any distinction between regions of tendon supplied by medial or lateral branches at the same level.

On microangiographic images of transverse tendon sections there was a relatively uniform intratendinous vascular network proximal and distal to the fetlock canal (that space traversed by the flexor tendons and their sheath across the palmar aspect of the metacarpophalangeal joint, bounded on its dorsal aspect by the metacarpointersesamoidian ligament and on its palmar aspect by the palmar annular ligament). The segment of the DDFT enclosed within the fetlock canal was consistently devoid of endotendinal vessels. This endotendinal avascularity began 2.5 cm distal to the proximal insertion of the digital sheath and extended 4.5 to 5.5 cm distad. Vessels observed in this region on anatomic dissections and dorsal to palmar microangiograms were confined to the surface of the tendon and did not penetrate it (Fig 6).

Microscopic evaluation confirmed the results of the microangiographic studies. Barium filled vessels to the size of arterioles. An extensive endotendinal vascular network was observed, except in the region of the fetlock canal where vessels were confined to the palmar surface of the tendon (Fig 7). When present, vessels appeared to be arranged longitudinally around the tendon fascicles. Variable amounts of fibrocartilage were found throughout the DDFT; however, the location of the fibrocartilage was not limited to the regions of endotendonal avascularity. Numerous nests of fibrocartilage were found in the fetlock canal portion of the DDFT that was devoid of endotendinal vessels. However, the distal 2.0 to 2.5 cm of the sheathed portion of the DDFT had a well-developed intrinsic blood supply but also was heavily infiltrated with fibrocartilage especially on its dorsal surface (Fig 8). No pathological changes were noted, except for several small focal areas of mineralization in two tendons.

The 3-D reconstructions and resulting images and animations confirmed the vascular distribution identified with the latex injected anatomic preparations. This technique allowed observation of the vessels in relation to other anatomic structures. In addition, the location of the region of relative avascularity in the DDFT palmar to the fetlock could be appreciated. Vessels smaller than 1 to 2 mm in diameter could not be discerned clearly.

DISCUSSION

The extrinsic blood supply to tendons are derived from the following: the perimysial vessels at the musculotendinous junction; paratenon vessels in nonsheathed areas of the tendon; mesotenon vessels in sheathed areas; and periosteal vessels at the tendon-bone junction.[20] We showed that, in horses, the principal blood supply of the DDFT within the digital sheath is provided by mesotenon vessels. However, intratendinous vessels from the nonsheathed portion of the DDFT seem to penetrate a small region of the proximal sheathed portion of the tendon. In humans, the vascular supply of the flexor digitorum profundus (FDP) tendon within the digital sheath is provided by condensations of the areolar tissue mesotenon, which are called vincula.[21] In humans, the blood supply of the FDP tendon is derived from three sources: vessels within the synovial folds in the proximal reflection of the tendon sheath, the vinculum longus, at the level of the proximal interphalangeal joint, and the vinculum brevis, distally. There is very little or no communication between these vascular systems.[21] A previous study of the DDFT in horses identified only two extrinsic vascular supplies.[5] Results of our study indicate that the DDFT within the digital sheath has three principal extrinsic vascular sources. Above the fetlock, the DDFT is supplied by either a branch of the medial palmar artery (A. digitalis palmaris communis II) or a branch of the medial palmar digital artery (A. digitalis [palmaris propria III] medialis) that penetrates the synovial sheath at its proximal reflection. Below the fetlock, at approximately the middle of proximal phalanx, the DDFT is supplied by vessels from the palmar branch to the proximal phalanx of the lateral and medial palmar digital arteries (Ramus palmaris phalangis proximalis). The most distal aspect of the

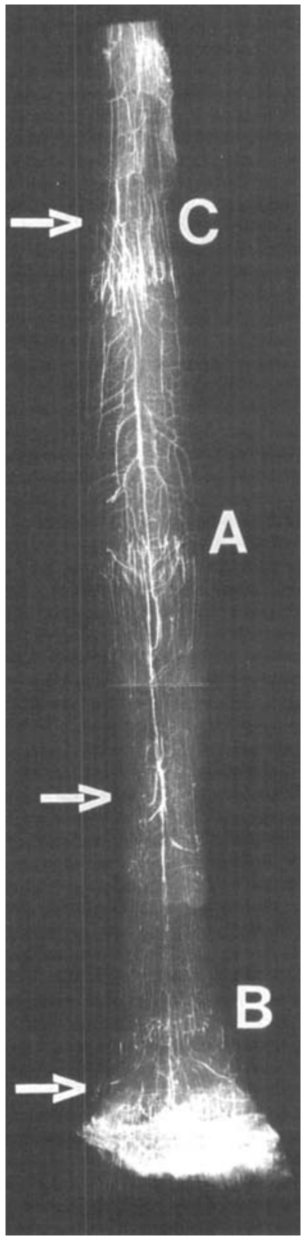


Fig 5. Dorsal to palmar microangiogram of the sheathed portion of the DDFT. The level at which the proximal, middle and distal (arrows) blood supplies enter the tendon are shown. A distinct region (A) can be seen where the intratendinous vessels arising from the proximal and middle extrinsic vessels appear to meet. There is a similar but less distinct region (B) between the intratendinous vessels from the middle and distal extrinsic blood supplies. (A) also corresponds to the level of the fetlock joint space. Intrinsic vessels from the nonsheathed portion of the DDFT can be seen penetrating the proximal extent of the digital sheath (C) supplying the proximal 2.0 to 2.5 cm of the sheathed portion of the tendon.

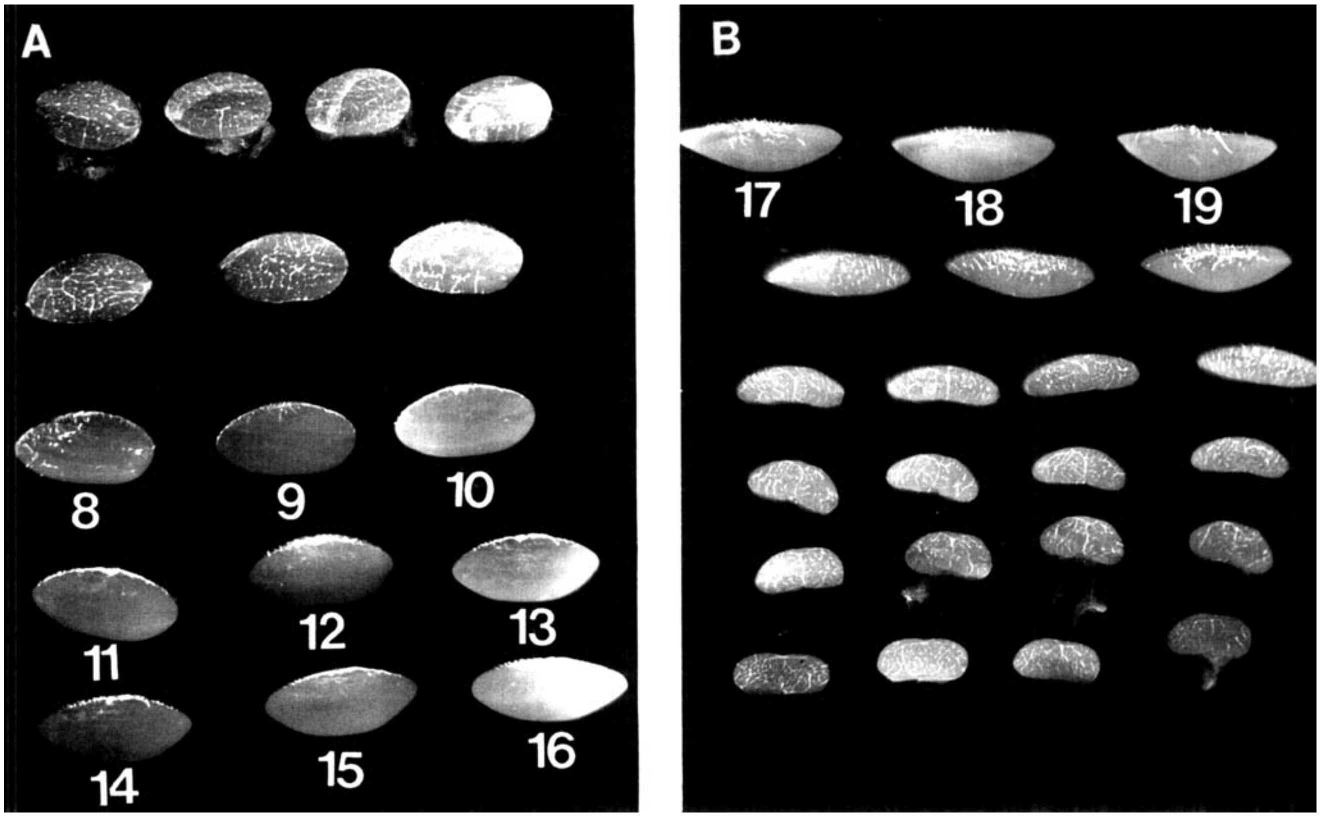
ensheathed tendon receives branches from the lateral and medial palmar digital arteries. Each of these vessels is carried in a condensation of areolar connective tissue or vinculum that extends from the synovial sheath to the tendon. These vessels provide the tendon an extensive intratendinous blood supply with the exception of the region of tendon within the fetlock canal. There seems to be a delineation between the regions of tendon supplied by each level of extrinsic vessels. Whether these areas depict the presence of a segmental blood supply or of overlapping, anastomosing blood supplies is a subject for further investigation.

The microangiographic and histological findings from this study are similar to descriptions of the intrinsic blood supply to tendons in other species.[22-24] In vascularized areas of the tendon, fascicles are surrounded by endotendon carrying a series of longitudinally oriented vessels. These vessels are derived from surface vessels by transversely oriented vessels. The parenchymal vessels are thought to be strictly interfascicular and do not penetrate the collagen bundles.[22]

The distribution of the intrinsic blood supply of the tendon seems uniform in those areas that are vascularized. However, areas devoid of vessels are common within sheathed tendons.[8,9] Avascular or hypovascular regions have been documented in the superficial and deep digital flexor tendons in humans and dogs.[10-14] Such regions are located on the concave aspect of the tendon as it passes over a joint or bony prominence. An example is the volar avascular zone of the human DDFT at the level of the proximal interphalangeal joint.[21] We found that in horses, there is an extensive intratendinous vascular network throughout the sheathed tendon except that portion of the DDFT within the fetlock canal where vessels are confined to the palmar surface of the tendon. Here too, the avascular area occurs on the concave aspect of the tendon as it passes over a joint. These differences in intratendinous vascular architecture may be related to the mechanical forces to which this tendon is subjected.

As tendons pass over joints or bony prominences they are subjected to increased frictional and compressive forces. Studies in dogs, rabbits, and cows have suggested that biochemical and morphological variations occur in these regions that reflect specialization of tendon function to accommodate increased demands.[15,16] As noted previously, these regions often are avascular or hypovascular. In addition, these same regions often contain fibrocartilage, which is thought to be more resilient to increased compressive and frictional forces. The proteoglycans of the cartilage allow movement of fluid during cyclical compression and facilitate the transport of nutrients to avascular regions.[15,17]

Increased frictional and compressive forces also may be anticipated along the dorsal aspect of the DDFT in the distal portion of the equine limb. We found that the sheathed portion of the equine DDFT had variable amounts of fibrocartilage es-



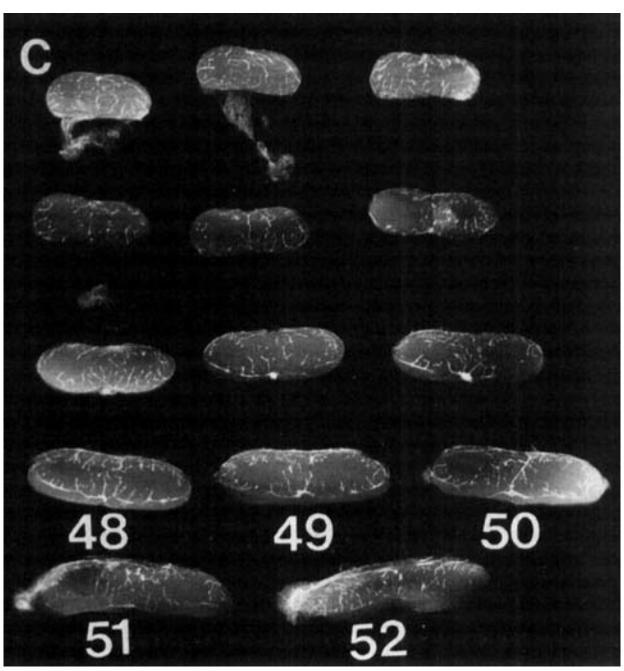


Fig 6. Microangiographic images of sequential 4-mm transverse sections of the sheathed portion of the DDFT. Sections in each photograph are arranged from proximal to distal in sequence. The palmar aspect of the tendon is oriented toward the top of the page. Slices 8 to 19 represent the region of the DDFT which courses through the fetlock canal; this region is devoid of endotendinal vessels. The vessels seen in this area in Fig 1 and Fig 5 are confined to the palmar surface of the tendon. Slices 48 to 52 are the distal most 2.0 to 2.5 cm of the sheathed portion of the DDFT which is heavily infiltrated with fibrocartilage along its dorsal aspect.

pecially along the dorsal aspect of the distal most 2.0 to 2.5 cm, however, contrary to our initial hypothesis, was not limited to the region of avascularity.

The 3-D reconstruction technology developed and used in the present study was able to confirm the location of the extrinsic vessels identified on anatomic dissection. The major advantage of this tech-

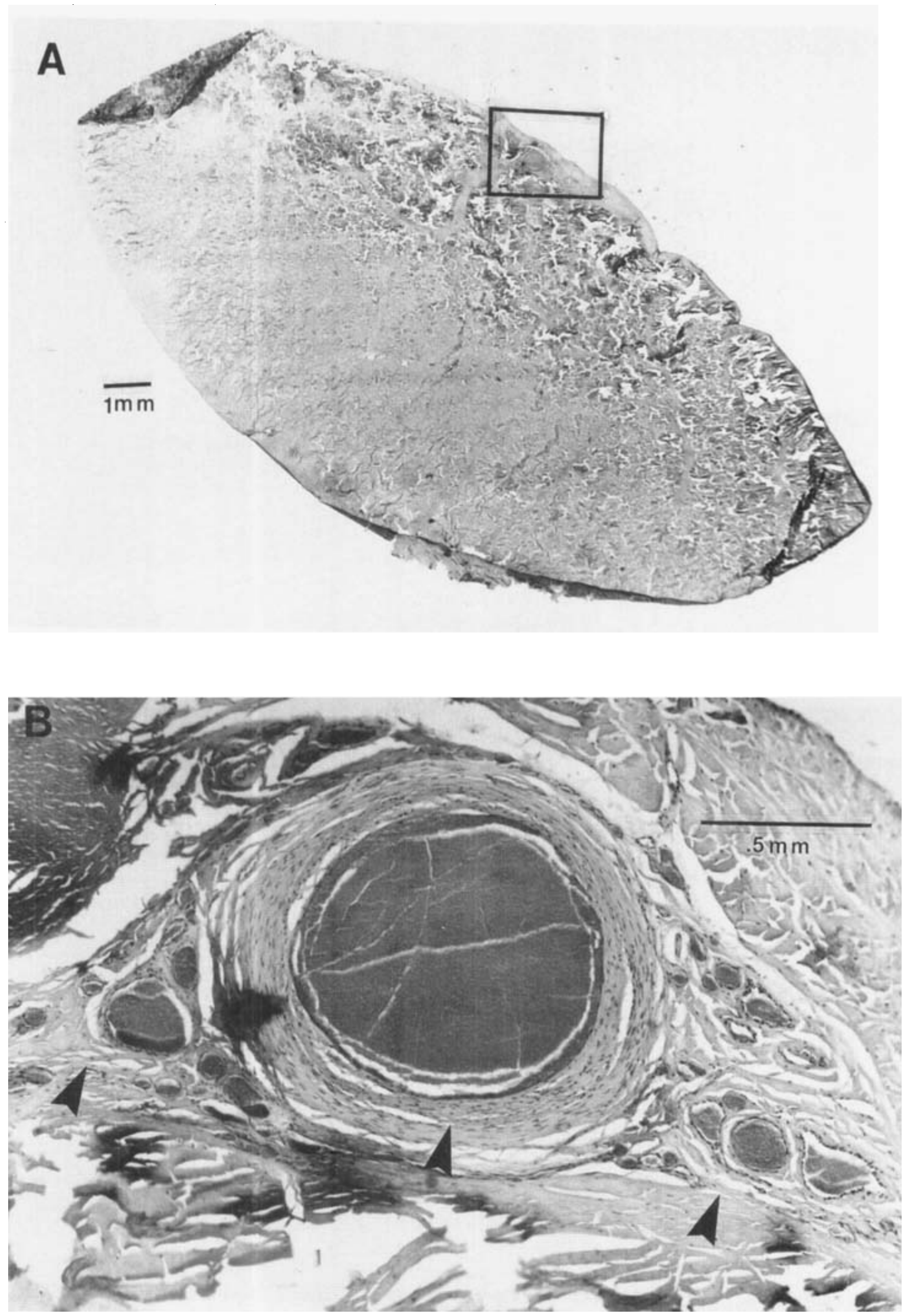


Fig 7. Photomicrographs of a transverse section from the DDFT within the fetlock canal. This section corresponds to slice 15 in Fig 6. (A) Low power view illustrating a lack of endotendinal vessels. (B) Higher power view of barium filled vessels (arrows) within the square (A); vessels are confined to the palmar surface of the tendon.

nology was the ability to observe those vessels and gain a 3-D perspective of their relation to surrounding anatomic structures. Images of tendon, injected vessels, bone, and skin could be rendered singly, or in any combination, to observe their geometric relationship. This was impossible to do with the dissected specimens because the tendon and vessels were removed from the limb. A limitation of this technology in the present study was that vessels smaller than 1 to 2 mm in diameter could not be seen clearly. Because the quality of 3-D images depends mostly on the quality of the primary images,[25] the resolution of the 3-D images in this study was limited by the slice thickness of the CT scanner which was 4 mm.

A recent report describing endoscopy of the digital sheath in horses recommended that the arthroscope be inserted through the cul-de-sac on the palmar surface of the tendon sheath, 1 to 2 cm palmar to the digital neurovascular structures and between the

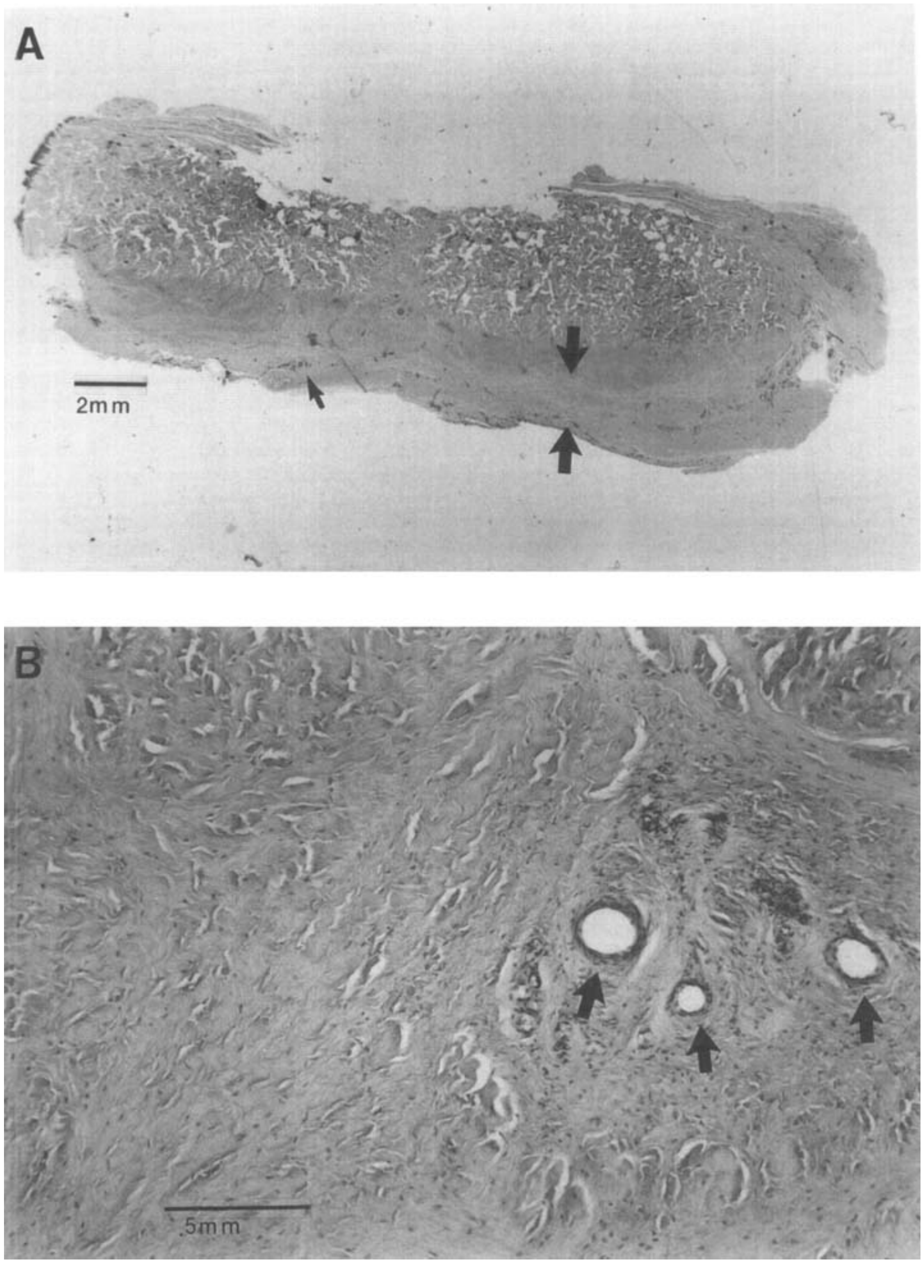


Fig 8. Photomicrographs of a tendon section taken from the distal most 2.0 to 2.5 cm of the sheathed portion of the DDFT. This section corresponds to slice 51 in Fig 6C. (A) Low power view of the entire tendon section illustrating the zone of dorsal fibrocartilage (large arrows) and endotendinal vessels (small arrow). (B) High power view of the endotendinal vessels (arrows) seen in (A).

annular ligament and proximal digital annular ligament.[19] The results of our study indicate that these arthroscopic portals should not interfere with the blood supply to the tendon. Special care should be taken to insert the arthroscope between the superficial and DDFT rather than deep to the DDFT because the middle blood supply to the DDFT is associated with the vincula, synovial villi, and fibrous bands located in this area. The location of the extrinsic blood vessels should also be avoided when making an instrument portal. For example, if an instrument portal is needed proximal to the fetlock, the portal should be placed on the lateral aspect of the sheath to avoid the vessel on the medial aspect of the proximal reflection of the tendon sheath.

The sheathed portion of the equine DDFT has three principal extrinsic blood supplies, which provide a well-developed intrinsic blood supply, except for the portion of the tendon which passes through the fetlock canal. The dorsal aspect of the sheathed portion of the DDFT is heavily infiltrated with fibrocartilage at its distal most 2.0 to 2.5 cm. Knowledge of the location of the principal extrinsic vascular sources may help avoid inadvertent damage to these structures during tenoscopic examination or other surgical procedures involving the DDFT, the digital sheath or both structures. Furthermore, the presence of fibrocartilage, a region of avascularity, and a segmenal blood supply that may fail to provide adequate collateral circulation could all play a role in the characteristically poor outcome after injury to the sheathed portion of the DDFT.

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REFERENCES

1. Honnas CM, Schumacher H, Cohen ND, et al: Septic tenosynovitis in horses: 25 cases (1983-1989). J Am Vet Med Assoc 199:1616-1622, 1991
2. Bradley JR, Baxter GM, Parks AH, et al: The use of indwelling drains in the treatment of septic tenosynovitis. Proc Am Assoc Equine Practnr 35:251-258, 1989
3. McIlwraith CW: Diseases of joints, tendons, ligaments and related structures, in Stashak TS (ed): Adam's Lameness in Horses (ed 4). Philadelphia, PA, Lea & Febiger, 1987, pp 339-481
4. Watkins JP: Tendon and ligament biology, in Auer JA (ed): Equine Surgery. Philadelphia, PA, Saunders, 1992, pp 910-915
5. Webbon PM: Equine tendon stress injuries. Equine Vet J 5:58-64, 1973
6. Webbon PM: A histological study of macroscopically normal equine digital flexor tendons. Equine Vet J 10:253-259, 1978
7. Norberg AI, Raker CW, Dodd D: Equine tendinitis–an angiographic and histologic study. Proc Am Assoc Equine Practnr 13:243-254, 1967
8. Peacock EE: The vascular basis for tendon repair. Surg Forum 8:65-69, 1988
9. Peacock EE: A study of circulation in normal tendons and healing grafts. Ann Surg 149:415-428, 1959
10. Frey C, Shereff M, Greenidge N: Vascularity of the posterior tibial tendon. J Bone Joint Surg 72:884-888, 1990
11. Korn S, Schunke M: The blood vessel system of the tendon of the long head of the biceps brachii muscle. Unfallchirurg 92:43-47, 1989
12. Zhang ZZ, Zhong SZ, Sun B, et al: Blood supply of the flexor digital tendon in the hand and its clinical significance. Surg Radiol Anat 12:113-117, 1990
13. Gelberman RH, Khabie V, Cahill CJ: The revascularization of healing flexor tendons in the digital sheath. A vascular injection study in dogs. J Bone Joint Surg 73:868-881, 1991
14. Kujat R: The microangiographic pattern of the rotator cuff of the dog. Arch Orthop Trauma Surg 109:68-71, 1990
15. Okuda Y, Gorski JP, An KN, et al: Biochemical, histological and biomechanical analysis of canine tendon. J Orthop Res 5:60-68, 1987
16. Koob TJ, Vogel KG: Site-related variations in glycosaminoglycan content and swelling properties of bovine flexor tendon. J Orthop Res 5:414-424, 1987
17. Merrilees MJ, Flint MH: Ultrastructural study of tension and pressure zones in a rabbit flexor tendon. Am J Anat 157:87-106, 1980
18. St. Clair LE: Myologia, in Schaller O (ed): Illustrated Veterinary Anatomical Nomenclature. Stuttgart, Germany, Ferdinand Enke Verlag, 1992, pp 122-123
19. Nixon AJ: Endoscopy of the digital flexor tendon sheath in horses. Vet Surg 19:266-271, 1990
20. Mayor L: The physiologic method of tendon transplantation. Surg Gynecol Obstet 22:298-306, 1916
21. Lundborg G, Myrhage R, Rydevik B: The vascularization of human flexor tendons within the digital synovial sheath region—structural and functional aspects. J Hand Surg 2:417-427, 1977
22. Edwards DA: The blood supply and lymphatic drainage of tendons. J Anat 80:147-152, 1946
23. Brokis JG: The blood supply of the flexor and extensor tendons of the fingers in man. J Bone Joint Surg 35B;131-138, 1953
24. Smith JW: Blood supply of tendons. Am J Surg 109:272-276, 1965
25. Hillman DE, Llinas RR, Canaday M, et al: Concepts and methods of image acquisition, frame processing, and image data presentation, in Toga AW (ed): Three-Dimensional Neuroimaging. New York, NY, Raven Press, 1990, pp 3-38