ORIGINAL COMMUNICATION

The Arterial Anatomy of the Achilles Tendon: Anatomical Study and Clinical Implications

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The Achilles tendon is the most frequently ruptured tendon in the lower limb and accounts for almost 20% of all large tendon injuries. Despite numerous published studies describing its blood supply, there has been no uniformity in describing its topography. The current study comprises a detailed anatomical study of both the intrinsic and extrinsic arterial supply of the Achilles tendon, providing the detail sought from studies calling for improved planning of surgical procedures where damage to the vascularity of the Achilles tendon is likely. A dissection, microdissection, histological, and angiographic study was undertaken on 20 cadaveric lower limbs from 16 fresh and four embalmed cadavers. The Achilles tendon is supplied by two arteries, the posterior tibial and peroneal arteries. Three vascular territories were identified, with the midsection supplied by the peroneal artery, and the proximal and distal sections supplied by the posterior tibial artery. The midsection of the Achilles tendon was markedly more hypovascular that the rest of the tendon. The Achilles tendon is at highest risk of rupture and surgical complications at its midsection. Individuals with particularly poor supply of the midsection may be at increased risk of tendon rupture, and approaches to the tendon operatively should consider the route of supply by the peroneal artery to this susceptible part of the tendon. Clin. Anat. 22:377–385, 2009. © 2009 Wiley-Liss, Inc.

Key words: Achilles tendon; anatomy; vascular; orthopaedic surgery; leg; heel

INTRODUCTION

The Achilles tendon is one of the longest and strongest tendons in the body, and yet is the most frequently ruptured tendon in the lower limb and accounts for almost 20% of all large tendon injuries (Edwards, 1946; Gillies and Chalmers, 1970). Despite this, there is neither consensus in the literature as to the principle cause for this, nor ways in which to minimize its incidence. The presence of regions of poor vascularity has been postulated as a potential cause; however this has not correlated with many of the previous anatomical studies.

The Achilles tendon has long been known to be poorly vascularized, and the tendon was once considered to be avascular because of its pale color and lack of visible blood vessels (Peacock, 1959; Theobald et al., 2006). This potentially poor arterial supply has contributed to the 'vascular' theory for tendon rupture. In addition to identifying sites for increased risk of rupture, an understanding of the arterial supply of the tendon is also paramount to describing approaches to the tendon during surgery. These situations include for harvest as use as a vascularized tendon graft, and for surgical lengthening of the Achilles tendon in the correction of ankle

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Received 23 September 2007; Revised 16 November 2008; Accepted 19 November 2008

Published online 27 January 2009 in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/ca.20758

equinus (Green, 1942; Graham and Fixsen, 1988; Goldstein and Harper, 2001; Dietz et al., 2006). Understanding the precise arterial supply of the Achilles tendon is essential in these settings, as minimizing tendon damage can maximize operative success and aid healing and subsequent function. Mapping arterial territories can also assist in understanding many pathological tendon processes, such as pathological tendon rupture and/or tendonitis. With injury and disease to the Achilles tendon a common event, surgical repair is also common, with improved appreciation of its vascular anatomy paramount (Aström and Westlin, 1994; Ahmed et al., 1998).

Despite numerous published studies over the past 50 years describing the blood supply of the Achilles tendon (Lagergren and Lindholm, 1959; Langberg et al., 1972; Carr and Norris, 1989; Niculescu and Matusz, 1988; Schmidt-Rohlfing et al., 1992; Karcz et al., 1996; Sanz-Hospital et al., 1997; Langberg et al., 1998; Taylor and Pan, 1998; Zantop et al., 2003; Theobald et al., 2005; Attinger et al., 2006), there has been no uniformity in describing its topography. In fact, despite these previous works, no previous studies have explored how the Achilles tendon is supplied, and rather the assumption has been made that it is supplied evenly and equally from its two source arteries. The current study comprises a detailed anatomical study of both the intrinsic and extrinsic arterial supply of the Achilles tendon, providing the detail sought from studies calling for improved planning of surgical procedures where damage to the vascularity of the Achilles tendon is likely (Lea and Smith, 1972; Stein et al., 2000).

METHODOLOGY

A dissection, microdissection, histological, and angiographic study was undertaken on 20 cadaveric lower limbs from 16 fresh and four embalmed cadavers. The cadavers comprised a combination of male and female cadavers, of an age ranging from 60 to 85 years of age. All specimens were injected with lead oxide solution using the protocol devised by Rees and Taylor (1986).

Initial macroscopic dissection was performed to remove skin, large muscle bellies and bone, and more detailed, microdissection was completed using a surgical microscope. Key anatomical landmarks, such as the calcaneal tuberosity, were preserved as a marker for tendon insertion. The Achilles tendon was removed from the lower limb in continuity with its arterial supply. The paratenon was carefully preserved. Dissection was completed in a staged manner, with radiographs and photographs sequentially taken.

Cross-sectional analyses of each tendon was undertaken by sectioning the tendon at 1 cm intervals with a surgical saw to demonstrate both the extrinsic and intrinsic blood supply to the tendon at various levels. Histological sections of tendons were prepared. The tendons were soaked in paraffin for two weeks, sectioned with a microtome, and stained with Haematoxylin and Eosin. Measurements of length and cross-sectional dimensions were performed with the use of microcalipers.

RESULTS

The origin of the Achilles tendon is from the muscle fibers of gastrocnenius and soleus muscles, and it inserts into the posterior surface of the calcaneus, immediately distal to the posterior–superior calcaneal tuberosity. The midsection of the Achilles tendon is subjectively defined as the area of the tendon deemed to be the thinnest in width, and this region was found to be located 4–7 cm proximal to the insertion (see Fig. 1 and Table 1). Given the subjective location of the origin of the tendon, the length of the Achilles tendon is difficult to determine, however the average length is 15 cm, ranging from 12 cm to 17 cm. On cross-section, the insertion of the tendon is flat, and spreads out as it attaches to the tuberosity of the calcaneus. The midsection is oval shaped and this section is substantially narrower than its insertion and origin. The origin is rectangular in shape and thickens as it blends with muscles fibers.

Patterns of Arterial Supply

The Achilles tendon is supplied by the peroneal artery laterally and the posterior tibial artery medially, in a transverse territorial fashion. Three vascular territories were identified: Proximal section, midsection, and distal section (see Figs. 2a and 2b, and Figs. 3a

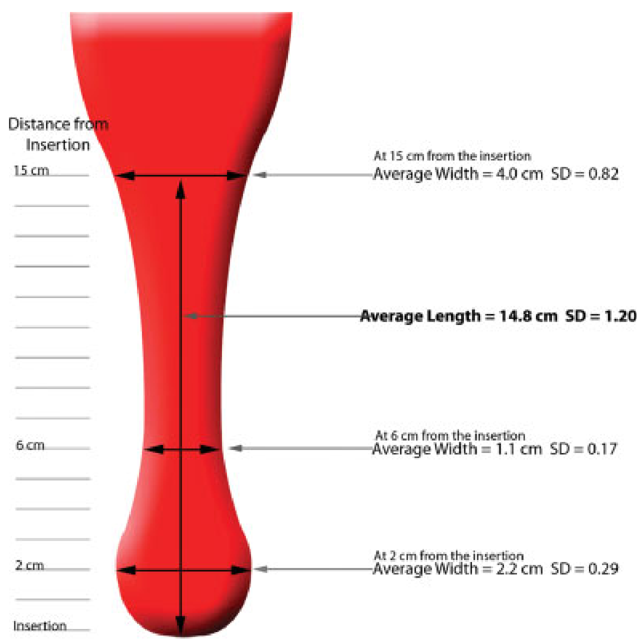

Fig. 1. Schematic demonstrating the dimensions and anatomical features of the Achilles tendon. The tendon width is measured at three locations: 2 cm, 6 cm, and 15 cm from the insertion. Note: The diagram is not to scale, and all numbers are given in cm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE 1. Anatomical Features of the Achilles Tendon

Cadaver number	Tendon length (cm)	Width at 2 cm from insertion	Width at 5 cm from insertion (cm)	Width at 15 cm from insertion (or origin) (cm)
1	15	2.5	1.3	4.5
2	15	2.5	1.3	4.5
3	15	1.8	1.1	5.5
4	15	1.8	1.1	5.5
5	15	2.6	1.0	3.0
6	15	2.6	1.0	3.0
7	14	2.0	0.9	4.2
8	14	2.0	0.9	4.2
9	17	2.1	1.4	3.8
10	17	2.1	1.4	3.8
11	15	2.5	1.0	3.2
12	15	2.5	1.1	3.2
13	12	2.0	1.1	3.0
14	12	2.1	1.1	3.0
15	15	2.6	1.1	3.5
16	15	2.6	1.1	3.5
17	15	2.0	1.0	5.0
18	15	2.0	1.0	5.0
19	15	2.0	0.8	4.0
20	15	2.0	0.8	4.0
Mean	14.8	2.2	1.1	4.0
Standard deviation	1.20	0.29	0.17	0.82

Specimens 1–16 are fresh (unembalmed) specimens, and specimens 17–20 are embalmed.

and 3b). The distal section of the tendon, comprising the insertion and up to the distal 4 cm of the tendon was found to be supplied by the posterior tibial artery. The midsection of the tendon, which is ~4–7 cm from the insertion, was supplied by the peroneal artery. The proximal section of the tendon, 7 cm from the insertion up to the musculo-tendinous junction, was supplied by the posterior tibial artery.

The majority of the Achilles tendon was supplied by the posterior tibial artery, with the only important exception being the tendon midsection. The area of the tendon supplied by the peroneal artery, the midsection, was visibly less vascular. The extrinsic and intrinsic vessel numbers in the tendon midsection were visibly reduced in all radiographs and histological cross sections of the Achilles tendon.

Two areas of anastomosis, or choke zones [the area between two vascular territories with narrow anastomotic vessels (Taylor and Palmer, 1987)], were identified among the three territories. The proximal area of anastomosis was found between the proximal section and the midsection, whereas the distal area of anastomosis was found between the midsection and the distal section (see Figs. 2a, 2b, 3a, and 3b). Both areas were found to be comparatively hypovascular on dissection and angiography, with fewer and smaller caliber vessels seen.

Details of Vascular Anatomy

The Achilles tendon was mainly supplied by arteries from its anterior and deep surface, with branches either looping around or passing transverse through the tendon to gain access to its posterior superficial surface. The arteries on the anterior surface of the Achilles tendon were found to be larger and more numerous than the smaller posterior arteries, which contributed less to the tendon blood supply in all regions except for the tendon insertion (see Figs. 4 and 5).

A layer of deep fascia covering the Achilles tendon acted as a conduit for entering blood vessels. These vessels then spread like a thin network of arteries to cover the tendon's surface within the paratenon layer. The paratenon was shown to be a vascular tendon sheath, wrapping around the tendon in such a way that removal of the paratenon would remove all vascular supply to the tendon.

The arteries of the Achilles tendon and its paratenon were orientated in three directions: Longitudinal, transverse, and deep. In most cases, the large arterial branches ran on the surface of the tendon transversely, in a direction perpendicular to the direction of tendon fibers. These large transverse vessels distributed numerous branches that ran longitudinally along the inter-fibrillar striations. The longitudinal vessels were also seen to run deep into the tendon between the tendon fibers. The Achilles tendon fibers spiral from medial to lateral, with the arteries running within the inter-fibrillar striations also seen to spiral in a medial to lateral direction.

The arterial supply pattern to the Achilles tendon was a progressive fractal pattern, with each branching artery reproducing the pattern of its parent vessel. Arteries spread out at right angles to each other, and became progressively smaller, with large transverse arteries branching into numerous smaller longitudinal vessels, which further divided into even smaller transverse arteries. This pattern of branching enabled vessels to reach all areas of the tendon.

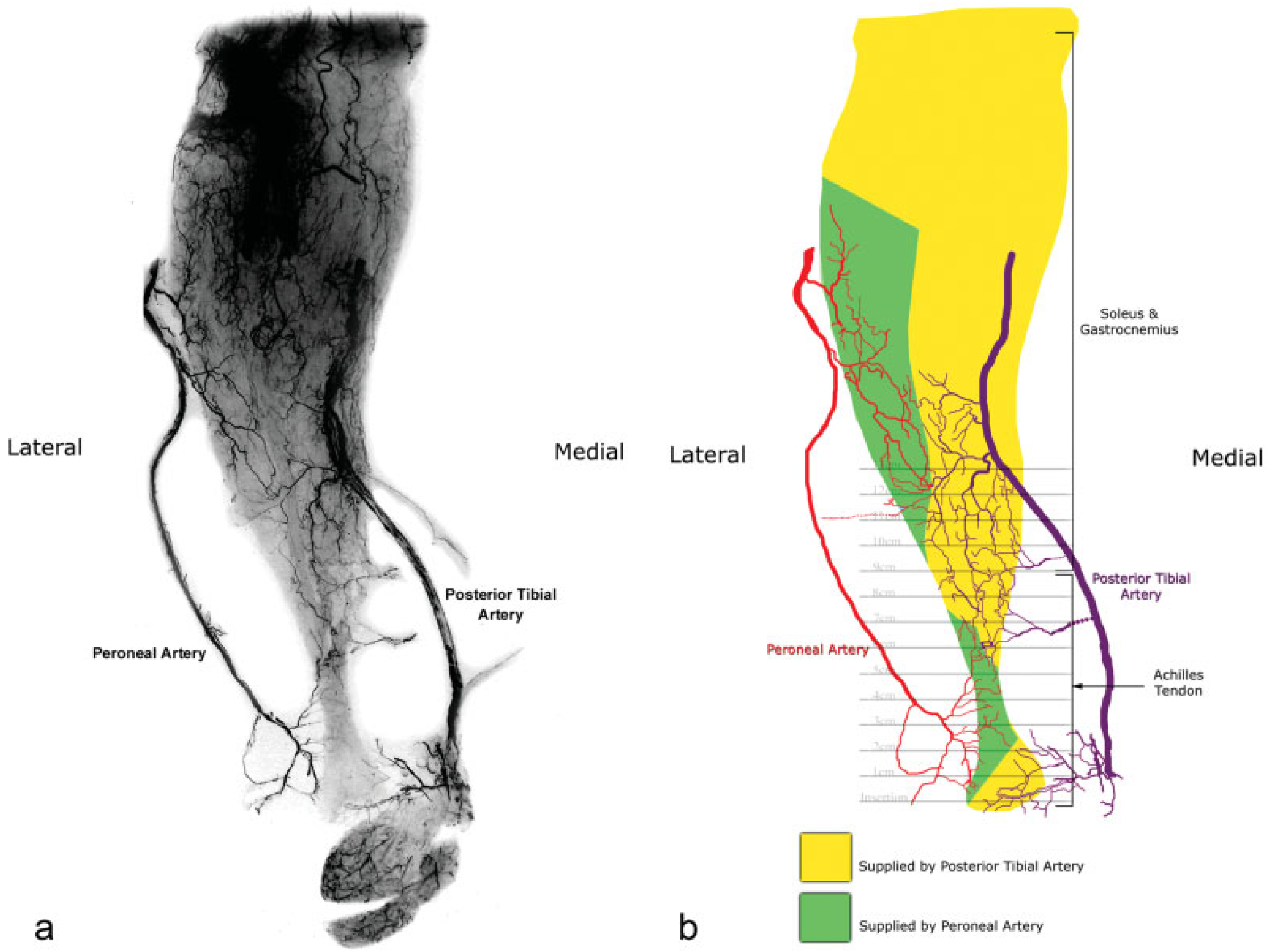

Fig. 2. **a**: Radiograph of the Achilles tendon vascular supply. The posterior tibial artery supplies the proximal and distal sections. The peroneal artery supplies the mid-section. **b**: Schematic of the Achilles tendon vascular supply. There are three vascular territories: Proximal, mid-section, and distal. The posterior tibial artery supplies the proximal and distal sections. The peroneal artery supplies the mid-section.

DISCUSSION

An understanding of the vascular anatomy of the Achilles tendon has been sought previously, as a means to predicting and preventing tendon rupture, and as an aid to surgical approaches to the tendon. However, these studies have produced conflicting results (see Table 2). Utilizing advanced angiographic techniques, combined with microdissection and histological analyses, the current study has enabled a thorough anatomical study to revisit this anatomy.

Previous studies have either found or assumed that the Achilles tendon was equally supplied by the posterior tibial artery and the peroneal artery (Lagergren and Lindholm, 1959; Taylor and Palmer, 1987; Carr and Norris, 1989; Schmidt-Rohlfing et al., 1992; Taylor et al., 1992). In two recent studies of the lower limb, both concluded that the Achilles tendon was separated into two vascular territories divided in the midline (Taylor and Pan, 1998; Attinger et al., 2006). The medial and lateral territories were considered to be approximately the same size and supplied by the posterior tibial artery and peroneal artery, respectively. This has not been widely described in the literature, and the current study provided an alternative finding.

The current study found that the posterior tibial artery and the peroneal artery were indeed the two source arteries of the Achilles tendon. However, these two arteries supplied vastly different quantities of the tendon, and supplied three distinct vascular territories. These were transversely orientated territories, which were classified as the proximal, middle, and distal sections of the Achilles tendon (see Figs. 2a and 2b). It was found that the posterior tibial artery supplied the majority of the tendon, except for a small area in the middle of the tendon, which was supplied by the peroneal artery. This finding was uniform among our specimens, however, is vastly different from the currently held concept that the peroneal artery strictly supplied the lateral half

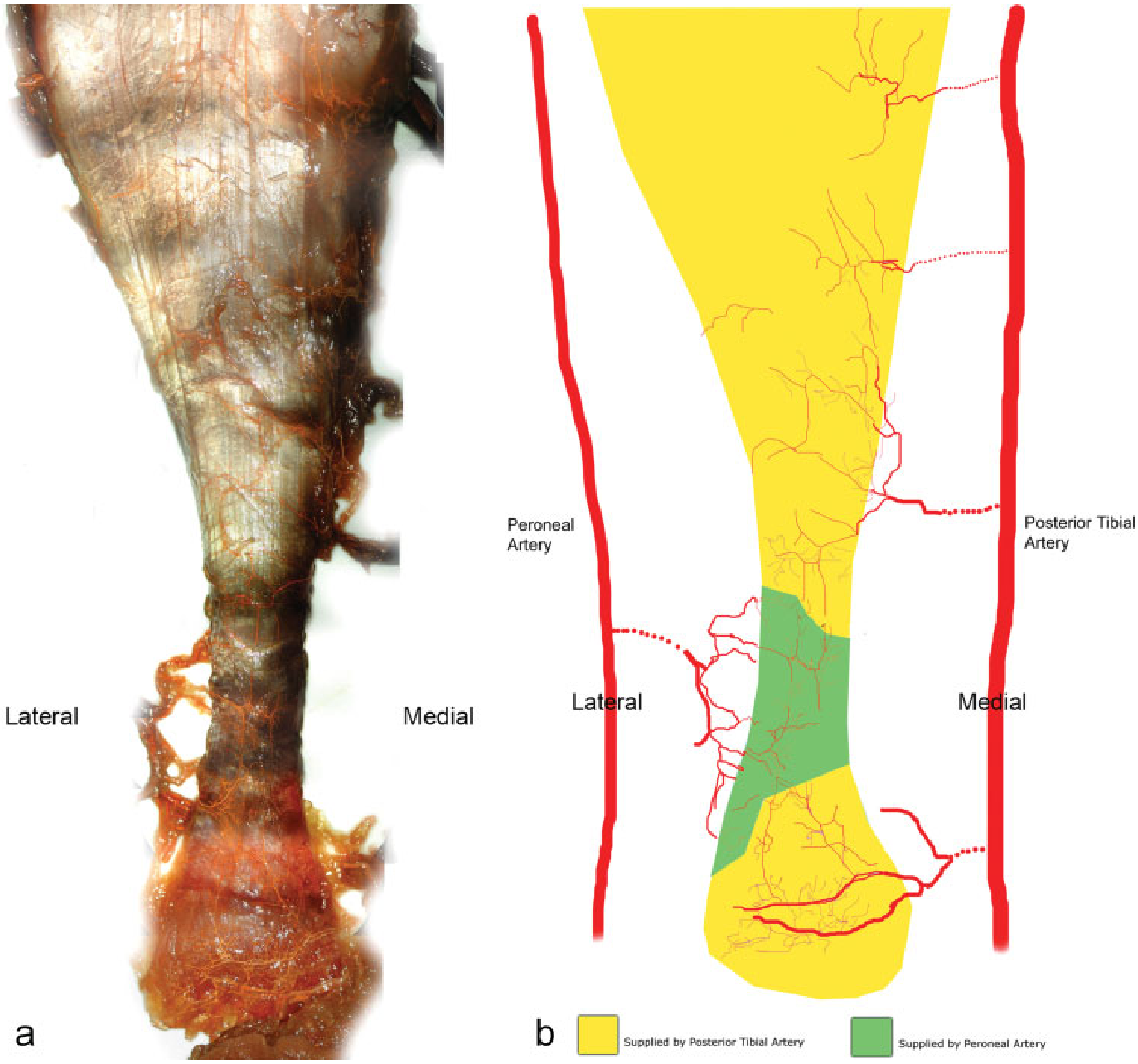

Fig. 3. **a**: Photograph of the posterior surface of the Achilles tendon. The posterior tibial artery supplies the proximal and distal sections. The peroneal artery supplies the mid-section. **b**: Schematic of the posterior surface of the Achilles tendon. There are three vascular territories: Proximal, mid-section, and distal. The posterior tibial artery supplies the proximal and distal sections. The peroneal artery supplies the mid-section. The insertion is very vascular, while the mid-section is relatively devoid of vessels.

of the tendon, whereas the posterior tibial artery supplied the medial half (see Fig. 6). This has significant clinical implications.

Implications for Tendon Rupture

Multiple factors proposed in the pathogenesis of tendon rupture. The use of fluroquinolone antibiotics have been associated with Achilles tendon rupture through an unknown mechanism (Melhus, 2005; Yu and Giuffre, 2005). In other cases, repeated microtrauma has also been postulated as a cause; however, the only well-established mechanism is the contribution of poor tendon vascularity to degenerative changes (Smith, 1965; Pufe et al., 2005). Studies performed on other tendons, such as the biceps brachii, quadriceps, tibialis anterior, tibialis posterior, and supraspinatus tendons, have demonstrated that the areas with the poorest blood supply are also the areas with the greatest propensity to rupture (Frey et al., 1990; Lohr and Uhthoff, 1990; Kolts et al., 1994; Stein et al., 1998; Petersen et al., 2000).

The midsection of the Achilles tendon is the most common region for rupture (Laine and Vainio, 1955; Reinherz et al., 1991; Campbell and Lawton, 1993). Many previous studies have shown that the midsection is also the most hypovascular region (Lagergren and Lindholm, 1959; Lea and Smith, 1972; Carr and Norris, 1989; Schmidt-Rohlfing et al., 1992; Ahmed et al., 1998; Zantop et al., 2003). We certainly also

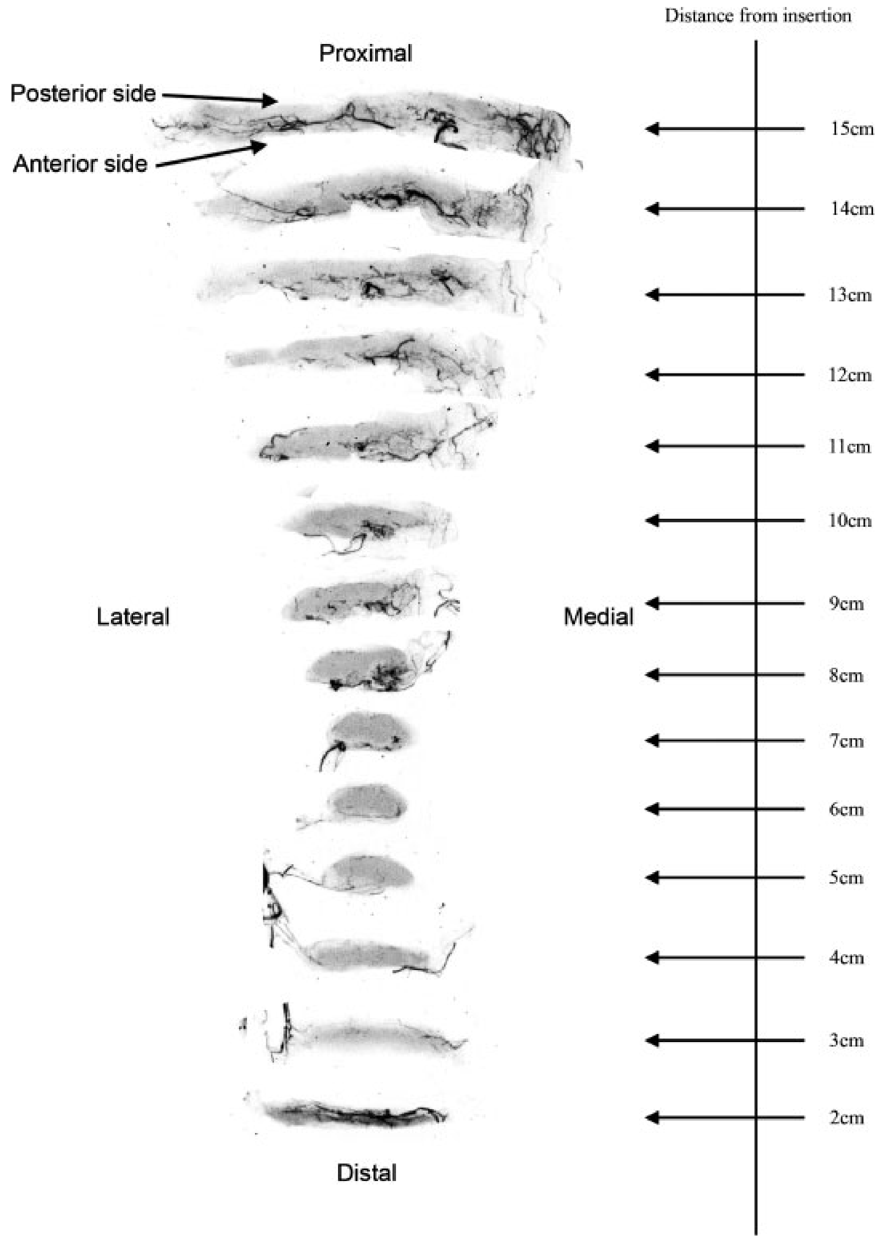

Fig. 4. Radiograph of the Achilles tendon cross section. A cross section was taken every 1 cm from the insertion. The area immediately above the insertion is supplied by the posterior vessels, whereas the anterior vessels supply the mid-section and the proximal tendon. The mid-section (4–7 cm) of the Achilles tendon is relatively avascular, and supplied by the peroneal artery. The distal and proximal tendon are supplied by the posterior tibial artery.

found this, with the number of vessels surrounding the tendon midsection (extrinsic supply) and running within the tendon midsection (intrinsic supply) visibly reduced on dissection, angiographic and histological cross-sections of the Achilles tendon (see Figs. 4 and 5).

The bilateral and symmetrical supply pattern espoused by previous studies, do not adequately

Fig. 5. Radiograph and schematic of the intrinsic blood supply to the Achilles tendon. (1) The insertion (1 cm) is supplied by posterior vessels from the medial artery (posterior tibial artery). (2) The midsection (4 cm) is poorly supplied by anterior vessels from the lateral artery (peroneal artery). (3) The proximal section (7–10 cm) is supplied by large anterior vessels from the medial artery (posterior tibial artery). (4) The aponeurosis (13 cm) is supplied by large anterior vessels from the medial artery (posterior tibial artery).

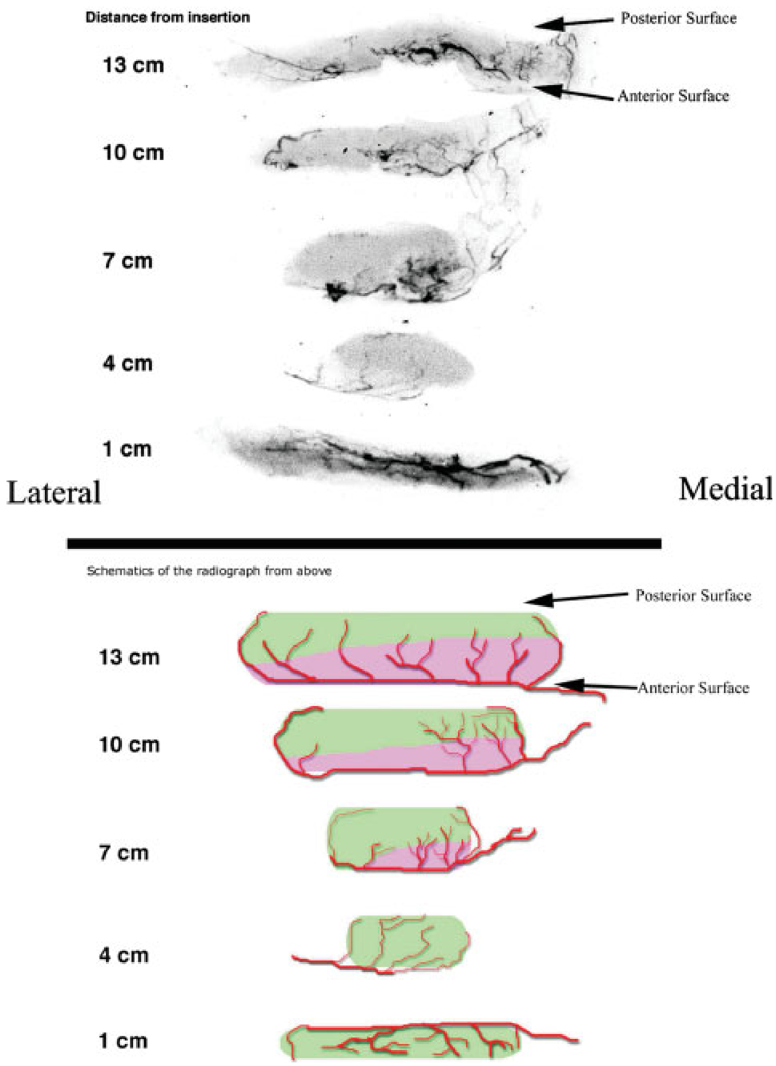

Figure 5

explain the relative hypovascularity of the midsection. This study postulates two new anatomical explanations for the hypovascular midsection based on dissection findings. The first is based on the finding that the peroneal artery supplies the tendon midsection, with the possibility that in susceptible individuals, the arterial branch from the peroneal artery is insufficient to prevent degeneration and facilitate healing. Figure 4 highlights that the tendon cross section 4 cm from the insertion is poorly supplied from the peroneal artery, relative to the rest of the tendon, while the posterior tibial artery territories may show increased resistance to ischemia in

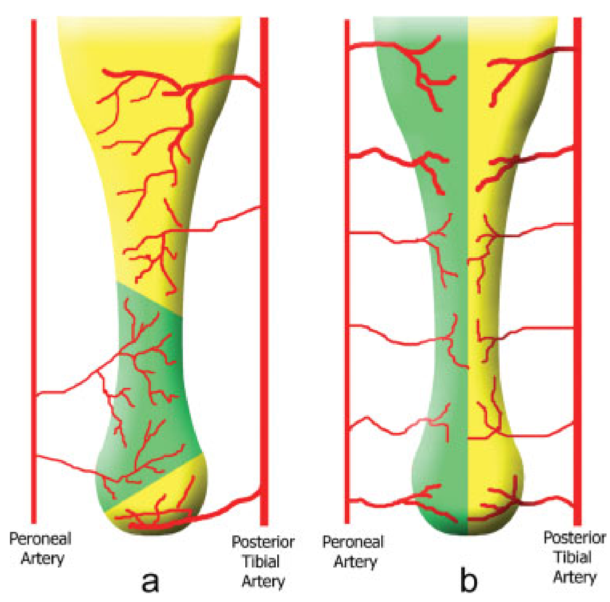

Fig. 6. Schematic of the Achilles tendon blood supply pattern. **a**: The supply pattern found in the current study, with the peroneal artery supplying the wedge-shaped midsection, and the posterior tibial artery supplying the proximal and distal sections. **b**: The supply pattern depicted from past studies, with the peroneal and posterior tibial artery supplying the Achilles tendon equally.

TABLE 2. Review of the Literature of the Vascular Supply to the Achilles Tendon, in Terms of Regions of Maximal and Minimal Vascularity

Author	Region of maximal vascularity	Region of least vascularity	Pattern of distribution
Ahmed et al., 1998	Insertion	Midsection	–
Astrom and Westlin, 1994	Midsection, Origin	Insertion	–
Attinger et al., 2006	–	–	The tendon is supplied equally from posterior tibial artery and the peroneal artery separated in the midline.
Carr and Norris, 1989	Insertion	Midsection	–
Lagergren and Lindholm, 1959	Insertion, Origin	Midsection	–
Langberg et al., 1972, 1998	Midsection	Insertion	–
Sanz-Hospital et al., 1997	Insertion	Midsection	–
Schmidt-Rohlfing et al., 1992	Origin	Midsection	–
Taylor and Pan, 1998	–	–	The tendon is supplied equally from posterior tibial artery and the peroneal artery separated in the midline.
Zantop et al., 2003	Origin	Midsection	–
Current study	Insertion, Origin	Midsection	Midsection supplied by the peroneal artery. Proximal and distal sections supplied by the posterior tibial artery

The current study can be seen to concur with most previous studies regarding the region of least vascularity; however, it does not correlate with the pattern of distribution described by Attinger et al. (2006) and Taylor and Pan (1998).

both the proximal and distal tendons because of their proximity to highly vascular tissues such as muscle and bone. A second possible explanation involves the choke zones (the area between two vascular territories with narrow anastomotic vessels) (Taylor and Palmer, 1987), with the proximal choke zone found to be just above the poorly vascularized midsection of the Achilles tendon. These unopened, small ''choke'' vessels may not adequately perfuse the ''choke'' zones, reducing the tendon midsection's capacity for self repair, permitting progressive degeneration.

Implications for Surgical Approaches

Achilles tendon lengthening is a common procedure, undertaken to correct ankle equinus or spasticity (Dietz et al., 2006). Although many surgical procedures and approaches have been described to achieve tendon lengthening, all of these procedures compromise tendon blood supply to some extent. The simplest procedure involves a full tenotomy, while more complicated procedures include slide lengthening and suturing (Morimoto and Ogata, 1968). Some of these procedures require open surgery, with full tendon exposure via large skin incisions, and some are performed percutaneously, with access to the tendon achieved via multiple limited skin incisions.

There are three main issues to consider in Achilles tendon surgery.

1. Tissues around tendons act as conduits for the arterial supply to the tendon.
2. The peroneal artery is the main source of blood supply to the Achilles tendon midsection.
3. The mid section of the Achilles tendon is hypovascular and is less likely to heal after surgery.

All open surgery necessitates dissection through the deep fascia, paratenon, and often the fat pad, all of which contribute to the blood supply of the tendon. Operations with limited incisions to the tendon are less likely to cause arterial disruption if guided by the findings of this study. Percutaneous tenotomy has shown to be very successful, particularly in terms of healing and complication rates, which might be due to the conservation of the paratenon and deep fascia (Majewski et al., 2006; Ng et al., 2006). If incision to the deep fascia and paratenon is unavoidable, a posterior longitudinal incision, based on the median line, is most desirable as it will cause the least amount of vascular disruption. To complete the surgery, the paratenon and deep fascia should be sutured together and realigned. Although suturing does not repair any damaged vessels, this close proximity between split edges may increase healing and has been demonstrated in previous studies (Frey et al., 1990; Stein et al., 2000).

The Achilles tendon midsection is only supplied by the peroneal artery on the lateral side, and hence preserving the lateral blood supply is important in maintaining the vascularity of the tendon midsection. As such, a medial edge incision will protect the blood supply to the Achilles tendon midsection and prevent postoperative rupture and operative success.

CONCLUSION

The Achilles tendon is at highest risk of rupture and surgical complications at its midsection. While the majority of the Achilles tendon is supplied by the posterior tibial artery from its medial edge, the peroneal artery provides supply to the middle section of the tendon laterally. The midsection of the Achilles tendon was found to be hypovascular in all cases. Individuals with particularly poor supply of the midsection may be at increased risk of tendon rupture, and approaches to the tendon operatively should consider the route of supply by the peroneal artery to this susceptible part of the tendon.

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