



RESEARCH ARTICLE

Fascicles of the adult human Achilles tendon - An anatomical study

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Fibers arrangement

Summary

The Achilles or calcaneal tendon is the structural base for the biomechanical work of the ankle joint. The purpose of this study is to describe the internal structure of the human Achilles tendon. The anatomy of the Achilles tendon has been described in lower mammals in which it has three parts which can be dissected from its beginning to the insertion onto the calcaneus. The partial ruptures of each part suggest that the human Achilles tendon may also be composed of parts.

The Achilles tendon is one of the most commonly torn tendons in the human body. Each segment of the Achilles tendon described by us can be ruptured separately, which can cause a partial dysfunction in flexion of the ankle joint as observed in clinical practice. We dissected 20 Achilles tendons previously fixed in 10% formaldehyde and 20 fresh-frozen Achilles tendons, paying particular attention to the relationship between the lateral and medial heads of the gastrocnemius and the soleus muscles. The layer-by-layer method and a microscope were used in our study. We found that the medial group of fibers from the medial head of the gastrocnemius muscle constitutes the posterior layer of the tendon. The lateral border of the tendon is composed of the fibers from the lateral part of the medial head of the gastrocnemius muscle. The fibers from the lateral head of the gastrocnemius muscle constitute the anterior layer of the Achilles tendon. The fibers from the soleus muscle are located in the anteromedial part of the Achilles tendon. Our findings are supported by clinical descriptions and observations of the partial rupture of the Achilles tendon.

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Introduction

The Achilles tendon is a common tendon of the triceps surae muscle (the soleus and the gastrocnemius muscles) and is located superficially along almost its entire length. The plantaris muscle tendon forms a part of the Achilles tendon in 65% of all cases (Anson and McVay, 1971). The Achilles tendon begins in the middle of the calf at the level of the lower margins of the heads of the gastrocnemius muscle.

The shape of the tendon in the transverse plane changes from flat at the beginning of the tendon to almost oval near the insertion. The Achilles tendon is fan-shaped as it could be seen at the level of the tuber calcanei.

The Achilles tendon is one of the most frequently ruptured tendons in the human body. The rupture occurs in the mechanism of overuse due to forces affecting the tendon during unsuitable physical activity (Cook et al., 2002; Hansen et al., 2003; Järvinen et al., 2004; Kader et al., 2002; Mahan and Carter, 1992). Physical activity is not the only cause of the Achilles tendon tendinopathy. The mechanism of tendinopathy is unclear, however some general factors are responsible for it, e.g. age, sex, height, weight, diabetes, gout or rheumatoid arthritis. Factors as *pes cavus* or foot wear belong to local factors (Cook et al., 2002; De Simone et al., 2003; Kader et al., 2002).

Some authors mentioned that the Achilles tendon is made up of fascicles but do not elaborate this issue (Bertolotto et al., 1995; Czynny, 2002; Richards et al., 2001).

The torsion of the tendon fibers can be seen in the Achilles tendon (Gils et al., 1996). The authors found that the fibers from the medial side of the muscular mass end superficially and those from the lateral side of the muscular mass end on the deep side of the tendon (Wood Jones, 1944). However, the author does not mention which muscular mass is indicated (was it the belly of the whole triceps surae muscle or separate muscles' bellies). Separate elements of the Achilles tendon were dissected in a beaver: one element from the medial head of the gastrocnemius muscle, one from the lateral head of the gastrocnemius muscle and one from the plantaris muscle and in other mammals one element from the soleus muscle (Parsons, 1894). It is said in the article that a similar structure can be seen in the human, though it was modified by a great development of the soleus muscle resulting from the adaptation to the erect position (Parsons, 1894).

In humans, the fibers from the gastrocnemius muscle form the postero-lateral part of the tendon

above the insertion, the remaining part is formed by the soleus muscle (Anson McVay, 1971; Wood Jones, 1944; Parsons, 1894). It was revealed that the posterior (superficial) part of the tendon is formed by the medial head of the gastrocnemius muscle. The anterior (deep) part of the tendon is formed by the lateral head of the gastrocnemius muscle. The fibers from the soleus muscle are surrounded by the fibers from the gastrocnemius muscle (Ciszek and Smigielski, 2003), which does not correspond with other studies (Anson and McVay, 1971). The aim of this study has been to describe the fibers forming the fascicles of the human Achilles tendon.

Material and methods

We examined 20 Achilles tendons previously fixed in 10% formaldehyde coming from the collection of the Department of Anatomy of the Medical University of Warsaw and 20 fresh-frozen triceps surae from cadavers from routine autopsies. The age of the examined cadavers ranged 38-80 (average age 67). There were 25 specimens from male limbs and 15 from female specimens. A microscope (fivefold and eightfold magnification), a scalpel and forceps were used. The layer-by-layer dissection method was performed during the dissection. At the beginning, the triceps surae muscle was dissected, and then the fibers from the gastrocnemius muscle were inspected under magnification. Then, the border between the fascicles from the medial and lateral heads was identified (Figure 1A). Afterwards, these fibers were separated from the fibers of the soleus muscle (Figure 1B-D). As a result of this procedure, we examined in detail the array of fibers originating in the gastrocnemius and soleus muscles. Particular attention was paid to the anterior surface of the Achilles tendon (Figure 2A). The intramuscular tendon of the soleus muscle was identified and carefully dissected from other fibers adjacent to the fibers of the gastrocnemius muscle. After that, the lumen of the retrocalcaneal bursa was opened and inspected by dissecting the fibers from the lateral head of the gastrocnemius muscle (Figure 2B).

A scalpel and forceps were used to separate the fibers, taking into consideration that the fibers from the particular parts of the triceps surae muscle show anatomical variation. During this procedure, macroscopic and digital magnification photographs were taken.

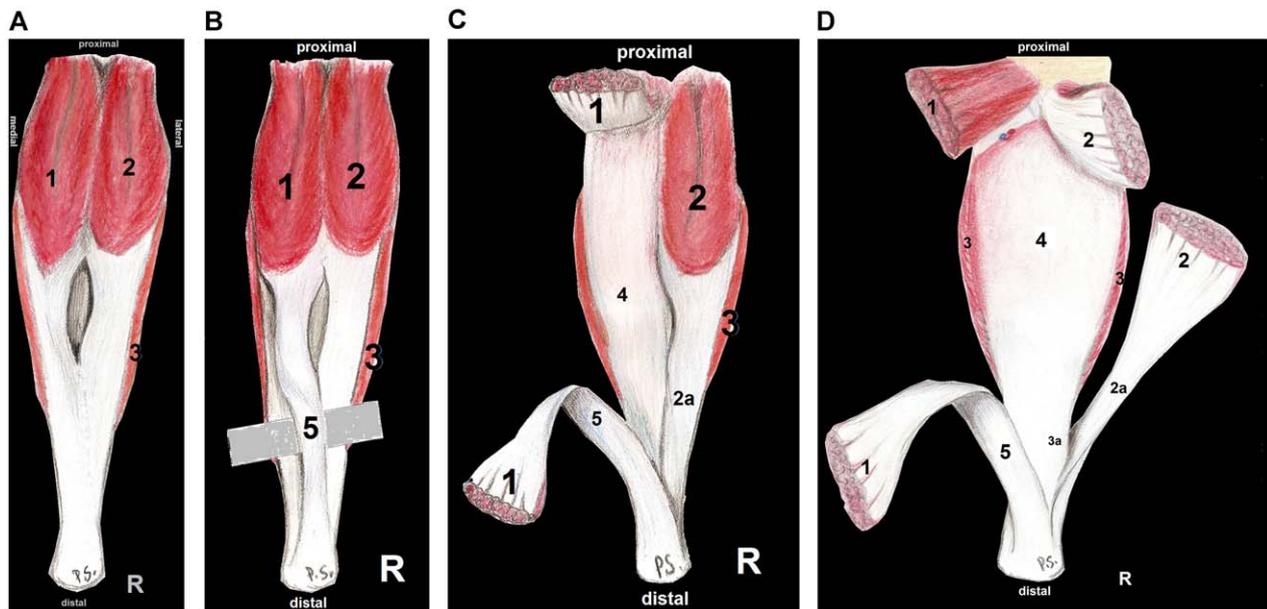


Figure 1. (A-D) The stages of dissection of the right Achilles tendon, posterior view. (1) Medial head of the gastrocnemius muscle, (2) lateral head of the gastrocnemius muscle, (2a) fibers from the lateral head of the gastrocnemius, (3) soleus muscle, (3a) fibers from the soleus muscle, (4) aponeurosis of soleus muscle and (5) fascicle from the medial head of the gastrocnemius muscle.

Results

The fibers and fascicles of the Achilles tendon have a very characteristic arrangement. Proximally, they run parallel and then rotate distally. It means that the fibers of the Achilles tendon, when forming fascicles, do not descend straight down but create a spiral structure. We divided the Achilles tendon into three equal sectors (proximal, mid part and distal). This division into three parts resulted from our observation of different arrangements of fibers at different levels. The average length of each sector is approximately 5 cm. In the proximal section, the fibers run parallel (Figure 5). In the mid part (Figure 3), the first signs of torsion can be observed (Figure 3), which are fully present in the distal part (Figure 4). The small triangular area (bordered by the contour of the heads of the gastrocnemius muscle and the horizontal line passing via the inferior pole of the lateral head) is a site at which the fibers from both heads cross (Figures 5 and 6). In the proximal section, additional stripes from the accessory head could be present. In our material we found only one instance of the accessory head at the medial head of the gastrocnemius muscle. The fibers arising from this accessory head participated in the formation of the Achilles tendon. Each part of the triceps surae is the beginning of a particular part of the Achilles tendon and can be dissected separately. Generally, the fibers, initially located in the

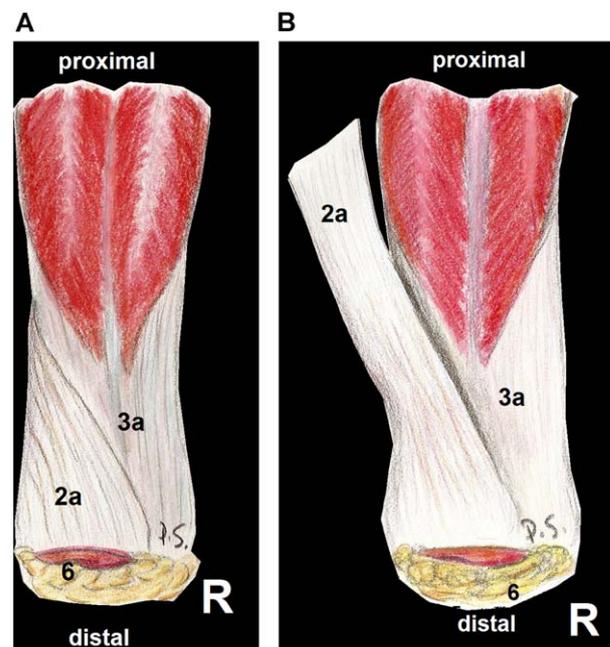


Figure 2. Dissection of the anterior surface of the right Achilles tendon, anterior view (continuation of Figure 1). (2a) Fibers from the lateral head and (3a) fibers from the soleus, 6-Kager's fat.

posterior layer, originate from the gastrocnemius muscle. Then, as they pass distally, they become spiral and, in the most distal portion, are located in the postero-lateral part of the Achilles tendon. In contrast, the fibers from the soleus muscle are

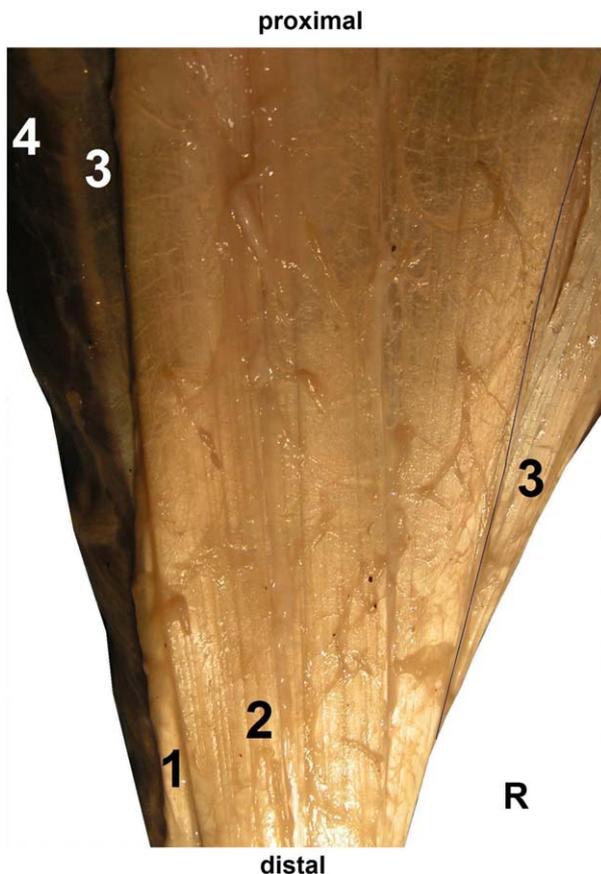


Figure 3. The middle part of the left Achilles tendon, posterior view. (1) Plantar muscle, tendon, (2) fibers from the medial head of the gastrocnemius muscle, (3) aponeurosis of soleus muscle and (4) soleus muscle (muscle fibers).

packed in the central and medial parts of the tendon (Figure 7). The fibers from the medial head of the gastrocnemius muscle descend inferiorly and constitute the posterior layer of the Achilles tendon (Figures 4 and 7). These fibers are grouped into two fascicles: one from the medial part (medial stripe), and one from the lateral part (lateral stripe) of the medial head of the gastrocnemius muscle (Figures 8 and 9). The division of fibers from the medial head of the gastrocnemius muscle corresponds to the arrangement of the fibers in the posterior (superficial) layer of the Achilles tendon. The medial stripe constitutes the medial margin (together with the fibers from the soleus muscle) and the lateral stripe, the lateral margin of the tendon. Both stripes overlap like tiles to form the posterior layer of the Achilles tendon (Figures 10 and 11).

The fibers from the lateral head of the gastrocnemius muscle descend inferiorly, laterally and anteriorly, wrapping around the fibers from the soleus muscle (Figure 9). In the distal part, in 36

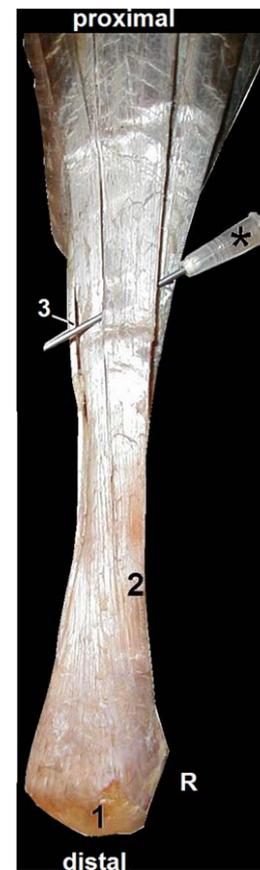


Figure 4. The right Achilles tendon, posterior view. (1) Tuber calcanei, (2) (and above the syringe) the fibers from the lateral part of the medial head of the gastrocnemius and (3) plantaris muscle tendon; * marks syringe.

specimens, the fibers from the gastrocnemius muscle formed the major part of the posterior layer of the Achilles tendon. The fibers from the soleus muscle form the posterior layer in 4 specimens. In 23 specimens, a greater part of the anterior layer was composed of the fibers from the lateral head of the gastrocnemius muscle. In 11 cases, the proportion of the fibers from the soleus muscle and the lateral head of the gastrocnemius muscle was equal. In 6 specimens, the fibers of the soleus muscle form a greater part of the anterior layer of the tendon. The Achilles tendon constitutes the posterior wall of the retrocalcaneal bursa (Figure 9). The fibers from the lateral head of the gastrocnemius muscle are arranged in the shape of an arc and “sit like a rider on a horse” or resemble the Eiffel Tower. Of all the fibers from the gastrocnemius muscle, this group shows the most significant variation in the distal part of the tendon. The arrangement of the fibers is as follows: the fibers originating in the lateral head of the gastrocnemius muscle and fibers from the soleus

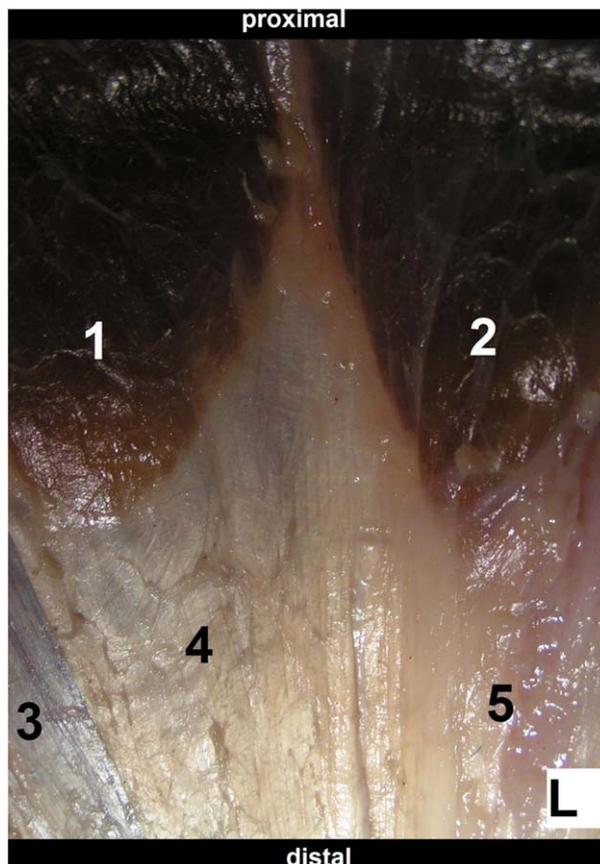


Figure 5. The space between the two heads of the left gastrocnemius, posterior view. (1) Lateral head of the gastrocnemius muscle, (2) medial head of the gastrocnemius muscle, (3) aponeurosis of soleus muscle, (4) fibers from the medial head of the gastrocnemius muscle and (5) fibers from the lateral head of the gastrocnemius muscle

muscle are located in the anterior layer of the Achilles tendon. The fibers from the medial head of the gastrocnemius muscle are located posterior to the fibers from the soleus muscle and the lateral head of the gastrocnemius muscle. The fibers from the soleus muscle are surrounded by the fibers from the gastrocnemius muscle (Figure 6).

Discussion

The Achilles tendon is not a homogenous structure since it is built up of fascicles which originate from the particular parts of the triceps surae muscle. We observed a wide range of rotation, from slight to extreme, causing the soleus component to be nearly obscure on the ventral surface (Anson and McVay, 1971). The range of rotation is variable, however it can always be observed (Gils et al., 1996; Anson and McVay, 1971; Gray's Anatomy, 2005).

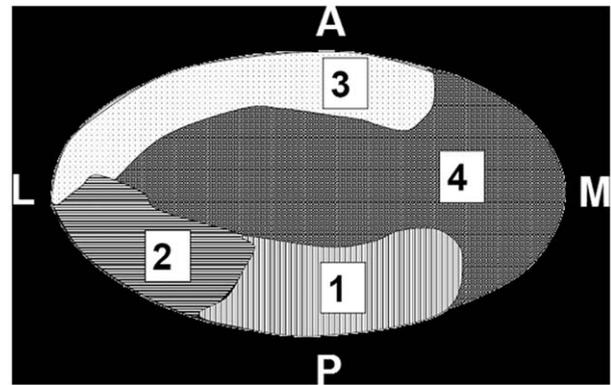


Figure 6. Transverse cross-section through the left Achilles tendon, 1 cm above tuber calcanei. (1) The fibers from the medial part of the medial head of the gastrocnemius, (2) the fibers from the lateral part of the medial head of the gastrocnemius, (3) the fibers from the lateral head of the gastrocnemius and (4) the fibers from the soleus, A: anterior, P: posterior, M: medial, L: lateral.

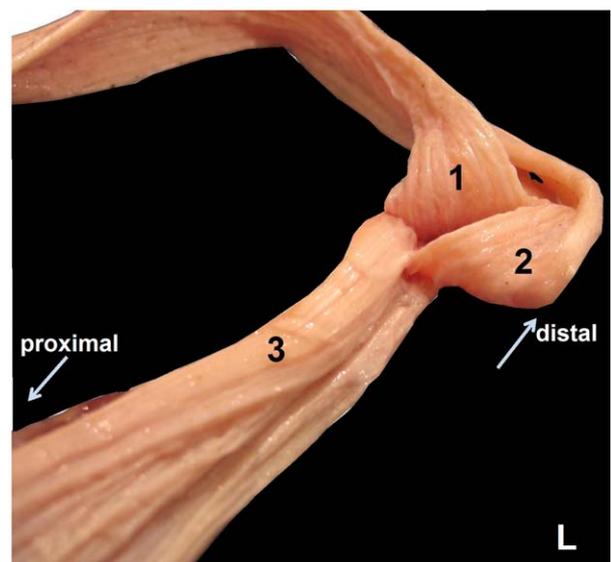


Figure 7. Dissected left Achilles tendon, superior view. (1) The fibers from the medial head of the gastrocnemius, (2) the fibers from the lateral head of the gastrocnemius and (3) the fibers from the soleus muscle.

Our study revealed that the fibers from the medial head of the gastrocnemius muscle pass laterally and posteriorly, whereas the fibers from the lateral head of the gastrocnemius muscle reach the anterior surface of the tendon (Wood Jones, 1944). The tendinous fibers from the medial and the lateral head of the gastrocnemius muscle and the soleus muscle form fascicles of the tendon.

We did not find sufficient data on the fascicles deriving from the triceps surae and constitute the Achilles tendon except for one study Ciszek and

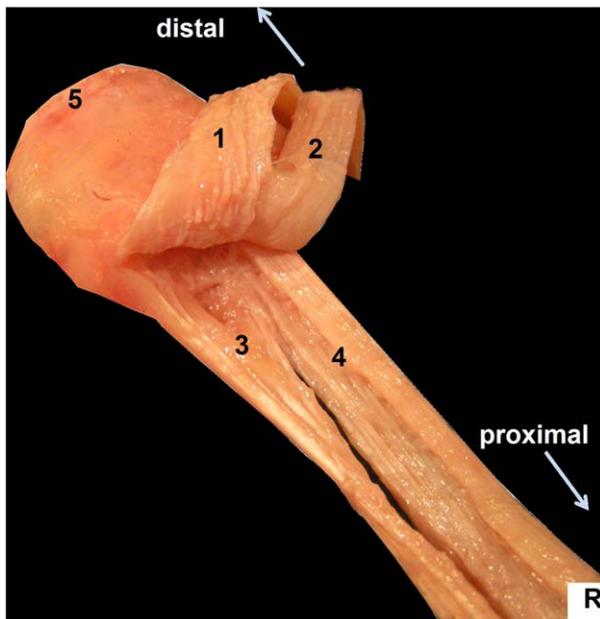


Figure 8. The right Achilles tendon, postero-lateral view. (1) The fibers from the medial part of the medial head of the gastrocnemius, (2) the fibers from the lateral part of the medial head of the gastrocnemius, (3) the fibers from the lateral head of the gastrocnemius, (4) the fibers from the soleus and (5) insertion of the Achilles tendon to the tuber calcanei.

Smigielski (2003) and Cizek et al. (2005). The authors dissected fascicles in the Achilles tendon: one from the lateral head forming the deep (anterior) part of the tendon, one from the medial head forming the posterior part of the tendon. The fibers from the soleus muscle are surrounded by the fibers of the gastrocnemius muscle. In contrast to Cizek and Smigielski (2003) and Cizek et al. (2005), in our study the deep part of the tendon was formed not only by the fibers from the lateral head of the gastrocnemius muscle but also by the fibers from the soleus muscle. The superficial layer of the tendon is formed by the fibers from the medial head of the gastrocnemius and soleus muscles. A similar organization of fibers was described in the Achilles tendon of a beaver (Parsons, 1894). Both in humans and beavers the fibers from the medial head of the gastrocnemius muscle form superficial fibers of the Achilles tendon and the lateral head's fibers form the deep part. In humans, the plantaris tendon is usually attached independently onto the medial surface of the tuber calcanei, whereas, in beavers it is located between the fibers from the gastrocnemius muscle. Soleus fibers, absent in beavers, are located centromedially in humans.

Some authors obtained a view of fascicles of the Achilles tendon in the ultrasound examination

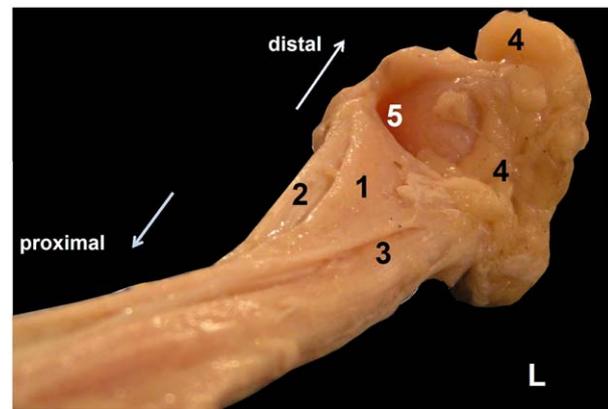


Figure 9. Left Achilles tendon, antero-medial view. (1) Fibers from the lateral head of the gastrocnemius muscle, (2) fibers from the medial head of the gastrocnemius muscle, (3) fibers from the soleus muscle, (4) Kager's fat and (5) retrocalcaneal bursa.

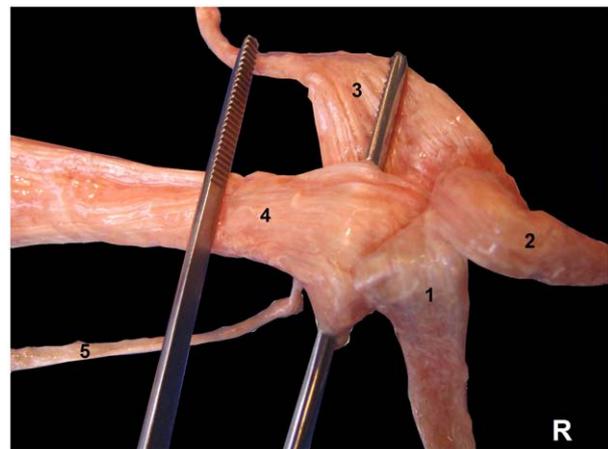


Figure 10. The superior view of dissected right Achilles tendon. (1) The fibers from the medial part of the medial head of the gastrocnemius, (2) the fibers from the lateral part of the medial head of the gastrocnemius, (3) the fibers from the lateral head of the gastrocnemius, (4) the fibers from the soleus muscle and (5) the plantaris muscle tendon.

(Czyrny, 2002). None of the authors provided detailed information about the fibers in the Achilles tendon; however, two groups of fibers were distinguished - from the gastrocnemius and soleus muscles. (Soila et al., 1999).

The most frequent arrangement of fibers in the Achilles tendon in the distal part of the tendon is that the fibers from the gastrocnemius muscle are located laterally and 1/3 of the anterior part of tendon is built of them (52% according to Anson and McVay, 1971). In our studies this variant was observed in 58%. In 29% of all the cases in our studies, there is a co-dominance of fibers and in

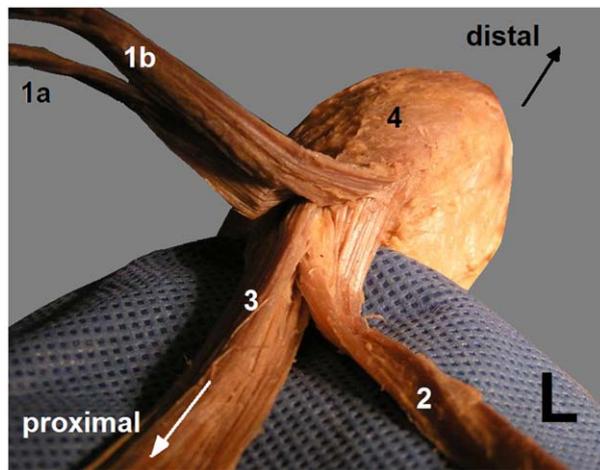


Figure 11. *The left Achilles tendon, superior view.* (1a) The fibers from the medial part of the medial head of the gastrocnemius, (1b) the fibers from the lateral part of the medial head of the gastrocnemius, (2) the fibers from the lateral head of the gastrocnemius, (3) the fibers from the soleus and (4) insertion of the Achilles tendon to the tuber calcanei.

the other study it was 35% (Anson and McVay, 1971). Whereas in 13%, 2/3 of the anterior border is composed of the fibers from the gastrocnemius muscle and the rest of the soleus muscle (Anson and McVay, 1971) in our data it was also 13%.

The fibers constituting the lateral margin of the Achilles tendon come from the lateral part of the medial head of the gastrocnemius muscle. The medial margin of the tendon is derived from the soleus muscle and the medial head of the gastrocnemius, however Cizek and Śmigielski (2003) states that the medial margin is composed of the fibers from the medial head of the gastrocnemius muscle. The anatomy of the medial margin we described is in accordance with the results obtained by other authors (Anson and McVay, 1971; Gils et al., 1996).

The fascicles formed by the tendon's fibers of the Achilles tendon can be dissected as well as observed. Three fascicles can be torn separately which may mean that they can "work" independently. The authors mentioned the ruptures of the fascicle from the medial head of the gastrocnemius muscle and the fascicle from the soleus muscle Cizek and Śmigielski (2003), Śmigielski (2008). According to the clinical experience of one of the authors (Śmigielski) partial rupture of the Achilles tendon occurs quite often and up to one fourth of its pathologies are partial ruptures (Śmigielski, 2008). The comparison of the intraoperative perspective and the results of our anatomical studies allow us to observe that the segments described in

our study fit these fragments of the Achilles tendon that are injured in partial ruptures.

The Achilles tendon is composed of three fascicles each from a different part of the triceps surae muscle. The fascicles come from the three heads of the triceps surae and are twisted so the fibers from the medial head of the gastrocnemius muscle are located posteriorly (superficially) and the fibers from the lateral head are located anteriorly (deeply). Thus, the fibers from the soleus muscle are located in the central and medial part of the tendon. As a result of such an arrangement the anterior margin of the Achilles tendon is composed primarily of the fibers from the lateral head of the gastrocnemius muscle and secondly by the fibers from the soleus muscle. The posterior margin of the tendon is composed mainly of the fibers from the medial head of the gastrocnemius muscle and partially of the fibers from the soleus muscle. The medial margin is composed of the fibers from the soleus muscle. The lateral margin is composed of the fibers from the medial head of the gastrocnemius muscle.

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