Quantitative assessment of intravascular volume of the human Achilles tendon

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Submitted 99-05-04. Accepted 99-10-22

ABSTRACT – **The pathogenesis of Achilles tendon rupture remains unclear, but vascular patterns may play an important role. We determined the intravascular volume of the Achilles tendon using a new method with injection of radioisotopes. A solution of Tc-99m and gelatin-ink was injected into the lower limbs of body donors. The intravascular volume of each 1 cm section of the Achilles tendon was measured using a gamma well counter. We found that the distal part of the Achilles tendon (0–2 cm above the calcaneus) had an intravascular volume of 59–98 μL/g tendon tissue. In the middle part of the tendon (3–6 cm above the calcaneal insertion), the intravascular volume was much less: 27–43 μL/g tissue. The proximal part of the tendon (7–9 cm) had an intravascular volume between 51–100 μL/g tendon tissue. The reduced vascularization in the middle part of the human Achilles tendon may play a role in degeneration and spontaneous rupture of the tendon.**

■

Histological examinations of 891 ruptured Achilles tendons showed degenerative changes in 97% (Józsa and Kannus 1997). More than 90% of the ruptures occur in a region between 3–6 cm above the insertion in the calcaneus (Holz 1980, Carr and Norris 1989, Kannus and Józsa 1997). In this region, blood supply is poor (Lagergren and Lindholm 1958, Wladimirov and Andreeff 1971, Carr and Norris 1989, Graf et al. 1990). However, there is no agreement about the relation betwen poor blood supply and rupture of the Achilles tendon (Schmidt-Rohlfing et al. 1992, Thermann 1999). A recent histomorphometric study, showed that the number of blood vessels per cross-sectional area does not differ significantly along the course of the tendon (Ahmed et al. 1998).

We determined the intravascular volume of the Achilles tendon in various segments.

Material and methods

10 lower limbs of fresh frozen cadavers, mean age 67 (41–81) years, were injected with a solution of 20 MBq Tc-99m, india ink (1%) and gelatin (10%) under continous manual pressure. The solution (temperature 37 °C) was injected simultaneously into the anterior, posterior tibial and peroneal arteries of the limb. The injection pressure (120 mm Hg =160 Pa) was controlled by a pressure gauge. Radiographs of the lower limb in two planes, including an evaluation of patient's past history were taken to exclude major arteriosclerotic specimens from the experiment.

The tendons were dissected after the injection. The paratenon and, if necessary, the musculature were removed. The tendon was cut into 9 segments each with a length of 1 cm (Figure 1). The sections were put into test-tubes and weighed.

The activity (counts per minute = cpm/μL) of the injection solution (inj.-sol.) was measured in a gamma well counter (Multilogger LB 5310, Dr. Berthold, Hanover). Then the activity (cpm/mg) in the test-tubes was measured (Figure 2). After correction of the half-life of Tc-99m, the injected intravascular volume (μL/g tendon) was:

$$t_0\text{cpm test-tube} \times (\mu L_{\text{injection solution}}/(t_0\text{cpm}_{\text{inj.-sol.}} \times g_{\text{test-tubes}})) = \mu L_{\text{intravascular volume}}/g_{\text{tendon}}$$

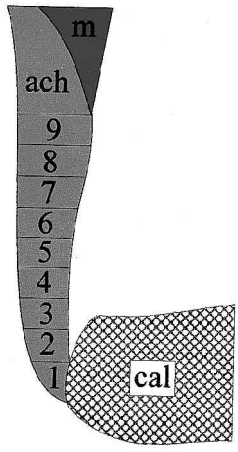

Figure 1. Schematic drawing of the Achilles tendon (ach), the musculus triceps surae (m) and the calcaneus (cal). The Achilles tendon was dissected into nine sections from 1 to 9 cm above the calcaneus.

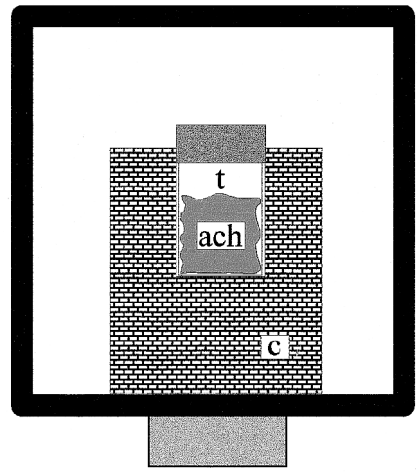

Figure 2. Schematic drawing of the gamma well counter and a cross-section of the Achilles tendon (ach) in a test-tube (t) that is put into the scintillation-crystal (c).

To check the injection technique, 10 other cadavers, mean age 72 (45–87) years, were injected with the same solution using the same protocol as for the measurement of the intravascular volume. After 10 half-lifes all specimens were analyzed macroscopically and cleared using Spalteholz's method (1914). The various segments were examined under a low power microscope.

Results

Macroscopic anatomy

The blood supply of the Achilles tendon mainly arose from the anterior paratenon of the tendon from where vessels entered the tendon. The proximal part of the tendon was supplied by a recurrent branch of the posterior tibial artery while the distal part was vascularized by the rete arteriosum calcaneare, supplied by the fibular and posterior tibial arteries.

An avascular area could be seen close to the insertion of the tendon into the calcaneus. Next to this area, in the posterior distal part of the tendon, there was dense injection of vessels. In the tendon, most blood vessels had a longitudinal course.

Measurements with radionuclides

The average intravascular volume varied from one segment to another (Figure 3). The segment with the lowest intravascular volume was segment 4 (27 μL/g). The segment with the highest intravascular volume was segment 9 (100 μL/g) next to the musculo-tendinous transition.

When the tendon was divided into three regions, we found the lowest intravascular volume in the middle region (3–6 cm above the tendon insertion), 36 (28–46) μL/g. The volume in the distal part (0–2 cm) was 74 (59–89) μL/g and in the proximal part (7–9 cm), 75 (51–100) μL/g.

Discussion

Many attempts have been made to clarify the pathogenesis of spontaneous rupture of the Achilles tendon. The literature provides a wide spectrum of factors that may predispose a tendon to rupture spontaneously (Zwipp et al. 1989). In most tendon ruptures, degenerative changes can be found with no definite etiological explanation (Kannus and Natri 1997). A key factor for degeneration of tendon tissue might be hypoxy (Kannus and Józsa 1997). We found hypovascular areas in all Achilles tendons from 3 to 6 cm above the calcaneal insertion. The rupture usually occurs in this region (Holz 1980, Thermann 1999).

Qualitative descriptions have been published about reduced blood supply in the middle region of the Achilles tendon (Lagergren and Lindholm

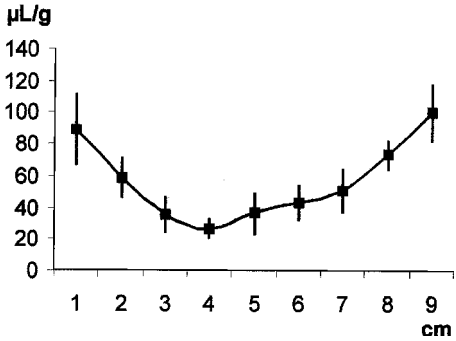

Figure 3. Diagram of intravascular volume per gram tendon (µL/g) of each cross-section from 1 to 9 cm (cm) above the calcaneal insertion of the achilles tendon; standard deviation. The lowest volume (28 µL/g) was found 4 cm above the calcaneus. This is the region most prone to rupture.

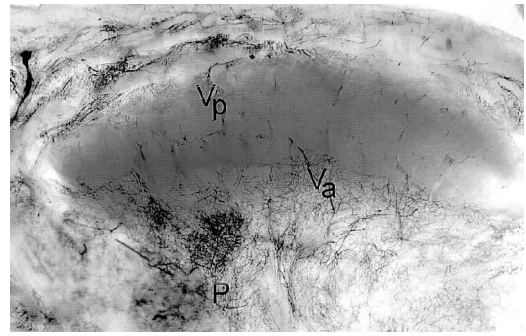

Figure 4. Horizontal section of the Achilles tendon after preparation with the Spalteholz method. Many small vessels enter the tendon anteriorly (Va) whereas only a few vessels enter it posteriorly (Vp). The well-vascularized paratenon (P) lies mainly anterior to the tendon (×3).

1958, Håstad et al. 1958/9, Wladimirov and Andreeff 1971, Carr and Norris 1989, Graf et al. 1990). None of these studies give quantitative results about the vascularization. Lagergren and Lindholm (1958) and Carr and Norris (1989) found a reduced blood supply on angiography of the lower limbs. Angiography shows a summation of all vessels between the x-ray emitter and the detector. This includes the paratenon and the soft tissue around the Achilles tendon but the vascularization of the tendon tissue is not seen well. Other studies using vascular injections of the Achilles tendon (Wladimirow and Andreef 1971, Graf et al. 1990), however, have not shown a quantitative relation between vascularization and location in the Achilles tendon.

However, hypo- and avascularity have been described in sliding tendons of the musculus supraspinatus, biceps brachii, quadriceps and tibialis anterior (Tillmann and Schünke 1991, Kolts et al. 1994, Stein et al. 1998, Petersen et al. 1999). Ruptures in these tendons generally occur in the region of reduced blood supply. As early as 1938, Plötz described hypovascular areas in sliding tendons that were always found in the region most exposed to pressure and shearing forces. In the middle region of the Achilles tendon there may be a mechanical explanation of the reduced blood supply. As the Achilles tendon descends, it spirals about 90° laterally, so that the fibers that were originally posterior become lateral and anterior fibers become medial (Jones 1944, Seegesser et al. 1995). The significance of the rotation is that a region of concentrated stress is produced in the middle of the tendon (Kannus and Józsa 1997). Åström and Westlin (1994) evaluated blood flow in the human Achilles tendon with laser Doppler flowmetry. They showed reduced flow in the middle of the tendon, a negative correlation to age and lower flow in men than women. These findings correlate directly with the incidence of Achilles tendon ruptures.

Tendon degeneration and rupture appear to be a multietiological disorder but vascularization seems to be an important factor. The reduced vascularization in the middle of the Achilles tendon may play a role in reduced healing of microruptures leading to degeneration and spontaneous rupture of the Achilles tendon.

We thank Prof. Dr. med. E. Henze (Klinik für Nuklearmedizin CAU Kiel) for use of the Nuclear Medicine Laboratory and Prof. Dr. med. B. Tillmann (Institut für Anatomie CAU Kiel).

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