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ORIGINAL ARTICLE

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# Lesions of the Achilles tendon

## A sonographic, biomechanical and histological study

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**Abstract** Thirty-four Achilles tendons were explanted post-mortem. The explantation took place less than 24 h after death. The tendons were examined by means of ultrasonography and after explantation assessed histologically and biomechanically. In the sonograms 19 changes in echogenicity were noted. Changes in form with an increase in the diameter of the tendon of up to 10 mm (compared with the contralateral side) were found in 6 tendons. The changes in echogenicity and form were found most frequently 2–4 cm from the insertion of the tendon at the os calcis. At a speed of 5 mm/min, the average force needed until rupture occurred was calculated as 27.6 N/mm$^2$. The tear was located on average 29.7 mm from the bony insertion of the tendon at the calcaneus. Histologically, necroses could be found most frequently in all regions of the tendon, followed by scars and fissures. When there were differences of more than 25% in tensile strength between the right and left sides, there was a histological change in the weaker tendon at the site of the tear. Sonographic changes in form pointed to histological lesions in this region. Changes in the echogenicity led to the detection of degenerative changes of the tendon, but they have to be analysed carefully, as they are prone to artefacts. There was not statistically relevant correlation either with regard to tensile strength or to the site of the rupture for sonographically proven changes in the area of the rupture. However, when there was a sonographically abnormal finding in the course of a tendon, the tendon tore at an earlier point than those exhibiting no abnormality. Sonography proved to be a useful method in the detection of degenerative lesions of tendons. A direct influence on the biomechanics of the tendon could not be found.

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## Introduction

Degenerative changes in the Achilles tendon are of great importance because this tendon is the strongest one in the human body. For a long time achillodynie [1] was the only known disease of the Achilles tendon, and primarily described a bursitis of inflammatory, rheumatic or mechanical origin [12]. The degeneration of a tendon is a collection of varying histological changes. With advances in diagnostic the evaluation of pain in the Achilles tendon has become more and more differentiated. Up to now there has been no method of diagnosis with which degeneration and danger of rupture can be qualified and quantified. Modern imaging methods can demonstrate various changes in the course of tendons. It remains unclear how far these changes influence the tensile strength of the tendon. This is of particular interest in the treatment of active sportsmen with lesions of the Achilles tendon. We have undertaken a study to find out how sonography can contribute to an improvement in the diagnosis of these problems.

## Material and methods

Thirty-four Achilles tendons from a total of 18 donors were explanted post-morten. The donors were between 28 and 74 years of age (mean 54.8 years). No evidence of previous achilles tendon problems could be found in their history.

The time between death and explantation was in no case longer than 24 h, as autolytic changes during this period are negligible [6].

The tendons were examined statically and dynamically in situ by means of sonography using a Siemens Sono SL1 or a Dornier A 3200, a 7.5-MHz transducer and a water pellet whilst the patient was in the prone position. Special emphasis was put on the dynamic examination. The tendon was explanted in total together with the bony insertion, and the surrounding fatty tissue was removed. Then each tendon was examined once more in a physiological (0.9%) solution by means of a 7.5-MHz transducer, with special attention being paid to degenerative changes. The examination was carried out in two standard planes [20] (longitudinal and cross-sectional). The following data were documented: sonographic thickness and width, transition into the muscle area of the triceps surae muscle, and sonographic changes in the tendon. The tendons were dissected sharply in the middle of the longitudinal axis by means of a scalpel, and one-half was examined histologically and the other biomechanically.

At a distance of 8, 6, 4, 2 and 0 cm above the insertion of the tendon, longitudinal sections were removed for histological diagnosis. Findigs which deviated from normal in the sonographic examination were assessed separately. The insertion of the tendon was then subjected to a decalcification process with ethylene diamine tetra-acetic acid (EDTA). The tendon sections were embedded in paraffin. A rotation microtome was used to make paraffin sections 5 μm thick, and these were subjected to 5 colouring procedures.

Within the framework of the biomechanical examinations, a mould of the longitudinal and cross-sections was made of each specimen using an aluminium form created especially for this purpose and filled with a self-hardening moulding foam (DIN 4102). The macroscopic appearance, length and circumference were measured at a distance of 2, 4, 6 and 8 cm from the calcaneus and then documented. After the tendons had been fixed with clamps, they were subjected to tensile strain in a universal testing machine (ZWICK # 1454). A speed of 5 mm/min and a length of 20 mm were selected, and the load needed for the distance was documented on a graph. The speed remained constant at all times. The exact location of the tear was established, and the surface at the level of the rupture was determined with the help of cross-sections of the moulds; thus, the location of the rupture and the tensile strength of the specimens could be deduced and expressed in $N/mm^2$. The sonographic and histological findings were correlated with the biomechanical results.

The statistical evaluation was carried out by means of the Friedmann or Wilcoxon-Mann-Whitney test.

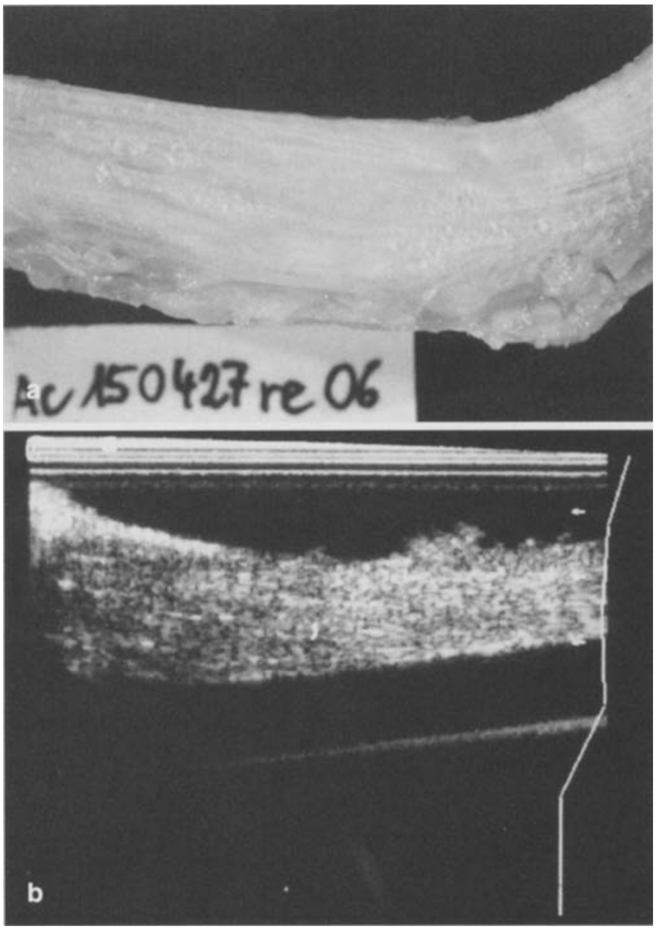

**Fig. 1** **a** Macroscopically visible increase in the diameter of the tendon; histologically, a large area of necrosis was found. **b** Corresponding sonogram: change in the form (increase in diameter) and echogenicity of the tendon

## Results

Seven of the donors were female and 11 male. The average length of the tendons was 63.9 mm (SD 13.9) for men and 54.1 mm (SD 13.8) for women.

### Sonographic results

We found 19 changes in echogenicity in the 34 tendons examined (Fig. 1). In 11 cases it was increased and in 8 cases reduced. The changes in echogenicity varied between 5 and 51 mm. In 6 of the specimens examined, we found changes in form with a thickening of the tendon of up to 10 mm in comparison with the contralateral side. The percentual incidence of sonographic changes in relation to the distance from the calcaneus was similar to that of the histological changes. The changes in echogenicity and form were found most frequently betwen 2 and 4 cm from the insertion of the tendon in the calcaneus. The thickness measured sonographically varied in the course of the tendon from 2.8 to 8.3 mm. The width lay between 12 and 31 mm.

### Biomechanical results

At a speed of 5 mm/min, the average amount of force needed before the tendon ruptured was calculated to be 27.6 $N/mm^2$ (range: 14.4–53.4 $N/mm^2$). We were able to load all specimens to the point of rupture (Table 1).

The rupture lay between 5 and 50 mm (mean 29.7 mm) from the insertion of the tendon at the calcaneus. The

**Table 1** Biomechanical data

| | All tendons | No histological finding | Positive sonographic finding |
|---|---|---|---|
| Length (mm) | 63.9 | 60.1 | 60.4 |
| Level of rupture (mm) (according to distance from calcaneus) | 29.7 | 37.4 | 29.1 |
| Force (N) | 921.8 | 984.3 | 972.7 |
| Tensile strength ($N/mm^2$) | 27.6 | 34.6 | 27.0 |

graphic documentation of the tearing experiments exhibited a similar curve for all specimens: at the beginning there is a phase which is convex to the ordinate, then comes a linear section whose upward tendency is the last third occasionally flattens of with the appearance of a tooth saw. This is where the tendon began to tear. After reaching the highest point, the curve fell rapidly.

### Histological results

In the histological assessment we distinguished between changes which were located directly in the insertion area at the calcaneus and those located further along the course of the tendon. Necroses could be found most frequently in all regions, followed by scars and fissures (Table 2).

When comparing left and right Achilles tendons, we found differences in tensile strength of less than 15% in 50% of the donors. When there was a difference of more than 25%, a histological change of the weaker tendon could be observed at the location of the tear. The stronger tendon exhibited no significant finding at the site of rupture. The tendons of patients over 60 years of age exhibited a slightly reduced average tensile strength in comparison with patients under 40 and those between 40 and 60 years of age.

All macroscopic abnormalities could be documented in the sonograms. Sonographic changes in form pointed to histological changes in this area (Table 3). Changes in echogenicity and form were found most frequently 2–4 cm from the insertion of the tendon at the calcaneus, but they are prone to artefacts. Only if they could be visualized in two planes did they lead to the diagnosis of degenerative lesions of the Achilles tendon. At a distance of 2 cm from the calcaneus, we found a correlation of 77.1% between histologically diagnosed changes of the tendon and sonographic findings. Sonography was able to demonstrate macroscopically invisible changes. At the origin of the tendon, there was no statistical correlation. A sonographic differentiation of the various histological changes was not possible.

There was not statistically significant correlation to sonographic evidence of changes in the rupture area, with respect to either tensile strength or location of the rupture. However, tendons with a sonographic abnormality ruptured at an earlier point than those which exhibited no abnormality. The location of the rupture was dependent on the histological evidence of necroses, tears and fissures in the course of the tendon.

**Table 2** Histological finding according to distance from the calcaneus

| | Necrosis | Fissure | Scar | Ossification | Others |
|---|---|---|---|---|---|
| 0–1 cm | 26 | 16 | 17 | 5 | 13 |
| 2 cm | 11 | 4 | 11 | 6 | 18 |
| 4 cm | 3 | – | 6 | 2 | – |
| 6 cm | 1 | – | 7 | 1 | – |

Different histological changes can be found in the same region of the tendon

**Table 3** Comparison of histological and sonographic findings (distance to the calcaneus: 2 cm)

| Tendons | Sonographic changes | No sonographic changes |
|---|---|---|
| Histological changes | 7 | 6 |
| No histological changes | 2 | 20 |

Different histological changes found at the same area are counted only once

## Discussion

Our examination tests showed that the so-called degenerative changes in the tendon do not give rise to uniform histological findings. Therefore, we made a distinction between scars, necroses, fissures, etc.

Sonography is an excellent non-invasive method of examination for the assessment of intra- and periarticular changes in soft tissue [7, 14, 21]. Sonographic changes in the form of the tendon can be clearly documented. They can also be reproduced by different examiners, and in every examination. In correlation with histological changes they point to so-called degenerative changes in the Achilles tendon. Changes in echogenicity are more difficult to interpret. The tendon only exhibits its homogenous echolucent pattern when the transducer is held directly above it. If this is not the case, artificial changes in echogenicity occur, which can also happen if the tendon is extremely relaxed. Changes in echogenicity can also arise at the origin of the tendon, when the transducer is not held exactly parallel to the iradiating fibers of the tendon. This may explain the difficulty of detecting lesions in this area. Thermann et al. [13] classified the changes in the structure of the tendon into four grades from thick, light inner echoes to punctual inner echoes. We were not able to find a correlation between these changes in structure and histological changes. Such fine sonographic changes in structure are so extremely prone to artefacts that we did not include them in our standard programme of examination after termination of this study. When imaging is carried out in the correct position, changes in echogenicity in the tendon must be reproducible in two planes at right angels to each other [20]. Only then can we be sure of the diagnosis. Clinical symptoms are not always present when there are positive ultasound findings. Kainberger et al. found no sonographic anomalies in 18 of 124 cases of achillodynie. A correlation between length of complaint and extent of sonographic findings could not be established either [13]. In 5 cases Kainberger and colleagues had positive ultrasound findings without any clinical symptoms.

A tension stretching curve for tendons was represented in graphic form as early as 1847 [29]. At the commencement of loading, the curve rises convex to the ordinate; this part of the curve is steeper for persons who are physically fit [25]. Most of the physiological strain takes place in this phase. Then follows an almost linear phase which represents the increasing tension and stretching: here the proprioceptors are activated in vivo. Halfway into this phase the physiological limit is reached, and the helices of the tertiary structure are elongated. The first fibres begin to tear, and the curve becomes flatter. The lower the speed, the earlier the fibres tear (creep phenomenon).

In our study we found that the maximum load we could put on the Achilles tendon was lower than that stated in certain articles [22, 27, 29]. This is partly due to the choice of donors, who were mostly older people, some of whom had been bedridden for a long time. In addition to this, the low speed of 5 mm/min led to a creep phenomenon, which reduced the biomechanical tensile strength even further.

In vivo a short-term stress of up to 25 times the body's weight can be tolerated [11]. If there is more than maximum stress, tearing occurs. The highest point of the curve can be equated with the tensile strength of the tendon. The tendon can be stretched to 115% of its initial length before tearing [27].

Data concerning the tensile strength of the healthy Achilles tendon vary in the literature. All in vitro examinations hitherto undertaken, however, exhibit a much lower resistance ot tearing than is the case in vivo [2, 10, 11]. This may be explained by adaptation to a higher load (Wolff's Law) and to viscoelastic behaviour in the living organism [22].

Calcifications in the Achilles tendons are described most frequently in the area of insertion [18, 24]. Formation of bone [9] implies a predisposition to the development of fissures. As our specimen showed, there is a tendency to tearing of the tendon even when the load applied is small.

A tear in the Achilles tendon occurs most frequently (> 90%) at the location where the blood supply is poorest, namely 2.5–6 cm cranial to the origin at the calcaneus [2, 4, 16, 17]; bony tears (< 1%), mostly a medial tear in the connection between muscle and tendon, and tears in the central area of the gastrocnemius muscle are rarer, a fact which was confirmed in our study.

Analysis of the rupture area shows histological changes in this zone in almost 70% of the tendons. Just under 20% of the tendons tore at the narrowest point. Sonographic changes were present in 20% of the tendons in the rupture area.

Lagergren and Lindholm established with the help of angiographic and microangiographic examinations that the part of the tendon with the smallest diameter, located 3–5 cm above the calcaneus, is also that with the poorest vascularisation; moreover, pathophysiologically degenerative, obliterative and inflammatory changes in the vessels are additional influences on the tensile strength [17].

Sonography proved to be a useful method in the detection of degenerative lesions the Achilles tendon. As a reproducible, non-invasive and inexpensive method it has become part of our routine diagnostic programme.

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