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ORIGINAL ARTICLE

The Achilles Tendon Insertion is Crescent-shaped

An In Vitro Anatomic Investigation

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Abstract Anatomic and operative textbooks and current literature do not clearly describe the Achilles tendon interface to the calcaneal tuberosity. We dissected 51 specimens to identify the detailed anatomy of the Achilles tendon insertion. Achilles tendon fascicles expanded from the anterior aspect of the distal Achilles tendon over the retrocalcaneal bursa to the anterior part of the Haglund's tuberosity in nearly half of the specimens. The insertion of the transverse section of the Achilles tendon regularly had a crescent-shape corresponding to the posterior calcaneal prominence. In transverse sections, all specimens had a curved appearance with a radius of curvature ranging from 13.8 mm to 43.6 mm (mean, 20.4 mm) and Achilles tendon extensions to the lateral and medial calcaneal surfaces reached 1.0 mm (mean) and 3.5 mm (mean) anterior in relation to the most posterior point of the calcaneal tuberosity. Knowledge of the arcuate configuration and of the medial and lateral extensions of the plantaris and the Achilles tendon insertion with respect to the transverse plane is important to avoid iatrogenic complications during resection of Haglund's tuberosity.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research.

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Introduction

Posterior heel pain frequently is caused by Haglund's disease. This entity was first described by Patrick Haglund in 1928 [24, 31, 43]. It is characterized clinically by localized pain and swelling at the medial and lateral distal Achilles tendon border resulting from retrocalcaneal bursitis. A prominent posterosuperior calcaneal tuberosity is believed to be the initiating mechanical cause leading to a retrocalcaneal bursa impingement against the corresponding anterior Achilles tendon border [24, 31, 43]. A rigid posterior shoe counter is believed another inducing factor [11]. Because of different therapies, some authors recommend differentiating Haglund's disease from Achilles tendinopathy [22, 31, 36, 43] and from Achilles insertional tendinopathy [22, 26, 37].

Nonoperative treatment often fails to relieve symptoms. Approximately 50% of the patients undergo surgery [30], however, open surgery has been reported to have disappointing results (fair and poor) in 20% to 50% of patients [13, 20, 22, 28, 38, 36]. Operative treatment comprises resection of Haglund's tuberosity and the associated retrocalcaneal bursa. Likely owing to compression induced by the chronically inflamed and enlarged retrocalcaneal bursa, degeneration and partial tears of the corresponding anterior Achilles tendon fibers have been observed and are called "Achilles tendon impingement lesions" [21, 22]. Additional Achilles tendon surgery therefore may be necessary and can be performed only by open surgery [22]. Clinical analysis of failures has been focused on the amount of bone resected [4, 39] and orientation of the ostectomy line

[13, 36]. However, these variables apparently do not predict outcome, although the size of the remaining posterior bone ridge appears to correlate with poor results [12].

Different surgical approaches [4], including longitudinal [16], transverse [22, 39], and curved [10] skin incisions at the medial [33] and/or lateral [5, 26, 36, 38, 45] Achilles tendon margin or directed centrally [6] over and through the Achilles tendon, have been used. Dissections from cadaveric studies suggested the medial column of the Achilles tendon, the plantaris tendon, and the sural nerve are at risk in open and in endoscopic surgery [23, 46]. Endoscopic retrocalcaneal decompression seems to be a promising method, and success rates greater than 90% have been reported in some case series [14, 31, 43]. Results of endoscopic and open Haglund's resection were similar in one comparative nonrandomized prospective case series with a success rate of 80% [21].

Anatomy texts uniformly represent the posterior end of the calcaneal tuberosity as being convex [19, 29, 35, 44]. However, when the Achilles tendon also is illustrated, confusion is caused by presenting different insertional tendon shapes. Some anatomic [1, 29] and operative [5, 42] textbooks and articles [7, 32, 34, 41] have depicted the Achilles tendon insertion only from a lateral or medial view leading to the impression that the tendon's shape does not change from its oval midportion cross section to the insertional area [5, 7, 9, 29, 42, 44]. Images of the Achilles tendon insertion in a transverse plane occasionally are presented, showing a slightly bent [19, 27, 35] or an unbowed [8] Achilles tendon insertion. Relevant Achilles or plantaris tendon fiber extensions to the medial or lateral calcaneal wall are rarely [9, 35] or are not illustrated [1, 5, 7, 8, 19, 29, 32, 34, 41, 42].

Based on our operative experience and from MRI findings we hypothesized the Achilles tendon's transverse section is curved in the insertional area with relevant extensions to the medial and lateral calcaneal surface. These findings were observed on transverse sectioned specimens by gross morphologic appearance. We also hypothesized measurements can be performed reliably for the medial and lateral Achilles tendon extensions and the radius of the curvature of the Achilles tendon insertion in the transverse plane.

Materials and Methods

We harvested 51 specimens from 37 individual formalin-fixed Caucasian cadavers (13 male, 24 female). Donor age ranged from 51 to 96 years (average, 79.5 years). Dissection isolated the distal 5 cm of the Achilles tendon and at least the adjacent posterior two-thirds of the calcaneus. The Achilles tendon insertion with relation to the calcaneal tuberosity was examined for fascicles bridging over the retrocalcaneal bursa to the anterior part of the Haglund's tuberosity. If present, the plantaris tendon insertion was classified as proposed by Cummins et al. [9].

We then sawed horizontally oriented slices (Exakt Vertriebs GmbH, Norderstedt, Germany) in 3-mm steps starting parallel to the plantar surface (Fig. 1). Standardized photographs (Nikon Coolpix 990, Nikon GmbH, Düsseldorf, Germany) (resolution, 3.3 megapixels) were taken from the proximal side of all individual slices with a ruler added to assure real dimensions during later analysis. From each of the 51 specimens we selected one slice exhibiting the most proximal Achilles tendon insertion site for additional analysis (medial and lateral Achilles tendon extensions and radius of the Achilles tendon insertion curvature) by macroscopic investigation on a personal computer. These specific images were printed in five colors.

Four raters (two orthopaedic surgeons, Tester 1 [HL] and Tester 2 [SA]; one general practitioner, Tester 3 [JS];

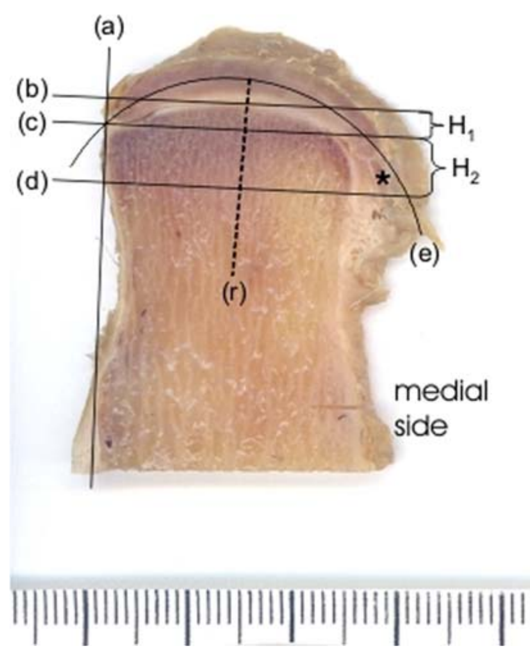

Fig. 1 A specimen for Achilles tendon insertion analysis in the transverse plane is shown. The Achilles tendon aligns crescent-shaped to the posterior calcaneus. For quantitative measurements, a tangent line was drawn to the lateral calcaneal bone surface (a). Rectangular to this, three additional lines were constructed as tangents to the most posterior calcaneal prominence (b) and to the anterior lateral (c) and medial (d) Achilles tendon, or if present, plantaris tendon borders, respectively. Distances between (b) and (c) = lateral extension (H_1) and between (b) and (d) = medial extension (H_2), respectively, also were obtained for analysis. The Achilles tendon insertion radius was determined as the length of the radius (r) of the arc of a circle approximately constructed through the midportion of the depicted Achilles tendon insertion (e). The ruler has 1-mm increments. * = plantaris tendon.

and one sports scientist, Tester 4 [TN]) independently measured medial and lateral Achilles tendon extensions and the radius of the Achilles tendon insertion curvature using an identical set of 51 hard copies to analyze interrater reliability. An investigator meeting was held before instituting the independent assessments. Examiners were given instructions regarding measurement techniques, and several prints were evaluated and discussed in the group. First gross anatomic morphology was assessed if the Achilles tendons transverse sections had an arcuate appearance on the photographs. Measurements then were performed on the hard copies using identical commercially available set squares with 1-mm increments (Aristo 1552, Geotec GmbH, Wörgl, Austria). First, a reference line representing the approximated calcaneal longitudinal axis was drawn tangentially to the lateral calcaneal bone surface. Then, three additional lines were constructed rectangular to the lateral calcaneal surface line and tangential to the posterior calcaneus and to the lateral and medial Achilles tendon border, respectively. Linear measurements were made to the nearest 1 mm (Fig. 1). We made three linear measurements (Fig. 1): (1) lateral extension (H_1): rectangular distance between the tangents to the most posterior calcaneal point and the most anterior point of the lateral Achilles tendon border; (2) medial extension (H_2): rectangular distance between the tangents to the most posterior calcaneal point and the most anterior point of the medial Achilles tendon border. If a plantaris tendon was present, the most anteriorly located plantaris tendon contour was taken for measurement; and (3) Achilles tendon insertion radius: radius of the arc of a circle. Because specimens did not reflect exact circular arcs, construction was approximated through the midportion of the depicted Achilles tendon insertion using a compass (Quick-Set Compass, Faber-Castel AG, Stein, Germany). The obtained values (H_1, H_2, radius) measured with the set square were mathematically corrected for the magnification relative to the ruler shown in the respective image. Real values in millimeters were obtained by multiplication of the set square measured distances (H_1, H_2) and the radius with the magnification factor, which is obtained by 10 divided by the set square measured distance covered by 10 graduation lines on the ruler.

To assess interobserver reliability for the measurements, we computed the intraclass correlation coefficients (ICCs) (two-way random-effects model, absolute agreement) with 95% confidence intervals [40]. The Kolmogorov-Smirnov test was used to assess normal distribution for each tester. Descriptive statistics (mean and standard deviation) were performed for each tester's measurements. Values greater than 0.70 were considered acceptable and greater than 0.80 were considered accurate [17]. Interobserver reliability testing ranged from ICC 0.81 to 0.90 for the lateral (H_1) Achilles tendon extension, from 0.73 to 0.81 for the medial (H_1) Achilles tendon extension, and from 0.23 to 0.71 for the Achilles tendon insertion radius, respectively (Table 1).

Table 1. Interobserver reliability testing

Test	Observers [n]	Change in mean (SD)	ICC	95% Confidence interval	
				Lower limit	Upper limit
Lateral Achilles tendon extension H1 [cm]	1–2	0.01 ± 0.02	0.81	0.49	0.80
	1–3	0.00 ± 0.01	0.90	0.82	0.94
	1–4	0.01 ± 0.02	0.87	0.64	0.86
	2–3	0.01 ± 0.01	0.81	0.66	0.89
	2–4	0.00 ± 0.00	0.90	0.84	0.94
	3–4	0.01 ± 0.01	0.83	0.70	0.90
Medial Achilles tendon extension H2 [cm]	1–2	0.04 ± 0.04	0.74	0.54	0.85
	1–3	0.01 ± 0.03	0.78	0.62	0.88
	1–4	0.05 ± 0.05	0.81	0.68	0.90
	2–3	0.03 ± 0.07	0.78	0.64	0.87
	2–4	0.01 ± 0.09	0.74	0.54	0.85
	3–4	0.04 ± 0.02	0.73	0.52	0.84
Achilles tendon insertion radius r [°]	1–2	0.15 ± 0.07	0.23	0.13	0.38
	1–3	0.02 ± 0.02	0.71	0.49	0.83
	1–4	0.07 ± 0.04	0.67	0.42	0.81
	2–3	0.17 ± 0.05	0.50	0.13	0.71
	2–4	0.08 ± 0.11	0.47	0.07	0.69
	3–4	0.09 ± 0.06	0.65	0.40	0.80

Standard analysis of variance F-test was used to determine whether the ICC was different from zero. Descriptive statistics (means and standard deviations) were computed including measurements of all four raters for the extent of the lateral and medial Achilles tendon extensions to the respective calcaneal walls and for the radius of the approximated circular arc construction of the Achilles tendon's transverse section at its insertion.

Results

Gross anatomic investigation before sawing the specimens revealed relevant Achilles tendon fascicles originating at the anterior aspect of the distal Achilles tendon and bridging over the retrocalcaneal bursa to the anterior part of the Haglund's tuberosity in 21 (41%) of the specimens (Fig. 2). In 44 of 51 specimens (86%), a plantaris tendon was present. It inserted fan shaped into the medial extremity of the superior tuberosity (Cummins Type I) in 25 (49%) specimens, 0.5 to 2.5 cm anterior to the adjacent Achilles tendon margin (Cummins Type II) in eight (16%) specimens, the medial and dorsal surface of the terminal adjacent Achilles tendon (Cummins Type III) in seven (14%) specimens, and in the medial Achilles tendon border from 1 to 16 cm above the insertion (Cummins Type IV) in four (8%) specimens (Fig. 3). As analyzed on the hard copies, all transverse-sectioned Achilles tendon insertions formed an arcuate shape encompassing the posterior calcaneal tuberosity.

Achilles tendon fiber extensions were more pronounced on the medial side (Table 2). Referencing most posterior point of the calcaneal prominence, 96.1% (196 of 204) of the measurements showed the medial Achilles or plantaris tendon fibers extended to the medial calcaneal wall, whereas in 2.9% (six of 204) of the measurements the medial Achilles or plantaris tendon fibers were in line with the most posterior calcaneal prominence. In 1.0% (two of 204) of the measurements, the medial Achilles tendon border was located posterior to the posterior calcaneal

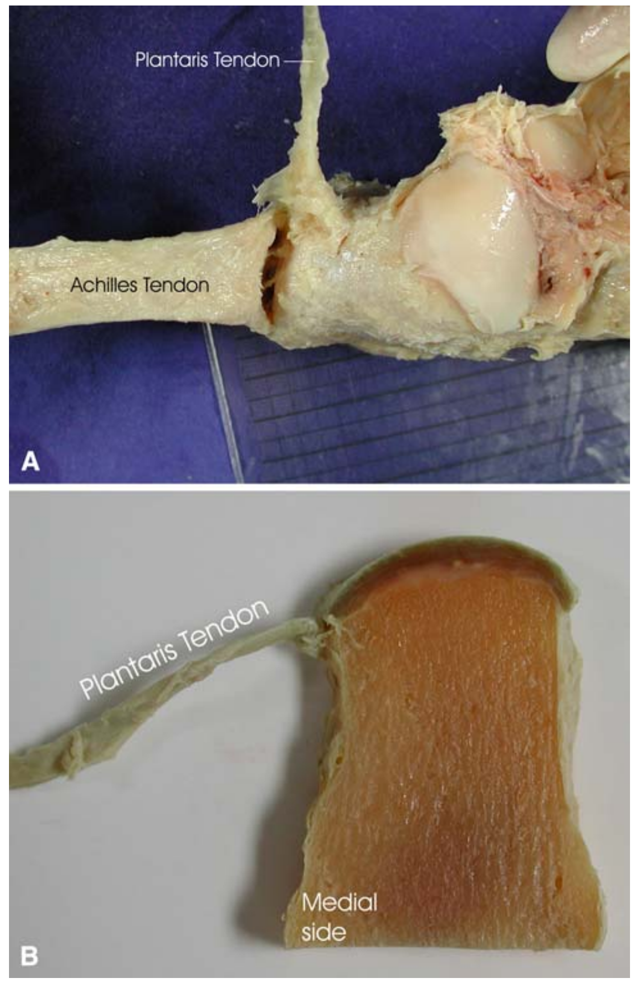

Fig. 3A–B Examples of a plantaris tendon (Cummins Type I [9]) building up the most medial tendon extension are shown. (**A**) A specimen is shown before dissection and transverse slice at the calcaneal insertion. (**B**) The plantaris tendon is preserved.

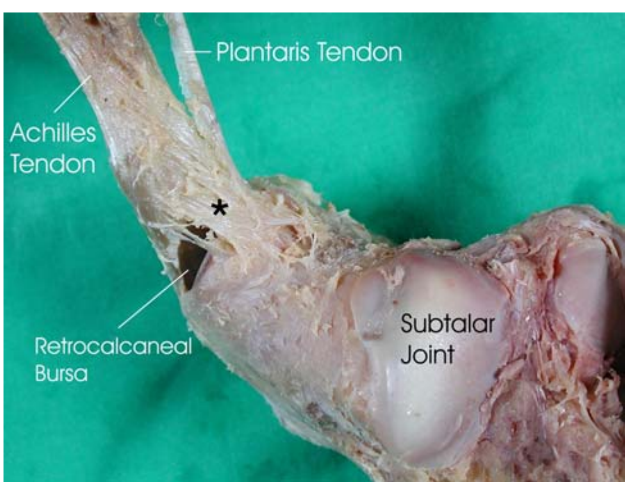

Fig. 2 The photograph shows an Achilles tendon fascicle originating at the anterior aspect of the distal Achilles tendon and bridging (*) the retrocalcaneal bursa to insert at the anterior part of the Haglund's tuberosity.

Table 2. Results of measurements taken from four raters

Measurement	Lateral Achilles tendon extension H1 [mm]	Medial Achilles tendon extension H2 [mm]	Achilles tendon insertion radius r [mm]
Mean	1.0	3.5	20.4
Standard deviation	1.5	1.8	3.8
Minimum	−2.3	−1.8	13.8
Maximum	5.5	9.1	43.6

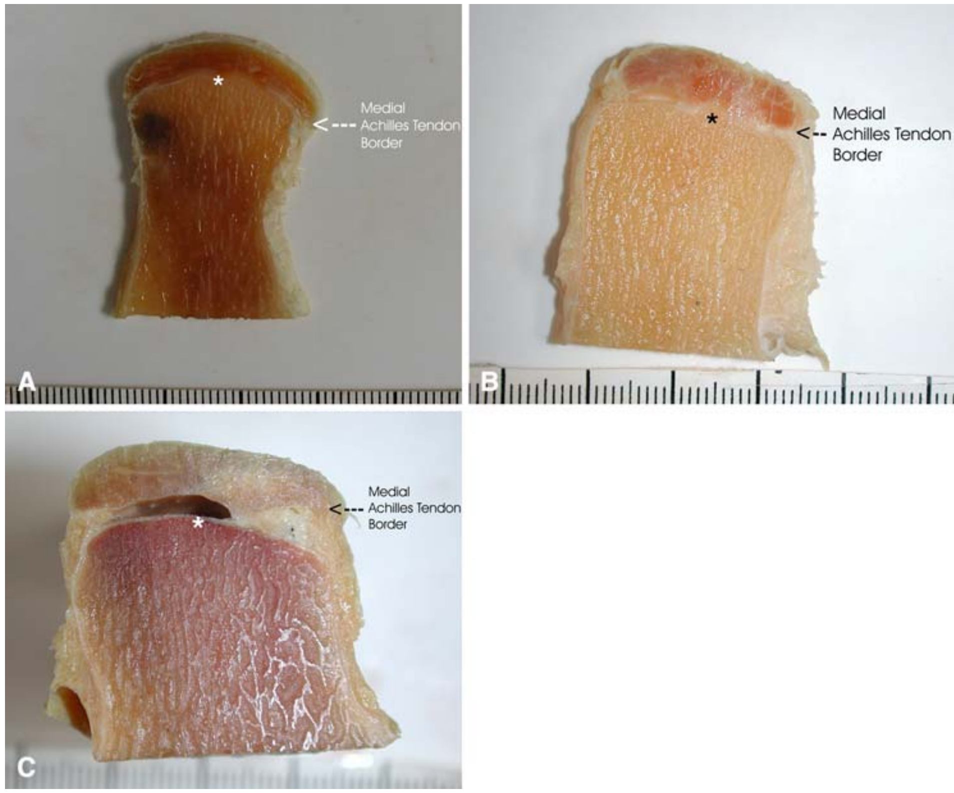

Fig. 4A–C Examples of medial Achilles tendon borders located (**A**) anterior, (**B**) equal to, or (**C**) posterior to the most posterior central point of the calcaneal tubercle (*) are shown.

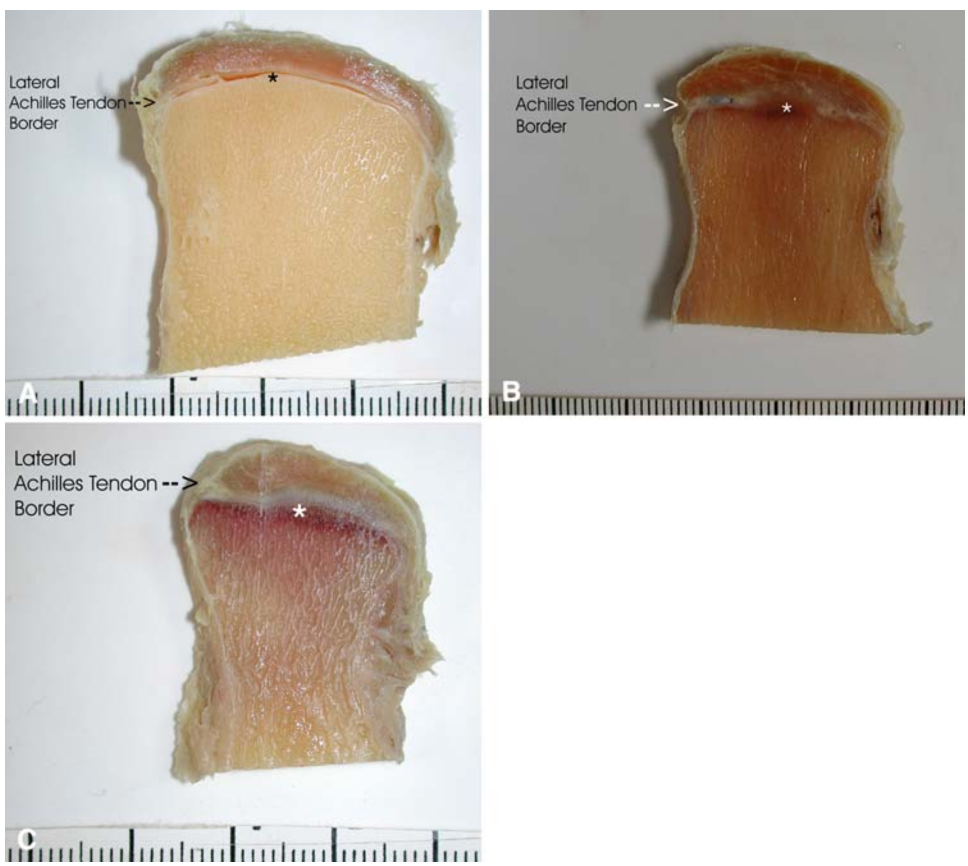

Fig. 5A–C Examples of lateral Achilles tendon borders located (**A**) anterior, (**B**) equal to, or (**C**) posterior to the most posterior central point of the calcaneal tubercle (*) are shown.

prominence (Fig. 4). Seventy-five percent (153 of 204) of the measurements showed the lateral Achilles tendon fibers extending to the medial calcaneal wall, whereas in 6.4% (13 of 204), the lateral Achilles tendon fibers were in line with the most posterior calcaneal prominence. In 18.7% (38 of 204) of the measurements the lateral Achilles tendon border was located posterior to the posterior calcaneal prominence (Fig. 5).

Discussion

The rationale for this study is derived from our experience with Achilles tendon and Haglund's disease surgery. From coronal view MR images and endoscopy of the hind foot, we postulated the Achilles tendon's transverse section turns from an oval in its midportion to an arcuate structure encompassing the calcaneal tuberosity at its calcaneal insertion. Iatrogenic lesions of the Achilles tendon fibers extending to the medial and lateral calcaneal surface and the sural nerve may be one reason for dissatisfying results after open resection of the Haglund's tuberosity [13, 20, 22, 23, 28, 36, 38]. Knowledge of the course of these structures is crucial for successful surgery in this area. Comparing endoscopic and open Haglund's resection in a nonrandomized prospective case series revealed no statistical differences regarding outcome assessed with the AOFAS score and complications (infection, altered sensation, scar tenderness) [21]. We therefore questioned if and to which extent fibers in the insertional Achilles tendon area extend to the medial and lateral calcaneal surface. Also with respect to the transverse plane, we wished to objectify the suspected arcuate Achilles tendon structure with macroscopic measurements.

Our results confirm there are Achilles tendon extensions to the medial and lateral calcaneal surfaces. However, our assumption of a crescent-shaped configuration is substantiated only by the descriptive anatomic appearance as constructing an approximated arc of a circle through the midportion of a transverse Achilles tendon insertion section was not reliable (ICC, 0.23–0.71). Achilles tendon fascicles expanding from the anterior aspect of the distal Achilles tendon over the retrocalcaneal bursa to the anterior part of the Haglund's tuberosity in nearly half of the investigated specimens but the clinical importance of these fascicles is unclear. The occurrence and insertional variety of the plantaris tendon are similar to those reported [9]. Anatomic reports of this area exclusively involved gross anatomic [7, 34] or sagittal sections [32, 41]. Observations performed only in one plane, however, may not reflect the Achilles tendons three-dimensional insertions. In general, cadaver studies, including this investigation, suffer from specific limitations. Tissue fixation and dehydration may cause shrinkage of the Achilles tendon resulting in an averaged error of measurement of 4.5% [15]. Calculated from this value, underestimations of the medial and lateral insertion extensions are less than 0.5 mm and therefore are not clinically important. Detachment of the Achilles tendon borders from the medial and/or lateral calcaneal wall during dissection (sawing) also might result in some underestimation. In addition, the specimens included in our study had normal anatomy, and drawing clinically relevant conclusions for approaches to chronically diseased Haglund's specimens is difficult as scar tissue may impede exposure of the anatomic structures at risk. Our data, therefore, should be confirmed by in vivo investigations, preferably using MRI.

Operative and some anatomic textbooks show the Achilles tendon and its calcaneal insertion. with respect to the sagittal plane [1, 5, 29, 42]. In this plane, transformation of the Achilles tendon cross section from an oval in its midsubstance to an arcuated or crescent-shaped configuration at its calcaneal insertion is not visible. The shape of the Achilles tendon in a transverse plane rarely is shown [19, 35]. Even in a MRI textbook, the image of an unbowed Achilles tendon insertion on an axial section is shown [8]. We found only one report stating the Achilles tendon terminates "at the medial and lateral bone border of the calcaneus" [7]. In contrast to our conclusion however, the authors judged these extensions as not being "significant," and no specific measurements were presented to justify their opinion [7]. We believe our observations are clinically important. The Achilles tendon extension around the medial calcaneal surface is more pronounced compared with the lateral side, with maximum values of 9.1 mm and 5.5 mm (Table 2), respectively. Surgery in this region comprises resection of the retrocalcaneal bursa and Haglund's tuberosity. Open and endoscopic approaches should not sacrifice healthy Achilles and plantaris tendon fibers [9, 23]. This theoretically means an operative approach from the lateral side technically should be easier to perform and should reduce the risk of iatrogenic lesions to the anterior central and medial Achilles tendon column, which potentially compromises the outcome (Fig. 6). However, an approach directly through the middle part of the Achilles tendon provides a good visual opportunity for the surgeon to resect the Haglund's protuberance on the medial and lateral side without damaging insertional fibers of the Achilles tendon medially or laterally. However, dividing an intact Achilles tendon may cause detrimental effects. One potentially can minimize the risk of an iatrogenic lesion by using a burr rather than a chisel. This would be similar to the endoscopic technique and minimize the risk of postoperative avulsion of the Achilles tendon [18]. However, in the absence of controlled studies, the literature does not clarify the superiority of one approach over

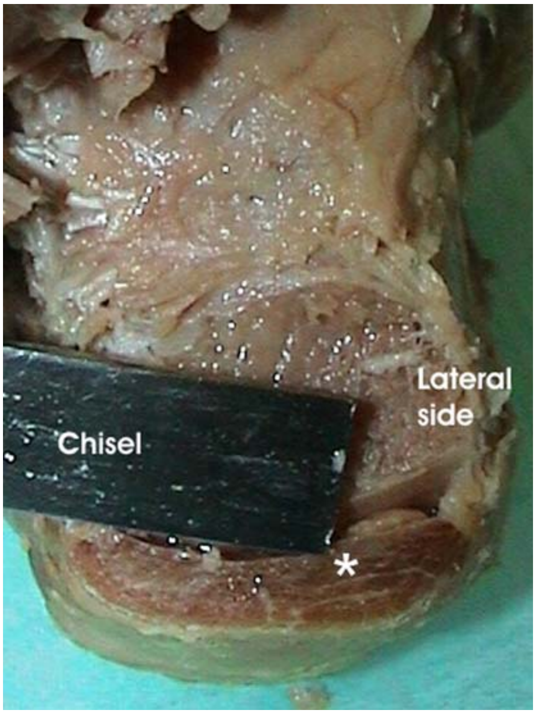

Fig. 6 The Haglund's tuberosity resection using a chisel from the medial side is shown. The central and lateral portion of the Achilles tendon at risk of iatrogenic injury (*) because it is directed posteriorly to completely remove the relevant bone. Reprinted with permission from Lohrer H, Arentz S. [Impingement lesion of the distal anterior Achilles tendon in sub-Achilles bursitis and Haglund-pseudoexostosis: a therapeutic challenge][in German]. *Sportverletz Sportschaden*. 2003;17:181–188.

another. The surgeon's preference to use the medial [21, 33], central [6], or lateral [13, 38, 39, 45] approach is based on his or her individual experience to avoid injury to the medial neurovascular bundle, peroneal tendons, and sural nerve.

Regarding the transverse section, some research suggests the Achilles tendon is characterized by a differential load distribution [2, 3, 25]. This means the distribution of load in the Achilles tendon varies with movements around the sagittal and transverse ankle and the subtalar axes. Broadening of the distal Achilles tendon around the posterior calcaneus may be of specific importance by lengthening the lever arm of the fibers to control inversion and eversion of the heel especially during walking and running. Unintended iatrogenic cutting of the medial, lateral, or central Achilles tendon extensions may be one reason for failed surgery resulting in persistent load-dependent Achilles tendon insertional pain and reduced sports ability.

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