



Original Article

Achilles tendon thickening does not affect elasticity and functional outcome after surgical repair of Achilles rupture: A retrospective study

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ARTICLE INFO

Article history:

Received 31 August 2023

Received in revised form

21 September 2023

Accepted 1 October 2023

Available online 27 October 2023

Keywords:

Achilles tendon rupture

Thickening

Elasticity

Functional outcome

ABSTRACT

Purpose: Previous studies have confirmed that Achilles tendon occurs Achilles thickening after repair surgery of the rupture. Although this mechanism has been elucidated in the laboratory, there are few reports on its impact on clinical function. We designed a retrospective study to investigate the Achilles thickening after Achilles tendon rupture repair and its correlation between the elasticity and post-operative function.

Methods: In this retrospective analysis, patients who underwent surgical treatment for acute Achilles tendon rupture from April 2016 to April 2020 were included. All the patients were regularly followed up at 3 months, 1 year, and 2 years after surgery. American Orthopaedic Foot Ankle Surgeon (AOFAS) scale and Leppilahti score were used to evaluate functional outcomes. Achilles elasticity was measured by ultrasound shear wave of elasticity. Achilles thickening was calculated as maximal transverse and longitudinal diameter in cross-sectional plane of magnetic resonance scan. Sample *t*-tests was used for different follow-up periods. Correlation between Achilles thickening and other factors were analyzed using Pearson's method. $p < 0.05$ indicates a statistically significant difference.

Results: AOFAS scale and Leppilahti score at 1 year were significantly higher than at 3 months post-operatively (both $p < 0.001$). These functional scales were also improved at 2-year follow-up significantly (both $p < 0.001$). The dorsiflexion difference showed gradually recovery in each follow-up period ($t = -17.907$, $p < 0.001$). The elasticity of the Achilles appeared to continuously decreases during the postoperative follow-up period in all position sets ($p < 0.001$). In thickening evaluation, the cross-sectional area of the thickest plane of Achilles was significantly higher at 1 year postoperatively (310.5 ± 25.2 mm²) than that at 3 months postoperatively (278.0 ± 26.2 mm², $t = -8.219$, $p < 0.001$) and became thinner in 2-year magnetic resonance scan (256.1 ± 15.1 mm², $t = 16.769$, $p < 0.001$). The correlations between Achilles thickening, elasticity, and functional outcome did not show statistical significance ($p > 0.05$) in every follow-up period.

Conclusion: Achilles tendon thickens after surgery in the 1st year, but begins to gradually return to thinning about 2 years after surgery. There was no significant correlation between the increase and decrease of thickening and the patients' clinical function scores, Achilles elasticity, and bilateral ankle dorsiflexion difference.

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Introduction

Achilles tendon rupture is a common sports injury of the ankle that occurs not only among professional athletes but also among active sports enthusiasts.^{1,2} People aged 35 – 50 years seem more

likely to suffer from such injury.³ Recent statistics indicate that the incidence of Achilles tendon rupture has shown an upward trend in the past 10 years, and the number of surgical treatments has also increased.⁴ Most acute Achilles tendon rupture can achieve almost full recovery and return to sports through precise surgical suturing and professional postoperative rehabilitation protocols. However, many clinical researches have reported that Achilles tendon shows significant thickening in subsequent clinical follow-up, even lasting for years, whether treated surgically or conservatively.^{5,6} The

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Peer review under responsibility of Chinese Medical Association.

influence of Achilles tendon thickening on clinical significance or mechanical properties of the tendon has not been clarified by surgeons. Therefore, we designed a retrospective case study that aims to explore the correlation between Achilles tendon thickening, clinical function, and tendon elasticity through a group of consecutive patients undergoing acute Achilles tendon repair. Our hypothesis was to investigate the Achilles thickening has an impact on elasticity or function.

Methods

Inclusion and exclusion criteria

From April 2016 to April 2020, patients who underwent surgical treatment for Achilles tendon rupture in our hospital were selected in clinical database. Inclusion criteria were: (1) patients with closed Achilles tendon rupture; (2) aged 18–59 years; (3) sports injury; (4) injury time less than 2 weeks; (5) no re-rupture during the follow-up period. In total, 84 patients with acute Achilles tendon rupture cases were studied, including 80 males and 4 females.

Surgical procedure and rehabilitation protocol

Surgery was performed under spinal anesthesia, in prone position. A posterior median incision was used to expose the Achilles. #2 Fiberwire suture (Arthrex Warsaw, USA) were used to suture the Achilles tendon with Kessler procedure. A short leg cast below the knee was used to fix the ankle. Antibiotics were routinely used to prevent infection. The postoperative short leg cast was fixed for 3 weeks, then the plaster was removed, and some weight-bearing exercises were performed in walking boots (the initial setup for range of motion of the ankle was 20° for dorsiflexion and 20° for plantar extension, and gradually increased according to functional exercise). Generally, after 3 weeks, the walking boots can be removed, and regular shoes can be worn to start walking and functional exercise. Regular sports such as jogging can start at 3 months after surgery. Competitive sports were allowed at 6 months postoperatively.

Postoperative follow-up

The patients were regularly followed up at 3 months, 1 year, and 2 years after the operation. The function was evaluated using the American Orthopedic Foot and Ankle Surgeon (AOFAS) scale and Leppilahti scores. The difference in bilateral ankle dorsiflexion was checked with a protractor in the supine position, and the difference was calculated bilaterally to compare with the preoperative condition. The measurement of Achilles tendon elasticity was measured with ultrasonic shear wave elastography (SWE) method (Supersonic Imaging AixPlore color Doppler, probe frequency of 4–15 MHz). The shear wave values (m/s) are measured in the long and short axis sections of the healed Achilles tendon at 3 positions: the natural neutral position, the maximum plantar flexion position, and the maximum dorsal extension position. An average of 3 measurements was taken. The Achilles thickening was evaluated by magnetic resonance (MR) scan as reported by Shalabi et al.⁷ The thickest layer of the healed portion of the Achilles in the coronal plane was selected, and the diameter of long axis and short axis were measured in this cross-section. The cross-sectional area of the Achilles tendon is calculated using the elliptical formula (Fig. 1).

Statistical analysis

PASW20.0 (SPSS Inc IBM Chicago, USA) statistical software was used for statistical analysis. The results were expressed as

mean \pm SD. Normal curves and probability-probability plots were used for normality testing to elasticity, functional score, and cross-sectional area of the Achilles tendon at different follow-up time points. If it follows a normal distribution, independent sample *t*-tests are used for data from different follow-up periods. If not, the rank sum test is used to compare the differences between groups. $p < 0.05$ is considered statistically significant. The correlation between the cross-sectional area, functional score, and elasticity of the thickened Achilles tendon was tested using Pearson's method.

Result

The average age of included patients is (37.1 ± 6.8) years (ranging from 21 to 57 years). There are 32 cases (38.1%) having body mass index ≤ 24 and 52 cases (61.9%) having body mass index > 24 . The average follow-up time is (37.1 ± 5.2) months (ranging from 29 to 51 months). In all 84 cases, Achilles tendon rupture healed successfully after surgery. One patient had superficial wound infection, which healed after dressing change. There were no complications such as re-rupture or Achilles contracture. In regular follow-up, functional scale showed continually improvement over 2 years. AOFAS (87.9 ± 3.1) and Leppilahti (90.5 ± 3.4) at 1 year were significantly higher than that at 3 months (AOFAS 80.3 ± 3.7 , $t = -14.404$, Leppilahti 80.7 ± 3.2 , $t = -17.907$, both $p < 0.001$). In 2 years follow-up, AOFAS (93.6 ± 3.4 , $t = -11.205$) and Leppilahti (95.9 ± 2.8 , $t = -11.090$) both keep improving significantly (both $p < 0.001$) (Fig. 2). The elasticity decreased significantly at 1 year than that at 3 months: neutral SWE (10.2 ± 0.5 vs. 9.1 ± 0.1 m/s, $t = -20.592$, $p < 0.001$), maximum plantarflexion SWE (7.8 ± 0.2 vs. 7.4 ± 0.2 m/s, $t = -10.940$, $p < 0.001$), and maximum dorsiflexion SWE (12.7 ± 1.4 vs. 10.5 ± 0.4 m/s, $t = -13.990$, $p < 0.001$). The decreasing trends remain in 2 years follow-up in a neutral position (10.9 ± 0.6 m/s, $t = -8.535$, $p < 0.001$), and maximum plantarflexion SWE (8.4 ± 0.1 m/s, $t = -23.444$, $p < 0.001$). However, maximum dorsiflexion SWE showed no statistical difference compared with 1-year follow-up (12.6 ± 0.9 m/s, $t = 0.744$, $p = 0.458$) (Fig. 3). The dorsiflexion difference at 1 year ($3.2^\circ \pm 2.5^\circ$) was significantly improved than that at 3 months ($6.9^\circ \pm 1.6^\circ$, $t = 11.294$, $p < 0.001$). While at 2-year visit, it was hard to find difference between both ankles ($t = 0.744$, $p = 0.458$) (Fig. 4). In MR scan measurement of Achilles thickening, cross-sectional area at 1 year was (310.5 ± 25.2) mm², thickened significantly at 3 months postoperatively (278.0 ± 26.2) mm², $t = -8.219$, $p < 0.001$. But at 2-year revisit, it decreased to (256.1 ± 15.1) mm² with a statistical difference ($t = 16.769$, $p < 0.001$) (Fig. 5). All the parameters were listed in Table 1.

The correlations between Achilles thickening, elasticity (in Max dorsiflexion, max plantarflexion and neutral position) and functional outcome did not show statistical significance ($p > 0.05$) in every follow-up time (Table 2).

Discussion

Clinical outcome of surgical treatment of Achilles tendon rupture has been widely recognized. Surgical treatment combined with early rehabilitation can enable most patients to return to sports.⁸ At present, the research focus on whether comprehensive treatment such as rehabilitation and early exercise can help to restore function earlier, reduce calf atrophy, and achieve sports performance after Achilles tendon rupture surgery. Many clinical studies have confirmed that early accelerated weight-bearing and active functional exercise can improve the height of heel lift and clinical functional score after Achilles tendon repair.^{9–11} However, regardless of the surgical method or rehabilitation protocol adopted, the thickening of the Achilles tendon after surgery seems

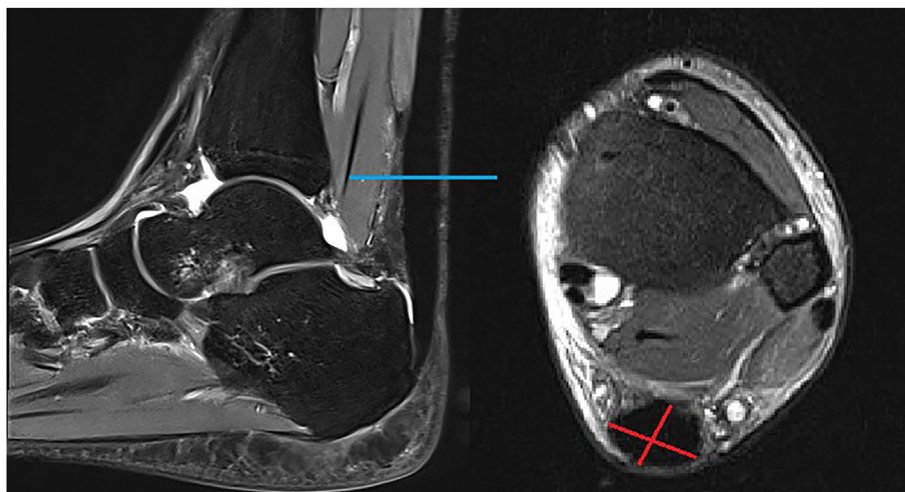


Fig. 1. Magnetic resonance scan of Achilles 1 year after surgical repair. The thickest layer of healed tendon (blue line) and diameter of its long axis and short axis (cross red line).

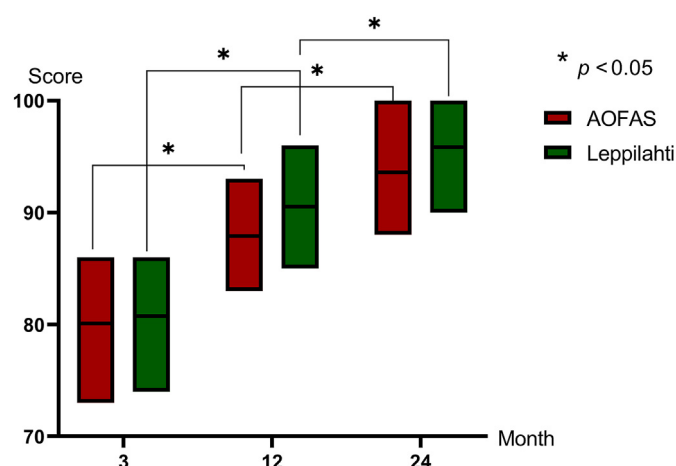


Fig. 2. Functional scale in difference follow-up period. AOFAS: American Orthopedic Foot and Ankle Surgeon.

difficult to change.¹² Tam et al.¹³ compared the MR images of Achilles tendon rupture after surgery, they implied that the tendon does not receive significant repair. The stages of the healing process including inflammation, reparative, and remodeling may cause tendon thickening. Aufwerber et al.¹² reported that early activity can avoid calf atrophy and improve ankle motion, but cannot improve Achilles tendon thickening and elastic changes. Interestingly, even in cases of delayed Achilles tendon rupture, Achilles tendon was reconstructed by flexor hallucis longus transposition, but thickening of the tendon and increasing volume of flexor hallucis longus were also found in follow-up time.¹⁴ Biz et al.¹⁵ reported ultrasound check showed a significantly greater incidence of thickening and alteration of fibrillar architecture in the percutaneous suture group. Chianca et al.¹⁶ studied the changes in MR and ultrasound after Achilles repair. MR showed repaired tendon is physiologically larger and wider than an intact one. Power doppler shows an increase in blood supply to the Achilles tendon and the appearance of new blood vessels. Schulze-Tanzil¹⁷ summarized the biology of Achilles tendon healing and implied that Achilles tendon thickening is related to elastic fiber proliferation, rearrangement, and neovascularization. In our study, the Achilles tendon thickened significantly within 1 year after reoperation, but gradually thinned during the 2-year postoperative observation. In contrast, Achilles

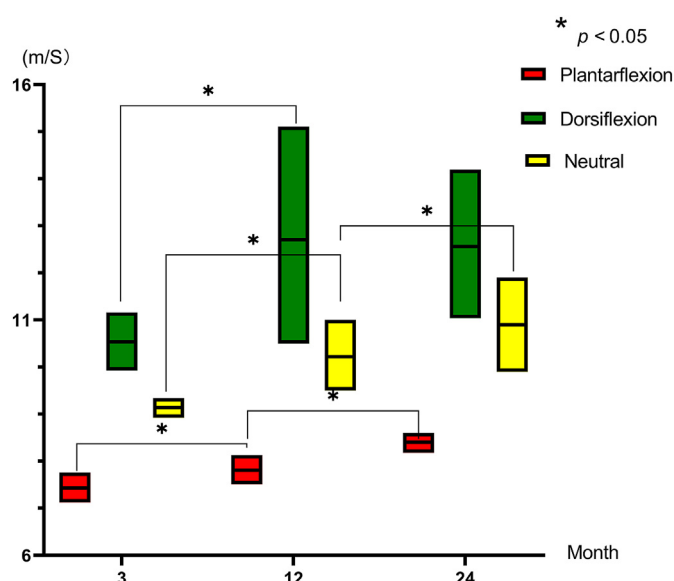


Fig. 3. Elasticity result measured by shear wave elastography in a neutral position, maximal dorsiflexion, and maximal plantar flexion.

tendon elasticity appeared to be in a constant state of decline at 2-year follow-up, regardless of the position in which it was measured. In brief, the morphological changes of the Achilles may also correspond to changes in the biomechanical properties, but this corresponding relationship has not been reported in clinical research at present.

According to Bruns et al.¹⁸, the initial healing mechanism is scar tissue thickening with the improvement of fiber orientation towards a tendon-like structure within 1 year. Parallel to this, the specific rupture force increased, and the thickness of the newly tendon-like area decreased. Zanetti et al.¹⁹ also reported post-operative tendon is commonly thickened, showing the most pronounced MR signal changes 3 – 6 months after surgery. The changes in MR signals of tendons correspond to changes in histological structure. Ciloglu et al.²⁰ also confirmed the thickness of the ruptured Achilles tendon was significantly higher than that of the uninjured site. Research has shown that during the process of collagen rearrangement after tendon rupture, its biomechanical

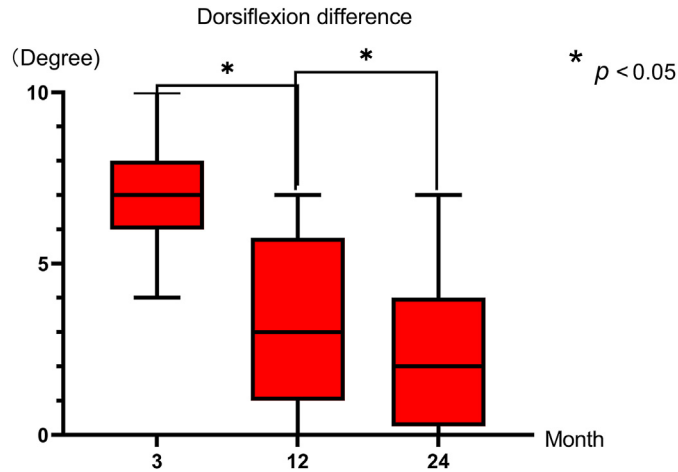


Fig. 4. Changes in ankle dorsiflexion between injury side to healthy side.

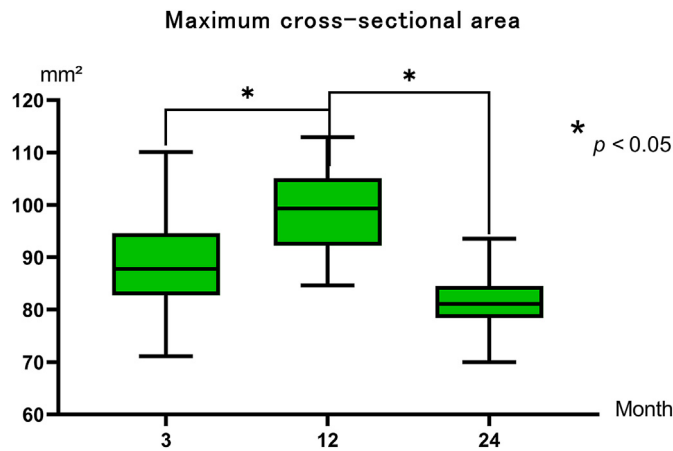


Fig. 5. Thickening of Achilles in every follow-up time measured in magnetic resonance scan of cross-section area.

properties also change accordingly with structural changes.^{21,22} Geremia et al.²³ compared the ruptured Achilles with the normal population and found that Achilles tendon ruptures had significantly lower elasticity compared to normal Achilles tendons. Frankewycz et al.²⁴ compared elastic wave velocity of ultrasound shear waves between healthy individuals and patients after Achilles tendon rupture surgery and found a decrease in the elasticity of healed Achilles tendon compared to the healthy population, even after a long-term healing stage. Li et al.²⁵ measured the longitudinal elasticity of the repaired Achilles tendon in 26 patients at 12, 24, and 48 weeks after surgery, and found a positive correlation between the AOFAS score and the repaired Achilles tendon elasticity. Busilacchi et al.²⁶ conducted a real-time ultrasound examination of the Achilles tendon after surgery and found that the Achilles tendon gradually stiffened (stiffness increased), and the elasticity and functional score showed a significant correlation. Corrigan et al.²⁷ studied the morphology of Achilles tendinopathy and believed that the thicker the tendon lesions, the worse the post-operative prognosis. Moreover, the decrease in Achilles tendon viscosity in thickening Achilles also indicates poor function. Other clinical researches also reported that if a patient has tendinosis, a power doppler ultrasound will detect the Achilles tendon thickening, blood supply increase, and local hyperplasia.²⁸ Möller et al.²⁹ reported no correlations between the radiological findings and the clinical parameters, such as muscle strength, endurance, and range of motion. According to our study, the cross-sectional area of the thickened Achilles tendon and the elasticity and postoperative function of the Achilles tendon showed no significant correlation, which was also observed at different postoperative follow-up periods.

Many factors affect the functional recovery of the Achilles tendon after healing. Carmont et al.³⁰ found a high correlation between age and functional recovery after Achilles tendon repair. The repair tension of Achilles is directly related to the height of the heel lift. In previous clinical reports, open incision and direct suture did not affect Achilles tendon thickening, but Achilles tendon thickening appears to be more significant if a minimally invasive percutaneous procedure was performed. Tarczyńska et al.³¹ confirmed there is no significant difference in diameter between

Table 1
Parameters in different follow-up times.

Time point	AOFAS	Leppilahti	Plantar flexion (m/s)	Dorsiflexion (m/s)	Neutral position (m/s)	Cross-sectional area (mm ²)	Dorsiflexion difference
3 months	80.3 ± 3.7	80.7 ± 3.2	7.4 ± 0.2	10.5 ± 0.4	9.1 ± 0.1	278.0 ± 26.2	6.9 ± 1.6
1 year	87.9 ± 3.1	90.5 ± 3.4	7.8 ± 0.2	12.7 ± 1.4	10.2 ± 0.5	310.5 ± 25.2	3.2 ± 1.5
2 years	93.6 ± 3.4	95.9 ± 2.8	8.4 ± 0.1	12.6 ± 0.9	10.9 ± 0.6	256.1 ± 15.1	2.5 ± 2.0
3 months vs. 1 year	$t = -14.40$ $p < 0.001$	$t = -17.907$ $p < 0.001$	$t = -10.940$ $p < 0.001$	$t = -13.990$ $p < 0.001$	$t = -20.592$ $p < 0.001$	$t = -8.219$ $p < 0.001$	$t = 11.294$ $p < 0.001$
1 year vs. 2 years	$t = -11.20$ $p < 0.001$	$t = -11.090$ $p < 0.001$	$t = -23.444$ $p < 0.001$	$t = 0.744$ $p = 0.458$	$t = -8.535$ $p < 0.001$	$t = 16.769$ $p < 0.001$	$t = 2.128$ $p = 0.039$

Data presented as mean ± SD, excepted statistical data.

AOFAS: American Orthopedic Foot and Ankle Society.

Table 2
Correlations of Achilles thickening, functional scale and elasticity.

Time	Achilles tendon condition	AOFAS	Leppilahti	Neutral position	Plantar flexion	Dorsiflexion	Dorsiflexion difference
3 months	Thickening	$r = -0.033$ $p = 0.768$	$r = -0.038$ $p = 0.730$	$r = -0.009$ $p = 0.934$	$r = -0.009$ $p = 0.934$	$r = -0.009$ $p = 0.937$	$r = 0.036$ $p = 0.744$
12 months	Thickening	$r = 0.089$ $p = 0.422$	$r = -0.038$ $p = 0.730$	$r = -0.009$ $p = 0.934$	$r = -0.009$ $p = 0.934$	$r = -0.009$ $p = 0.937$	$r = 0.036$ $p = 0.744$
24 months	Thickening	$r = 0.031$ $p = 0.778$	$r = -0.017$ $p = 0.876$	$r = 0.096$ $p = 0.385$	$r = 0.040$ $p = 0.715$	$r = 0.096$ $p = 0.386$	$r = -0.073$ $p = 0.511$

AOFAS: American Orthopedic Foot and Ankle Society.

acute or delayed Achilles tendon suture. Pierre-Jerome et al.³² conducted an MR study of patients with Achilles tendon over-strain and found that over-strain Achilles tendons are more prone to structural changes such as thickening and local degeneration. Bleakney et al.³³ examined the diameter of the affected Achilles tendon and the contralateral Achilles tendon and reported the anterior and posterior diameters of the ruptured tendon were significantly larger than the contralateral side. These reports indicate that Achilles tendon thickening does occur during the healing period after Achilles tendon rupture, which may be a biological phenomenon of tendon healing. Although there is no direct histological or physiological evidence to explain the effect on the mechanical properties of the Achilles thickening, based on our clinical observations we prefer to believe that Achilles tendon thickening as a physiological process of tendon healing may not affect adversely on clinical recovery.

There are some limits of this research. Firstly, the MRI only measured the cross-sectional area of the thickest section of the Achilles tendon and did not use more advanced MR measurements, such as volumetric analysis to assess the volume of the thickened Achilles tendon. Secondly, we did not investigate the difference in re-sectional area, elasticity, etc. between the healthy and the affected Achilles, but only chose the dorsal extension difference. This is mainly due to some literature reporting a relatively large reduction in the elasticity of the healthy Achilles tendon after Achilles tendon rupture, which may affect the measurements on the affected side and the baseline for comparison.^{34,35} Finally, most of the cases in this study were active people, not professional athletes, so the findings of this study have not been confirmed to apply to elite athletes.

Funding

This study was supported by grants from Sanming Project of Medicine in Shenzhen (SZSM201612078), Clinical research project of Peking University Shenzhen Hospital (LCYJ2021028).

Ethical statement

This study was approved by the ethics committee of Peking University Shenzhen hospital (2022 – 102). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Author contributions

Lu Bai designed research and performed surgery. Lu Wang did statistical work. Chen-Xi Wu did some of the patient's follow-up. Chang-Yue Xiong, Su-Meng Chen, Yu-Xin Yan did some patient's follow-up. Xin-Tao Zhang did project administration. Lu Bai and Chen-Xi Wu write the manuscript. All authors analyzed the data and were involved in writing the manuscript.

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