

# Modified Bunnell suture versus bundle-to-bundle suture for acute Achilles tendon rupture: A prospective comparative study of patients aged <45 years

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## Research article

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# Abstract

**Background:** This study was performed to compare the operative outcome between percutaneous repair (modified Bunnell suture) and open repair (bundle-to-bundle suture) for treatment of acute Achilles tendon rupture.

**Methods:** Seventy-two consecutive patients who underwent surgical treatment of Achilles tendon rupture were evaluated. Thirty-six patients were treated by the bundle-to-bundle suture technique (Group A), and 36 patients were treated by the modified Bunnell suture technique (Group B). Functional examination included measurement of the calf muscle circumference and performance of the single-leg heel-rise test. The length and diameter of the Achilles tendon were compared between the injured and uninjured sides using magnetic resonance imaging. The number of single-leg heel rises (height of >5 cm) performed within 15 s was compared between the injured and uninjured sides. The ankle joint range of motion was also recorded. The Achilles tendon total rupture score (ATRS), American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot scale score, and visual analog scale (VAS) pain score were used to evaluate the clinical outcome after a minimum 12-month postoperative follow-up period.

**Results:** In total, 61 patients were followed up. The mean follow-up time was not significantly different between Group A ( $23.73 \pm 2.81$  months) and Group B ( $22.61 \pm 3.96$  months). However, there were significant differences in the heel-rise test (Group A,  $1.74 \pm 0.96$ ; Group B,  $2.37 \pm 1.42$ ) and length of the Achilles tendon (Group A,  $11.98 \pm 1.64$  cm; Group B,  $11.11 \pm 1.74$  cm). The calf circumference of the injured side was significantly larger in Group A than B ( $p = 0.043$ ). The cross-sectional diameter of the Achilles tendon after open repair was significantly different from that after percutaneous repair. There were no significant differences in the ATRS, AOFAS score, or VAS score at the final follow-up between the two groups. One patient in Group A had delayed wound healing, which resolved in about 40 days.

**Conclusions:** Both suture methods described in this report can provide good clinical results. The bundle-to-bundle suture technique is more effective for restoration of the Achilles tendon length and muscle function. This method is safe, effective, and worthy of promotion.

## Background

Although the Achilles tendon is the strongest tendon in the body, it is still prone to rupture [1]. The incidence of Achilles tendon rupture is 6 to 18 of every 100,000 individuals and has increased in the last few decades [2]. The horsetail-like ends of the ruptured tendon are often located 2 to 6 cm above the tendon attachment point on the calcaneus [3].

Many Achilles tendon repair techniques have been described. Optimal treatment can be divided into conservative treatment, open repair, percutaneous repair techniques, or minimally invasive repair techniques [4-7]. However, a high rate of re-rupture has been reported after conservative treatment [8]. Furthermore, healing in a lengthened position may result in loss of calf muscle strength [9]. Open repair is associated with surgical complications, such as skin-tendon adhesions, infection, delayed healing of the

surgical wound, and suture granulomas [10]. Some scholars have reported that percutaneous repair of Achilles tendon rupture reduces destruction of the blood supply and lowers the risk of wound complications and infections [11]. Gaps may be created in the area of percutaneous repair, which can lead to postoperative tendon weakness and granulation hyperplasia. Newer open repair techniques have led to reduced complication rates and more successful outcomes compared with traditional open surgery [7, 12, 13]. The bundle-to-bundle suture technique is a type of open repair that minimizes loss of the Achilles tendon length and restores good ankle function [7, 12, 13]. This technique has been described for anatomical repair of the tendon with protection of the soft tissue envelope, preserving the hypovascularity of the rupture site [14].

The objective of this study was to compare the outcome of open repair (bundle-to-bundle suture) with percutaneous repair (modified Bunnell suture) for treatment of acute Achilles tendon rupture. We hypothesized that a better clinical outcome would be achieved by the bundle-to-bundle suture technique.

## Methods

### *Study population*

This was a prospective, randomized, comparative trial. All patients with acute Achilles tendon rupture (<7 days) were eligible for the study from May 2016 to January 2018 ( $n = 72$  in 19 months). Achilles rupture was diagnosed by clinical examination (the Thompson test) and magnetic resonance imaging (MRI) in each patient [15].

The inclusion criteria were (1) an age of 18 to 45 years, (2) body mass index (BMI) of  $<34 \text{ kg/m}^2$ , (3) closed injury, and (4) acute Achilles tendon rupture (<7 days). The exclusion criteria were (1) partial Achilles tendon rupture (diagnosed by means of MRI or intraoperative probe), (2) rupture of the insertion point of the Achilles tendon (<2 cm), and (3) diseases that may affect the results of the functional study tests, such as autoimmune disease, deep vein thrombosis, or neuropathy.

The CONSORT flow chart of patient selection is shown in Figure 1. All patients provided written consent to participate in the study and return for standardized follow-up examinations at 1, 3, 6, and 12 months after surgery. The operative technique was selected by assigning each patient an odd or even number according to their order of hospital admission.

Open repair (bundle-to-bundle suture) was performed in Group A ( $n = 30$ ), and percutaneous repair (modified Bunnell suture) was conducted in Group B ( $n = 31$ ). All patients' physical examinations and operations were performed by the same surgeon (FQ.Z).

### *Surgical procedures*

#### *Bundle-to-bundle suture*

The posteromedial Achilles tendon approach was used with the site of Achilles tendon rupture as the center. After the Achilles tendon rupture was exposed, the congested tissue was carefully removed and the ruptured Achilles tendon was shifted to expose the deep soft tissue. The deep soft tissue was sutured first, and the soft tissue bed of the Achilles tendon was then repaired, which was beneficial for the recovery and healing of the Achilles tendon blood supply. The horsetail-like ends of the ruptured tendon were aligned according to the anatomical characteristics of the Achilles tendon. The tendon band of the superficial proximal gastrocnemius was turned laterally and sutured to the band of the distal lateral end of the tendon, while the tendon band of the deep proximal soleus was turned inward and sutured to the band of the distal medial end of the tendon. The Achilles tendon was typically divided into several anatomical bundles, and the tendon bundles were then repaired in an end-to-end fashion from the deep aspect to the lamina using absorbable 4-0 sutures to connect the ends and 5-0 Prolene to reinforce the repair. The long tendon band was sutured to the short tendon band using 4-0 Prolene to avoid a short, retracted Achilles tendon and excessive plantar flexion of the ankle. Nonabsorbable 4-0 suture was used to suture the outer membrane of the Achilles tendon, deep fascia, subcutaneous tissue, and skin. This bundle-to-bundle suture technique was first introduced by Zhao et al. [14] (Fig. 2).

### *Modified Bunnell suture*

One mark was made in the middle of the depression of the ruptured Achilles tendon, and two or three marks were made on both sides of the distal and proximal Achilles tendon. Approximately 11 to 13 small 1-cm incisions were made at each mark to reach the deep fascia. PDS-II suture was threaded through the distal incision, passed through the tendinous tissue, and then threaded through the central incision. Next, a "Z" suture was performed by threading the PDS-II through the proximal incision and then through the central incision. The distal and proximal sutures were tightened to tie the ruptured end of the tendon, and the knot was then examined by the Thompson test. The transverse incision was sutured, and the stab incisions were closed. The sural nerve was protected during the performance of all incisions. This procedure was first introduced by Ma and Griffith [16] (Fig. 3).

### *Postoperative rehabilitation*

The postoperative rehabilitation was performed by an experienced physical therapist. The affected limb was lifted up, and the quadriceps femoris and triceps cruris were exercised by isometric contraction and relaxation on the second postoperative day. The stitches were removed at 2 weeks postoperatively. Partial protected weight bearing with walking boots was allowed until the patients had gradually achieved walking with a partial load at 4 weeks; the partial load was then changed to a full load within 4 to 6 weeks. Four layers of wedge insoles were placed inside the walking boots, and one layer was removed every 1 to 2 weeks. Flexion and extension of the ankle joint was allowed in the neutral position 6 weeks after surgery. After 2 weeks of full weight-bearing exercise with walking boots, the walking boots were removed. Walking with sneakers and functional ankle range-of-motion exercise were allowed at 2 months postoperatively, and heel-lifting functional exercise was allowed at 10 weeks postoperatively.

### *Functional evaluation*

Follow-up was performed 1, 3, 6, 12, and 24 months after surgery. The functional evaluation included both a functional examination and patient-reported outcome measures. The functional examination findings and clinical score were evaluated at 12 months.

The functional examination consisted of three main items: measurement of the calf circumference, measurement of the Achilles tendon width and anteroposterior dimension, and performance of the single-leg heel-rise test. All postoperative evaluations were performed by nonsurgical personnel who were unaware of the patients' surgical procedures. The calf circumference on the injured side was compared with that of the contralateral limb. The diameter and length of the Achilles tendon on the injured side were compared with those of the contralateral limb by MRI. The number of single-leg heel rises within 15 s (height of >5 cm) was compared with that of the uninjured side [17]. The height of the heel-rise test was monitored by one person. The ankle joint range of motion was recorded.

The patient-reported outcome measures were the Achilles tendon total rupture score (ATRS), American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot scale score, and visual analog scale (VAS) pain score [18].

### ***Statistical analysis***

Statistical analysis was performed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA). The demographic data and all outcome parameters were tested for deviation from the normal distribution. Differences between the injured and uninjured sides and differences between the two treatment groups were tested with a two-tailed, unpaired *t*-test. Differences in age, sex, BMI, and follow-up duration were examined using a paired-samples *t* test and Fisher's test or the  $\chi^2$  test for continuous variables and categorical data, respectively. Pearson's test differences in the ATRS, AOFAS score, and VAS score between the two treatment groups were determined with an unpaired-samples *t* test or the Mann–Whitney rank sum test. Pearson correlation analysis was performed during the functional examination of the patients. A *P* value of <0.05 was considered statistically significant.

## **Results**

Seventy-two patients were enrolled in the study, and 11 patients were excluded (partial rupture of the Achilles tendon, *n* = 4; rupture of the insertion point, *n* = 3; re-rupture, *n* = 3; postoperative deep venous thrombosis of the lower extremity, *n* = 1). Finally, 61 patients were included in this clinical study. No statistically significant differences were found in age, sex, or BMI between the two groups. The demographics of the patients are displayed in Table 1.

There was no difference in the mean follow-up time between Groups A and B ( $23.73 \pm 2.81$  vs.  $22.61 \pm 3.96$  months, respectively). No patient in either group had a negative heel-rise test result (height of  $\leq 5$  cm) at the final follow-up. The difference in the number of single-leg heel rises between the injured and uninjured sides was significantly smaller in Group A than B ( $1.74 \pm 0.96$  vs.  $2.37 \pm 1.42$ , respectively, *P* = 0.000). The Achilles tendon was significantly longer in Group A than B ( $11.98 \pm 1.64$  vs.  $11.11 \pm 1.74$  cm,

respectively;  $P = 0.048$ ). Groups A and B showed no difference in the range of dorsiflexion ( $19.06 \pm 2.42$  vs.  $19.25 \pm 3.24$  degrees, respectively) or range of plantar flexion ( $36.58 \pm 4.39$  vs.  $35.41 \pm 4.45$  degrees, respectively) at the final evaluation. The calf circumference was smaller on the injured than uninjured side in both groups. The calf circumference on the injured side was significantly larger in Group A than B ( $P = 0.043$ ). There was no correlation between the calf circumference and the heel-rise test. The cross-sectional diameter of the Achilles tendon was significantly smaller after open repair than after percutaneous repair ( $P = 0.000$ ) (Table 2). No significant differences were found in the ATRS, AOFAS score, or VAS score between the two groups (Table 3). No patient in either group developed postoperative complications (infection, sural nerve lesion, or re-rupture). However, one patient in Group A experienced delayed wound healing, which resolved in about 40 days. All bacterial cultures were negative.

## Discussion

The objective of this study was to compare the clinical effect of open repair (bundle-to-bundle suture) with that of percutaneous repair (modified Bunnell suture) for acute Achilles tendon rupture. Functional examinations and calculation of clinical scores were used to analyze the efficacy of the open and percutaneous techniques.

Rebeccato et al. [19] reported a 2% (0.67-cm) reduction in calf circumference on the injured versus uninjured side after surgery. The postoperative calf volume of the affected leg was 91% that of the healthy side [19]. In the present study, the calf circumference was smaller on the injured than uninjured side in both the percutaneous and open repair groups. The calf circumference after percutaneous repair was comparable with that after open repair at the final evaluation, whereas the calf circumference was greater after open repair than after percutaneous repair. Patients who can lift their heels >5 cm are considered to have normal Achilles tendon strength [17]. Haji et al. [20] reported that patients who underwent percutaneous repair performed more normal heel rises than those who underwent open surgery (92% vs. 83%, respectively). In the present study, the heel-rise test results were comparable 12 months after the bundle-to-bundle suture technique and modified Bunnell suture technique (numerical difference of 1.74 vs. 2.37, respectively). These results suggest that the bundle-to-bundle suture technique more effectively restores muscle strength; this may be due to the fact that no gap is present at the tendon rupture site after bundle-to-bundle suturing, allowing the tendon to heal better. Clinical evaluation of the calf circumference at the final follow-up demonstrated that the bundle-to-bundle suture technique produced a better result. However, there was no correlation between the calf circumference and the heel-rise test result.

Bundle-to-bundle suturing for Achilles tendon rupture is the most effective operation method to restore the anatomical structure and physiological characteristics of the tendon [4-6]. Open repair allows for direct repair of the rupture site and achievement of maximum mechanical stability [4-7, 21]; however, the complex sutures used in this technique can form a fiber block of the Achilles tendon that may result in keloid formation and shortening of the Achilles tendon [12, 22-26]. Open repair also causes scar contracture of the Achilles tendon, which has been described previously [27]. The Achilles tendon can

thus be repaired with a bundle-to-bundle suture technique to prevent thickening and adhesion of the tendon [28]. Gigante et al. [6] found that the anteroposterior and cross-sectional diameters of the Achilles tendon were not significantly different at 12 months after surgery between the percutaneous repair group and open repair group. In the present study, however, the cross-sectional diameter of the Achilles tendon was significantly larger in the percutaneous repair group than in the open repair group. Therefore, the bundle-to-bundle suture technique can more effectively reduce adhesion and hypertrophy of the tendon.

Percutaneous repair can better retain the range of motion of the ankle joint than can open repair, especially the dorsiflexion angle, as proven in previous studies [5]. However, the present study showed no difference in the range of motion of the ankle joint at the final evaluation between patients who had undergone open versus percutaneous repair. There was no significant difference in the range of motion (plantar flexion and dorsiflexion) of the ankle between the two methods. However, the Achilles tendon was longer in the bundle-to-bundle suture group. This result confirms that open repair (bundle-to-bundle suture) maximally preserves the length of the Achilles tendon and achieves good restoration of ankle function.

Our results also showed no difference in the clinical function scores (ATRS, AOFAS score, and VAS score) at the final evaluation between the two groups. In previous studies, the AOFAS ranged from 96.3 to 96.8 after percutaneous repair and from 96.1 to 98.7 after open procedures [29, 30]. The postoperative AOFAS significantly improved in both groups of the present study (Group A,  $95.40 \pm 3.65$ ; Group B,  $95.38 \pm 3.44$ ). However, we found no significant difference in the VAS score. At 12 months postoperatively, the average VAS score in the percutaneous and open group was 1.6 and 1.7, respectively ( $P > 0.05$ ).

Open repair can be complicated by deep and superficial infection and poor wound healing [30, 31]. The aim of percutaneous repair is to minimize the risk of complications [31-33]. A high rate of nerve injury has also been associated with percutaneous repair (2.9%) [5]. However, no nerve injury occurred in either group of the present study. The most frequent complication of open repair is poor surgical wound healing because the longitudinal incision, which is the most widely used incision type, is made in poorly vascularized skin [34]. In the present study, the incidence of poor wound healing was higher in the open than percutaneous repair group. However, only one such case occurred, and no bacterial infection developed. These findings are consistent with a systematic review by Li et al. [11], showing that the rate of wound infection is significantly lower after percutaneous puncture than open surgery. In the bundle-to-bundle technique of the present study, we used a medial incision, removed the blood clots, and preserved the aponeurosis to reduce the risk of poor postoperative wound healing.

Several limitations must be acknowledged when interpreting the results of the present study. There were fewer female than male patients in this series; thus, whether sex-related differences are present between the two techniques remains unclear. Randomized controlled trials may be the best way to identify the optimal surgical method with which to treat acute rupture of the Achilles tendon. Additionally, the number of included patients was small, and outliers might have had a significant influence on the results. Furthermore, all patients in the study were <45 years old; thus, whether the bundle-to-bundle suture

technique is applicable to patients aged  $\geq 45$  years remains unclear. Finally, a short-term follow-up study was conducted, preventing us from proving whether the results change over time.

## Conclusions

A better functional outcome (heel-rise test result) and longer Achilles tendon were achieved in patients treated by the bundle-to-bundle suture technique. Bundle-to-bundle suturing is a reliable, inexpensive, and nearly physiologic operation for treatment of acute Achilles tendon ruptures with satisfactory results.

## Declarations

Ethics approval and consent to participate

The investigation process was approved by the ethics committee of the Third Hospital of Hebei Medical University. Informed consent to participate in the study was obtained from all patients.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available because they contain patients' personal information. However, these datasets are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

None.

Authors' contributions

XM. Wang designed the study and drafted the manuscript. HX. Liu and HX. Liu acquired and interpreted the data. JH. Niu, C. Liu, and PK. Cao performed the measurements. F. Wang performed the surgeries, critically revised the manuscript, and provided the final approval of the version to be published. All authors read and approved the final manuscript.

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# Abbreviations

ATRS: Achilles tendon total rupture score, AOFAS: American Orthopaedic Foot and Ankle Society, VAS: visual analog scale, MRI: magnetic resonance imaging, BMI: body mass index

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## Tables

### Patient demographics

	Group A	Group B
Age	41.46±1.59	40.06±1.82
Sex(Male/Female)	28/2	28/3
BMI	24.21±3.26	24.37±3.23

“\*”:statistically significant difference between two groups ( $P>0.05$ ; Student’s t-test).

Table 2 Functional outcome after percutaneous repair versus open repair rupture.

	Group A	Group B
Follow-up	23.73±2.81	22.61±3.96
Rerupture rate	0	0
Dorsiflexion	19.06±2.42	19.25±3.24
Plantflexion	36.58±4.39	35.41±4.45
Heel-rise (uninjured vs. injured)	1.74±0.96*	2.37±1.42*
Calf muscle circumference (uninjured vs. injured)	1.74±0.94**	2.34±1.45**
Anteroposterior diameter	10.16±2.04	9.94±2.01
Cross-sectional diameter	16.54±1.55*	18.49±1.59*
Length	11.98±1.64	11.11±1.74

“\*” :statistically significant difference between two groups ( $P>0.05$ ; Student’s t-test).

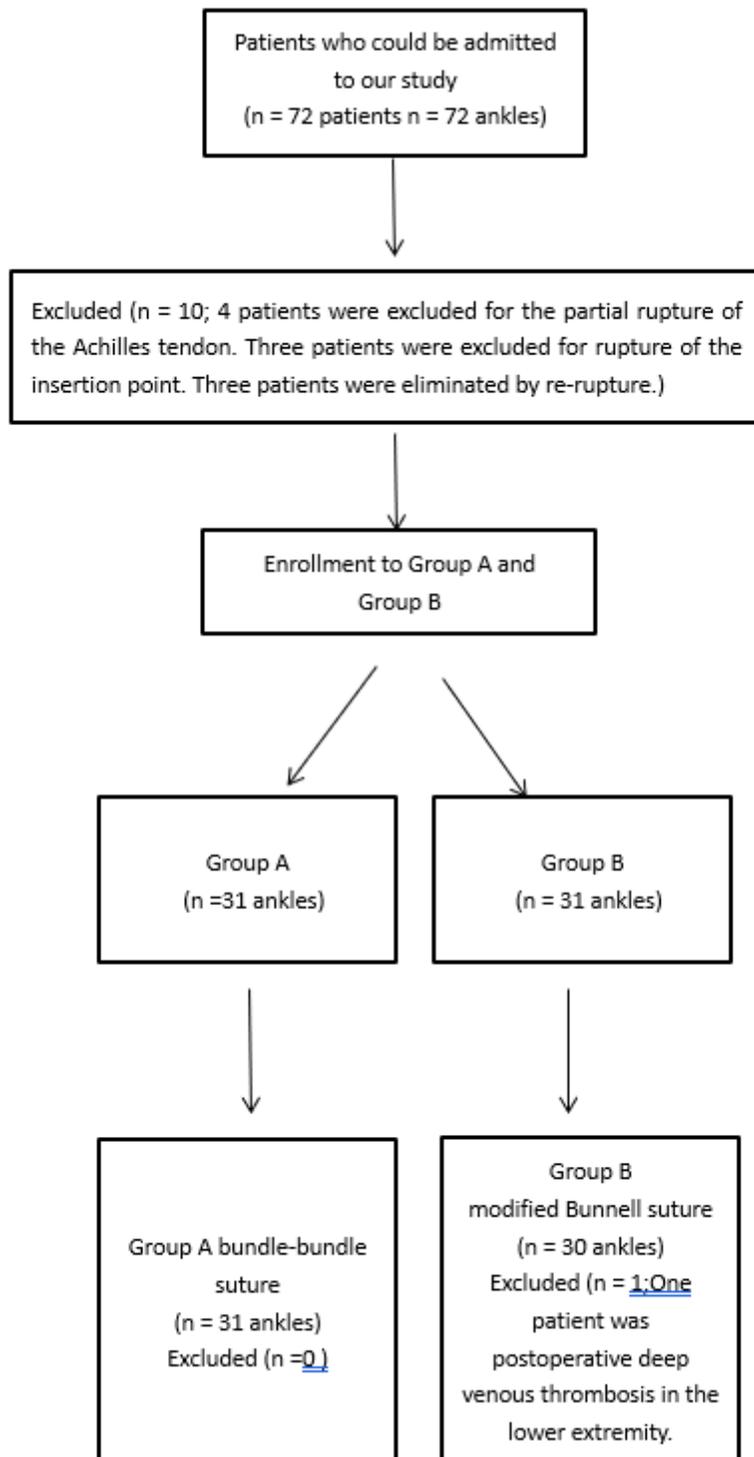
Table 3 Results of the postoperative score evaluation in both groups

	Group A	Group B
ATRS	90.67±2.67	91.10±2.50
AOFAS	95.40±3.65	95.38±3.44
VAS	0.36±0.49	0.32±0.48

“\*” : statistically significant difference between two groups ( $P>0.05$ ; Student’s t-test).

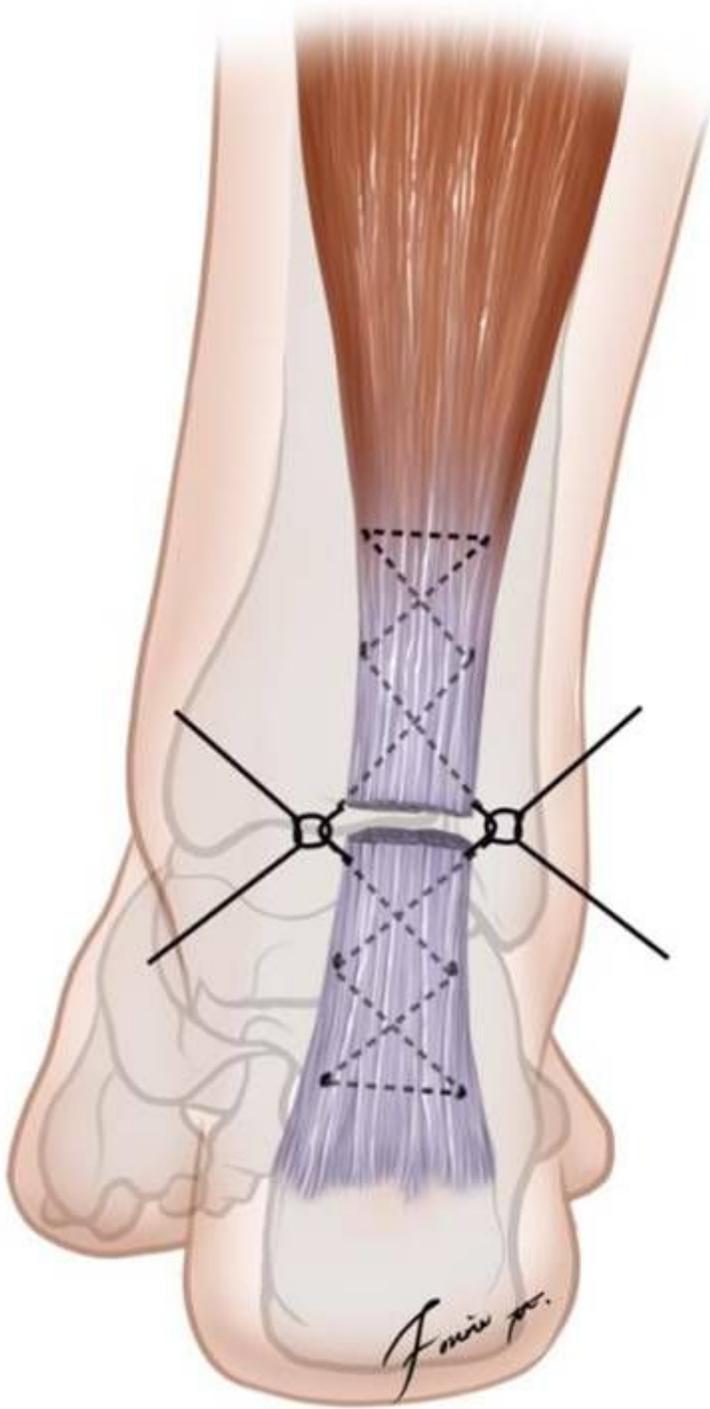
ATRS: Achilles Tendon Total Rupture Score; VISA-A: Victorian Institute of Sports Assessment-Achilles score; VAS: visual analogue scale score.

## Figures



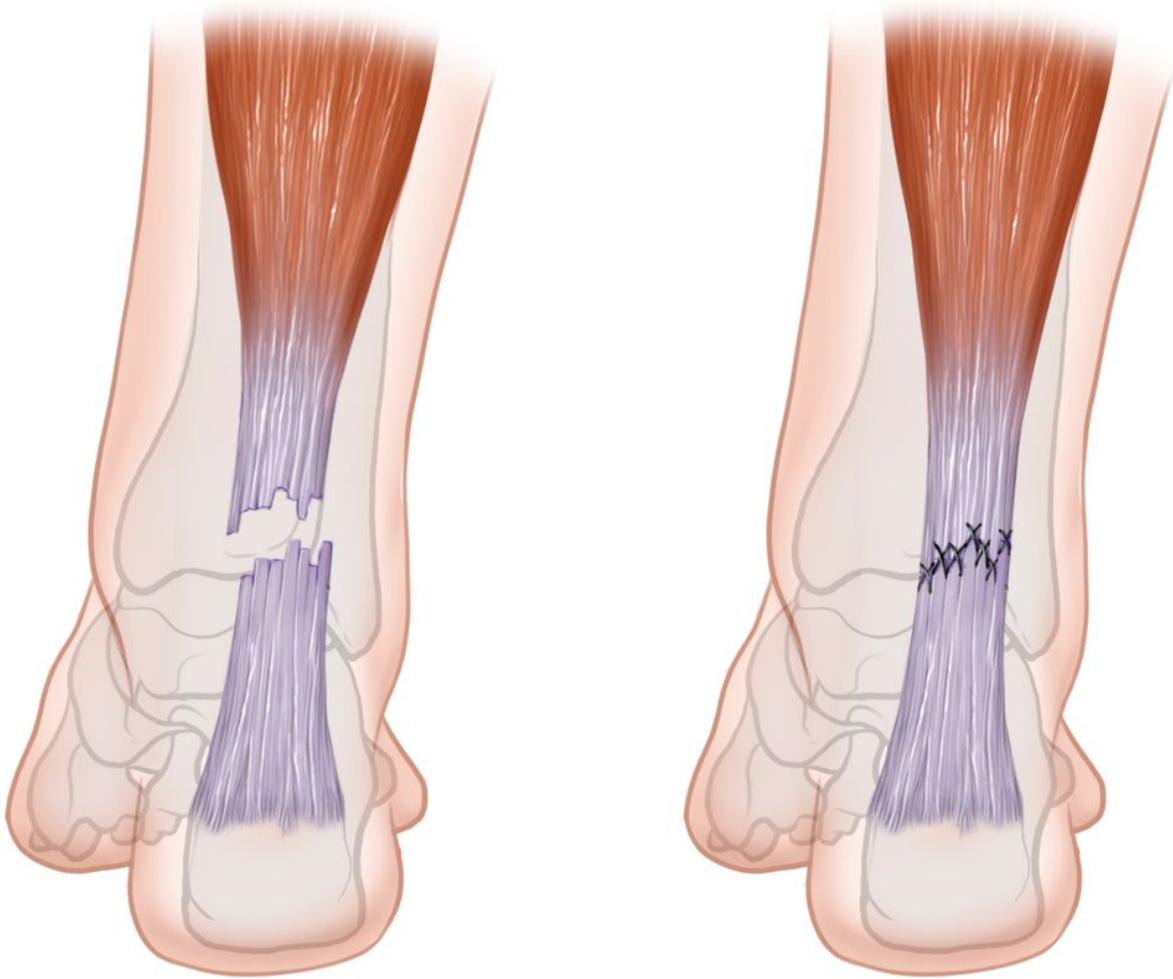
**Figure 1**

Patient flow chart



**Figure 2**

Diagrammatic drawing of the Achilles tendon sutured using open repair (bundle-to-bundle suture technique)



**Figure 3**

Diagrammatic drawing of the Achilles tendon sutured using percutaneous repair (modified Bunnell suture technique)