CLINICAL ARTICLE

A New Technique of Achilles Tendon Rupture Repaired by Double Transverse Mini-incision to Avoid Sural Nerve Injury: A Consecutive Retrospective Study

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Objective: Percutaneous suture is a classic technique used in Achilles tendon repair. However, the complication rates surrounding the sural nerve remain relatively high. Modified percutaneous repair technology can effectively avoid these complications; however, the surgical procedure is complicated. Hence, the present study was conducted to describe a redesigned repair technique for the Achilles tendon able to avoid sural nerve injury and reduce the complexity of the procedure.

Methods: Data of patients with acute primary Achilles tendon rupture at our hospital from January 2019 to May 2020 were included. Subjects with expectations for surgical scarring underwent a minimally invasive-combined percutaneous puncture technique. The surgical time, requirement for conversion to other technologies, and length of postoperative hospitalization were investigated to assess efficacy. The American Orthopedic Foot & Ankle Society (AOFAS) score and the Arner–Lindholm scale (A-L scale) were used to assess postoperative clinical outcomes (> 24 months). During the 2-year follow-up, MRI was performed to observe the healing of the Achilles tendon. In addition, subjective satisfaction with surgical scar healing was recorded.

Results: Twenty consecutive subjects with an average follow-up of 28.3 ± 4.5 months (range, 24–41) met the inclusion criteria. None of the 20 enrolled patients required a converted surgical approach. The mean surgical time was 26.9 ± 6.47 min (range, 20–44). None of the patients experienced dysesthesia or anesthesia around the sural nerve. No signs of postoperative infections were observed. MRI data showed that the wounds of the Achilles tendon healed completely in all the subjects. The AOFAS score increased from 55.6 ± 11.07 (range, 28–71) preoperatively to 97.8 ± 3.34 (range, 87–100) at the last follow-up. The A-L scale showed that 90% of the subjects ($n = 18$) presented as excellent and 10% of the subjects ($n = 2$) presented as good, with an excellent/good rate of 100%. Moreover, subjects' satisfaction for surgical scars was 9.1 ± 0.78 (upper limit, 10).

Conclusions: The results indicate that this technique can achieve good postoperative function, a small surgical incision, and high scar satisfaction. In addition, this technique should be widely used in suturing Achilles tendon ruptures.

Key words: Achilles tendon rupture; Minimally invasive suture; Percutaneous suture repair; Sural nerve injury

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Introduction

An acute Achilles tendon rupture is a common orthopedic injury that usually occurs during explosive movements of the calf muscles, such as when sprinting and jumping.[1–4] However, rupture can also occur because of unintentional missteps in low-level activities.[2,4] This type of injury occurs at a higher rate in men between 30 and 40 years of age. In a previous study, it was deduced that from 1953 to 2014, the mean age at which Achilles tendon rupture occurs had increased by at least 0.721 years every five years. The level of exercising activity in the older adult population also appears to be increasing.[2]

There are two views on treatments for ruptured Achilles tendons: surgical and non-surgical.[1,5] Both approaches are in line with international assessment guidelines,[6] but there is a higher risk of re-rupture with the non-surgical approach.[7,8] Surgical treatment can significantly improve the rate of postoperative resumption of sports activities and result in better ankle movement.[9] However, the risk of soft-tissue-related complications, such as infection and wound nonunion, increases after open treatment for Achilles tendon rupture.[8,10,11] The percutaneous repair technique can avoid these complications, but higher rates of sural nerve injury follow.[12,13] It is difficult for a surgeon to determine the tension of the sutured tendon because the ruptured tendon is not visible. The invention of assistive devices such as the Achillon device and the Dresden instrument makes percutaneous sutures more accurate[14–16]; however, the specificity of these devices has limited the widespread use of these techniques and did not avoid the risk of sural nerve injury.[17,18] Some modified procedures that do not rely on special equipment make sutures more reliable through additional incisions but still do not prevent sural nerve injury.[19] Therefore, a variety of surgical methods have been developed to avoid sural nerve injury based on percutaneous puncture techniques, but additional surgical incisions are required.[20,21] Considering various factors, we modified the existing technique: the location of the sural nerve was marked in advance, and the suture was performed using two mini-transverse invasive incisions that were consistent with the skin texture.

This study was a retrospective study describing the application of a modified minimally invasive suture for patients with fresh Achilles tendon rupture. The purpose of the study was: (i) to report the outcomes of a new minimally invasive suture technique for Achilles tendon to avoid sural nerve injury; (ii) to evaluate the efficacy and complications of this surgical method; and (iii) to provide a reference for the promotion of this technique.

Methods

Subject Population

All data was obtained from patients attending our hospital. This study was approved by the ethics committee of our hospital (approval number: 2021A-045, Supplemental File 1). All subjects provided written informed consent before surgery and data collection. Between January 2019 and May 2020, 22 patients with Achilles tendon rupture with expectation of scarring were treated for Achilles tendon rupture by an experienced surgeon.

Inclusion and Exclusion Criteria

The inclusion criteria were: (i) patients aged ≥18 years old; (ii) fresh Achilles tendon rupture (≤14 days); and (iii) the follow-up time was more than two years (>24 months). The exclusion criteria were: (i) treatment with steroid drugs; (ii) rupture at the musculotendinous junction; (iii) rupture at the calcaneal insertion; (iv) open rupture; and (v) re-rupture.

Surgical Technique

The patients underwent surgery under spinal anesthesia and in the prone position. A tourniquet was used, and the location of the tear was identified by palpation. Positive Thompson test results were used to confirm the diagnosis of Achilles tendon rupture. MRI confirmed the tear location (Fig. 1A). The distal incision was approximately 1.2–1.5 cm in length (between the medial and lateral border of the Achilles tendon). It was located approximately 1-2 cm above the lower edge of the defect (Fig. 1A,B) and was cut transversely along the skin texture. The fascia and tendon sheath were cut transversely, and the distal stump was combed with tissue forceps in the plantar flexion position. Non-absorbable sutures with controlled release needles (Ethibond* excel polyester suture, Ethicon LLC, Cincinatti, OH, USA) were used. The Bunnell technique was also used,[22] and this was done alongside the percutaneous puncture technique (Figs 2A and 3A). For any Achilles tendon stump that was too short to be sutured, it was necessary to pass the suture through the insertion site.

The proximal transverse incision was also about 1.2–1.5 cm, which was located at the upper edge of the Achilles tendon defect (Fig. 1B). To avoid injury to the sural nerve, it was ensured that the incision did not extend past the lateral border of the Achilles tendon (Fig. 1B). In any instance where the upper edge of the tendon defect was away from the calcaneal tubercle, the proximal incision needed to be more medial to avoid sural nerve injury (Fig. 2B,C). The subcutaneous tissue and tendon sheath were then incised. The proximal stump of the Achilles tendon was pulled out, combed with tissue forceps, and pulled out distally. Sutures were performed using the traditional Bunnell technique (Figs 2A and 3B), and the stump was reset.

The two free ends of the tendon were drawn from the distal incision. The ankle was positioned in full plantar flexion; the free ends of the tendon were tied with a double-throw knot, bringing the opposing ends of the tendon together and fixing three surgical knots (Fig. 3C). Then, the tails of the stumps outside the incision were reset, and the suture knot was buried in a deeper position. The paratenon and subcutaneous tissue were closed with absorbable triclosan-coated sutures (Coated Vicryl* plus antibacterial [polyglactin 910] synthetic absorbable suture, Ethicon,

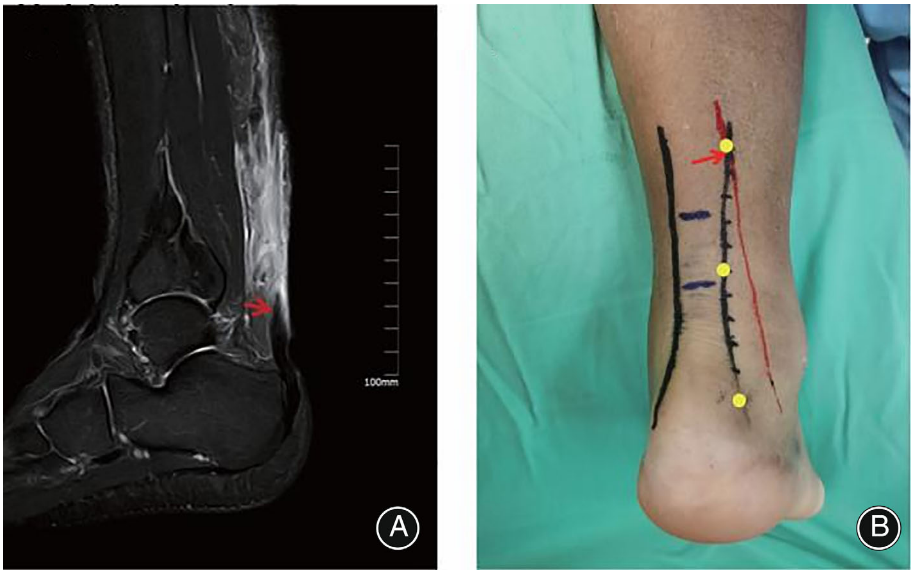

Fig. 1 Magnetic resonance image and preoperative incision location of a 27-year-old patient with Achilles tendon rupture. Sagittal T2-weighted magnetic resonance image of the ankle joint showing that the location of the Achilles tendon rupture was approximately 30 mm above the calcaneal tubercle (red arrow) (A). Preoperative skin marks show the location of the medial and lateral border of the Achilles tendon and sural nerve and mark the surgical incision (B). The black lines are the borders of the Achilles tendon, and the red line is the sural nerve. The blue lines represent the proximal and distal incisions (the distal incision was made 45 mm from the calcaneal tubercle). The distance above the calcaneal tubercle was marked on the lateral side of the Achilles tendon. The yellow dots represent 0, 50, and 100 mm, respectively. The red arrow is the cross point of the sural nerve and the lateral border of the Achilles tendon at a mean distance of 98 mm from the calcaneal tubercle

Cincinatti, OH, USA), and the skin incision with an internal suture. Finally, we applied sterile gauze dressing and plaster casting in front of the ankle joint below the knee, which was used to maintain the ankle at 20° (Fig. 3D).

Postoperative Rehabilitation

A cast was used to hold the foot at the 20° position to prevent forced ankle dorsiflexion. The subjects could still exercise their toes and knees, and isokinetic calf muscle contraction training was permitted. On the second day after surgery, the cast was replaced with a specially designed shoe (Zhong Zhan Kang Hao prosthetic orthopedic implement assembly center in Beijing, China) (Figs 4A,B). This allowed for adjustable ankle angles through a wedge of the heel and provided effective ankle fixation, so the subjects could perform full-load activities while using crutches. The foot was fixed at 20° for four weeks. By reducing the number of layers of the wedge (Fig. 4A), the fixed angle of the foot was reduced by approximately 5° per week until it was adjusted to a neutral position at 8 weeks. Then, the subjects could perform weight-bearing activities, and the use of crutches was discontinued. After 12 weeks, the shoe could be removed, proprioception and muscle strength training began to strengthen, heel-lifting training was allowed, and the subjects could gradually return to sports activities or heavy labor.

Follow-up and Evaluation

All subjects were followed up for no less than 24 months (>2 years). The operative time and the average postoperative hospital stay were recorded. Physical examination was conducted during follow-up, and the sural nerve sensation was used to judge whether there was an injury. The presence of complications, such as infection, re-rupture, and injury of the sural nerve, was recorded. The postoperative Thompson test[23] was conducted, and MRI (Philips Ingenia CX 3.0T, Eindhoven, the Netherlands) data was gathered during the 2-year follow-up. The ankle-hindfoot function was evaluated using the American Orthopedic Foot and Ankle Society (AOFAS) score.[24] At the last follow-up, AOFAS scoring was performed again, and the Arner–Lindholm score[25] was used to evaluate ankle function. Patients were asked to rate their satisfaction with the appearance of the scar on a scale of 1 to 10.

Statistical Analysis

All datasets were analyzed using SPSS statistics (version 25.0; SPSS; Chicago, IL, USA). Descriptive data are reported as mean $\pm$ standard deviation or range (minimum-maximum). The AOFAS scores in different periods were compared using paired sample t-tests, and the level of significance was set at $P = .05$.

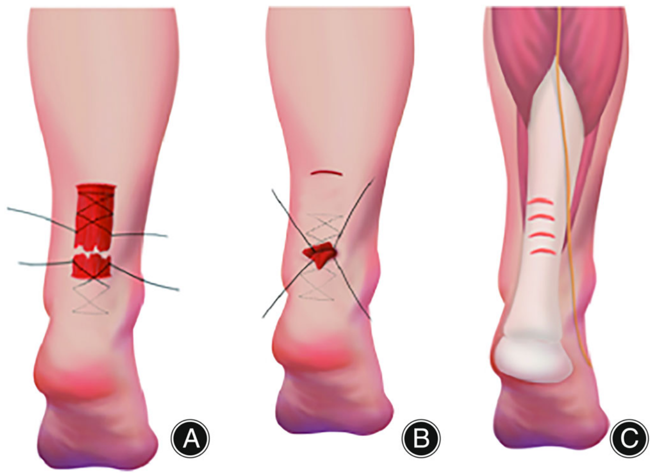

Fig. 2 Schematic diagrams of the Achilles tendon suture and surgical incision position change. Schematic diagram of the Achilles tendon suture (A). The Bunnell technique was used to suture the proximal Achilles tendon. The same method is used for the distal Achilles tendon but is performed by percutaneous puncture. The schematic diagram of the anastomosis of the Achilles tendon with the distal incision is shown in (B). The proximal stump of the Achilles tendon was sutured, restored, and knotted with the distal stump at the distal incision. The schematic diagram of the surgical incision location, Achilles tendon, and sural nerve location is shown in (C). The position of the transverse incisions was shifted to the medial side of the Achilles tendon as the distance from the calcaneus increased to avoid injury to the sural nerve.

Results

General Results

A total of 20 subjects were included in this study (19 males and one female) with a mean age of 35.65 ± 6.40 years (range, 23–52). Among them, 11 were injured in basketball, four in badminton, three in football, one in another recreational sport, and one in physical labor. Every patient underwent palpation of the tendon defect and had a positive Thompson test result.[23] The diagnosis was confirmed by MRI, and the location of the ruptures was within 4.53 ± 1.21 cm (range, 2.4–7.2) above the calcaneal tubercle. The surgical interventions were performed within 6.4 ± 2.6 days (range, 3–14) after the date of injury (Table 1). The procedure was successfully performed on all the subjects, and none required conversion to the surgical approach. The mean surgical time was 26.9 ± 6.47 min (range, 20–44 min), and the average postoperative hospital stay was 2.75 ± 0.85 days (range, 2–5 days) (Table 1). There were no procedure-related deaths and the patients were followed-up for 28.3 ± 4.5 months (range, 24–41 months) (Table 1).

Postoperative Recovery and Satisfaction with Surgical Scar Healing

All subjects underwent MRI at 12 months after the operation, which revealed that the Achilles tendon had completely healed (Fig. 5A). All subjects recovered their double heel rise and single-limb heel-rise functions (Figure 5B,C). Twelve subjects participated in low-impact sports, such as jogging and cycling, and eight participated in football, basketball, and other high-impact sports. Subjects' satisfaction with surgical scars was 9.1 ± 0.78 (range, 8–10) (Table 1).

Complications, American Orthopedic Foot and Ankle Society Scores and Arner–Lindholm Scale

None of the patients experienced dysesthesia or anesthesia around the sural nerve; the wounds healed within two weeks post-operation with no signs of infection, and no re-rupture of Achilles tendon occurred during follow-up. All patients paticipated in planned rehabilitation exercises. The AOFAS score increased significantly from 55.6 ± 11.07 (range, 28–71) preoperatively to 97.8 ± 3.34 (range, 87–100) at the last follow-up ($P < 0.05$) (Table 2). According to the Arner–Lindholm scale, 18 patients (90%) were rated as excellent and the remaining two patients (10%) as good (Table 2), with an excellent/good rate of 100%.

Discussion

Treatment of Achilles Tendon Rupture and Its Advantages and Disadvantages

No clear consensus exists on treating acute Achilles tendon rupture.[1,26] A meta-analysis[8] found that the rate of Achilles tendon re-rupture was significantly lower in the surgery group than in the non-surgery group (2.3% *vs* 3.9%), however, complications were significantly higher in the surgery group than in the non-surgery group (4.9% *vs* 1.6%). A multicenter, randomized, controlled study[27] found a 6.2% re-rupture rate in the non-surgical group, whereas that in the open surgery and minimally invasive surgery was 0.6%, respectively. However, the rate of nerve injury was 0.6%, 2.8% and 5.2% in the study. In addition, open surgery is associated with softer tissue complications. The wound-related complication rate after open surgery reportedly ranges from 8.2% to 34.1%, of which half were at least due to infections.[26]

Percutaneous repair significantly reduces interference with the surrounding tissue and avoids wound infection.[28] It is similar to open surgery regarding complication rates and time to return to work,[12] but may result in sural nerve injury.[12,13,29] A retrospective study[30] also found that the incidence of sural nerve injury during percutaneous puncture was as high as 13%. During the percutaneous suture technique, repair cannot be visually confirmed because of the soft tissue around the proximal Achilles tendon. Although devices such as the Dresden instrument[16] and Achillon device[14] have been developed to modify the percutaneous suture technique, these technologies are not widely used because they are not freely accessible. Keller *et al.*[31] reported a medium-term follow-up of the Dresden instrument for Achilles tendon sutures, and found that 2 of 100 patients had re-rupture, with no soft tissue or sural nerve

Fig. 3 Surgical photographs of the patient (from Fig. 1) with Achilles tendon rupture. In the plantar flexion position, the distal Achilles tendon tissue was pulled out using tissue forceps and sutured by percutaneous puncture (A). The proximal Achilles tendon tissue was pulled out from the proximal incision and sutured using the Bunnell technique (B). The proximal Achilles tendon tissue was pulled out from the distal incision, keeping full plantar flexion, and knotted with the distal stump of the tendon (C). Plaster casting was placed in front of the ankle joint and below the knee to maintain the ankle at approximately 20° (D)

complications, and the average AOFAS score was 97.7. Furthermore, in a prospective study[14] using Achillon devices for suturing, 82 patients were followed up for an average of 26 months with an average AOFAS score of 96. Morever, it was found that at least one suture penetrated the sural nerve in 5 of 18 specimens with standard sutures in a cadaveric study.[18] Endoscopy-assisted percutaneous repair and combined open and percutaneous repair technology have been invented to improve the accuracy of suturing.[32] However, surgery has become more complex and requires a learning curve, and infection and sural nerve injury complications cannot be avoided.[32] Therefore, we redesigned the percutaneous suture technique to become simpler and more reliable with two small transverse incisions that visually closed the proximal end of the Achilles tendon and prevented sural nerve injury. Notably, no reports of wound complications or sural nerve injury were recorded in all 20 patients.

The Sural Nerve Anatomy and Our Method to Avoid Sural Nerve Injury in Achilles Tendon Suture

The sural nerve is a sensory nerve that runs on the posterolateral aspect at the proximal end of the Achilles tendon, which extends downward and branches the sensation of the lateral ankle and foot. In a previous study, the nerve was found to cross the lateral border of the Achilles tendon at a mean distance of 9.8 cm from the Achilles tendon insertion into the calcaneum, and with a decrease in the distance from the calcaneum, it was farther away from the lateral border of

Fig. 4 A specially tailored shoe and wedge that is made of multi-layer sheets, which would be placed in the heel (A). A patient wearing the special shoe (B).

the Achilles tendon.[33] At the level of insertion of the Achilles tendon into the calcaneum, the sural nerve was 17.5 mm(3–40 mm) from the lateral border of the tendon.[33] Therefore, operating at the obtuse angle area formed by the sural nerve above the intersection and lateral border of the Achilles tendon is safe. Based on the adjacent relationship between the Achilles tendon and the sural nerve, in this study, we reduced the area of the obtuse triangle and made the operation safer. When the transverse incision was below the intersection level, the incision did not extend to the lateral edge of the Achilles tendon; and when the incision was near or above the intersection, it was shifted medially (Fig. 2C). To adapt to the difference in nerve intersections, we suggest that the deflection of the incision should start from a low position.

Whether the Suture of the Achilles Tendon Disrupts the Vascular Changes

Adequate blood supply is especially important for Achilles tendon repair. There are three main sources of blood supply to the Achilles tendon: longitudinal lines of blood supply from the muscle tendon junction, from the bone tendon junction, and from the exogenous segmental vascular system.[34,35] When an Achilles tendon rupture occurs, the proximal stump of the Achilles tendon will move proximally with the contraction of the posterior tibialis muscle, it can be inferred that the transverse vascular branches will be destroyed because the displacement compensation range is limited. The appearance of blood vessels during rabbit Achilles tendon repair is mainly concentrated in the periachilles tendon tissue,[36] so the peripheral tissue is very important for postoperative vascular reconstruction. We adopted the suture method of pulling out the proximal stump to avoid damage to the tissue near the tendon and to prevent the suture from interfering with the peritenon, which is conducive to the regeneration of blood vessels surrounding the Achilles tendon.

Location of the Incision

According to previous reports,[34,35,37] the middle part of then Achilles tendon (2–6 cm from insertion) is the watershed of blood supply, and the area with the lowest vascular density is

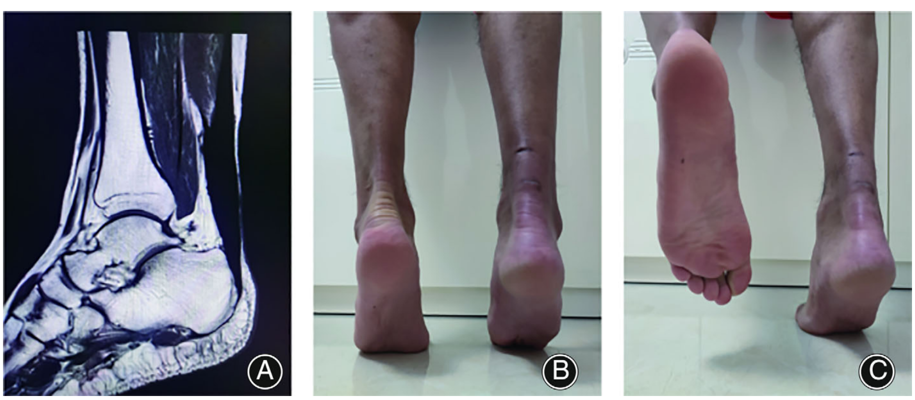

Fig. 5 One-year postoperative recovery in the patient (from Figs 1 and 3). Sagittal T1-weighted magnetic resonance image (A) shows that the signal intensity of the repaired tendon was the same as that of the intact tendon, and the anterior–posterior diameter of the sutured tendon was approximately 1.5 times the previous tendon (from Fig. 1A). The patient was able to stand on the tiptoes of both lower limbs (B) or injured lower limb (C).

TABLE 1 Characteristics of patient (n = 20)

Characteristics	
Age (years)	35.65 ± 6.40 (range, 23–52)
Sex	
Male/female	19/1
Side (cases)	
Left/Right	7/13
Cause of injury	
Basketball	11
Badminton	4
Football	3
Other recreational sports	1
Physical labor	1
Time from injury to surgery (days)	6.4 ± 2.60 (range, 3–14)
Gap after debridement (cm)	4.53 ± 1.21 (range, 2.4–7.2)
Follow-up period (months)	28.3 ± 4.52 (range, 24–41)
Surgical time (min)	26.9 ± 6.47 (range, 20–44)
Postoperative hospital stay (days)	2.75 ± 0.85 (range, 2 to 5)
Scar satisfaction (1–10)	9.1 ± 0.78 (range, 8 to 10)

the area with the worst blood supply. High stresses are experienced in the 2–5 cm range proximal to the tendon insertion because of the maximum fiber rotations in this area.[34] This implies an increased susceptibility to injuries in the free tendon[1,34] which indicates this surgical approach is appropriate for this type of Achilles tendon rupture but not for calcaneus insertion points or muscle junctions.

When an Achilles tendon rupture occurs, the proximal end of the tear retracts as the muscles contract,[38] whereas the distal end will not retract because it is fixed to the calcaneus. The proximal tendon can be pulled down, and the distal tendon can move upward as the ankle moves into plantar flexion; however, both are limited. If the distal incision position is too low, it is difficult to pull the proximal stump to the incision on the knot, while the distal stump will face the same difficulty if the distal incision position is too high. In two early cases, incisions were added to compensate for inexperience because the distal incisions were too low and were not included in the analysis. Therefore, the location of the distal incision is key to the operation and requires an accurate calculation. Preoperative MRI is important for determining the location of the distal transverse incision. We found that the distal transverse incision should be located 1.5–2 cm above the main part of the distal rupture (Figure 1A,B). In this area, the distal tendon can be compensated for by plantar flexion, while the proximal tendon can be anastomosed to the distal end by traction. To improve the accuracy of incision selection, we suggest that ultrasound should be used to locate Achilles tendon tears before surgery.

Strengths and Limitations

Our proposed technique can not only ensure that the suture area is visible, but it also avoids sural nerve injury. In addition, the technology is easy to perform, does not require special instruments, and has a short learning curve for surgical operations. As with the percutaneous puncture technique, this surgical technique is not suitable for Achilles tendon rupture at the calcaneal insertion point or muscle junction. In addition, the expansion of the transverse incision is limited, so it is not suitable for patients who require extensive surgery, such as chronic Achilles tendon rupture or for patients requiring sural nerve exploration. Due to the insufficient number of cases and the lack of longer follow-up observation, further clinical studies will continue to be carried out.

Conclusion

The double transverse incision technique is a new minimally invasive Achilles tendon suture technique, which can avoid the injury of sural nerve, is safe, convenient, and has good postoperative outcomes. Patients are highly satisfied with the incision, which can be widely promoted in clinical practice.

Acknowledgments

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TABLE 2 AOFAS hindfoot score and Arner-Lindholm scale

	Pre-operation	The last follow-up	Z/χ2 value	*P* value
AOFAS hindfoot score	55.6 ± 11.07	97.8 ± 3.34	−5.437	<0.001
Pain (40 points)	22 ± 8.94	39.5 ± 2.23		
Function (50 points)	23.6 ± 5.11	48.3 ± 2.20		
Alignment (10 points)	10	10		
Arner–Lindholm scale			47.505	<0.001
Excellent	0	18 (90%)		
Good	0	2 (10%)		
Poor	20 (100%)	0		

Abbreviations: AOFAS, American Orthopaedic Foot and Ankle Society: excellent, free from discomfort and essentially normal function; normal walking power, tip toe, calf muscle power; calf circumference <1 cm; Ankle ROM decrease <5°(PF/DF). good, mild discomfort; slightly decreased walking power, tip toe, calf muscle power; calf circumference <3 cm; ankle ROM decrease <15°(PF/DF). Poor, dissatisfied or marked discomfort; limp, inability to tip toe; calf circumference >3 cm; ankle ROM, DF decrease >10°or PF decrease >15°(PF/DF). PF, plantar flexion; DF, dorsiflexion.

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Author Contributions

Lihu Xu proposed the research idea, participated in research creation, searched the literature, conducted the clinical evaluation of patients, prepared the images, and drafted the manuscript. Jiaxin Jin, Jin Jiang, Zhongcheng Liu and Sylvia White participated in the first draft. Yayi Xia and Meng Wu significantly contributed to the formation of research methods. Peng Bo and Jinwen He performed the clinical evaluation of patients, prepared data for statistics, and participated in the interpretation of results. Guangyao Liu collected the MRI images.

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