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Review Article

Current treatment concepts for Achilles tendon rupture

Chen-Chie Wang[a,b], Pei-Yu Chen[c], Kai-Chiang Yang[d], Chung-Li Wang[c], Ing-Ho Chen[b,e]**

[a]Department of Orthopedic Surgery, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, New Taipei, Taiwan, [b]Department of Orthopedic, School of Medicine, Tzu Chi University, Hualien, Taiwan, [c]Department of Orthopedic Surgery, National Taiwan University Hospital and College of Medicine, National Taiwan University, Taipei, Taiwan, [d]School of Dental Technology, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan, [e]Department of Orthopedic Surgery, Hualien Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, Hualien, Taiwan

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Abstract

Achilles tendon rupture is a common and primary cause of lower limb tendon injury suffered during sports-related activities. The causes of Achilles tendon rupture include the calf muscle and tendon overuse, poor tendon quality, and various medical conditions. Historically, acute Achilles tendon rupture was treated conservatively. However, historical techniques are now associated with an increased risk of rerupture. To address this problem, open repair has been proposed. Open repair is associated with a reduced risk of rerupture; however, it is also closely associated with wound complications, like wound infection, whose treatment is time-consuming and costly. Therefore, minimally invasive Achilles tendon repair has been proposed as a promising option with acceptable functional outcomes. Nevertheless, despite its benefits, minimally invasive Achilles tendon repair is associated with increased risks of sural nerve injury and rerupture. In this review, we evaluate the currently used treatment strategies for acute Achilles tendon rupture and their historical evolution to provide evidence-based recommendations for physicians.

Keywords: *Achilles tendon rupture, Minimally invasive, Ultrasound*

Introduction

The Achilles tendon is the largest and most frequently injured tendon in the lower limbs. Achilles tendon injuries typically result from repeated microtraumatic events, such as overtraining or training errors, rather than acute traumatic events. Other causes of Achilles tendon injuries include chronic inflammation, degeneration, and chronic diseases like diabetes mellitus. Furthermore, the vascularity of this portion is paucity, and the tissue regenerative potential is limited when a tendon is injured. In 1693, Philip Verheyen became the first individual to describe the Achilles tendon in his anatomy book *Corporis Humani Anatomia*, in which he called it "tendo Achilles," replacing the term "tendo magnus" originally used by Hippocrates [1]. However, the delineation of Achilles tendon rupture can be traced back to the 16th century and the work of Ambroise Paré, who provided a clear delineation of the symptoms, signs, and prognosis of Achilles tendon rupture despite not specifically using the term "Achilles tendon" [2]. Later, various bandaging techniques with favorable outcomes, like Monro's bandage, were proposed [1,3]. In 1929, Qenu published a comparative study demonstrating excellent results with both open repair and conservative treatment for Achilles tendon rupture, although the authors reported a preference for open repair [4]. Notably, the debate over surgical versus nonsurgical intervention for Achilles tendon rupture remains alive today, indicating ongoing controversy in the field.

Achilles tendon anatomy

The Achilles tendon is the largest tendon in the human body, connecting the calf muscles, including the gastrocnemius and soleus muscles, to the calcaneal tuberosity. It has an approximate length of 15 cm and an approximate width of 6 mm, and it extends from a proximal wide fan-like shape and distal cord-like shape. During the development of tendon tissue at the musculotendinous junction, the gastrocnemius–soleus

**Address for correspondence:* Prof. Chung-Li Wang, Department of Orthopedic Surgery, National Taiwan University Hospital, 7, Chung Shan South Road, Taipei, Taiwan. E-mail: chungli@ntu.edu.tw
Prof. Ing-Ho Chen, Department of Orthopedics Surgery, Hualien Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, 707, Section 3, Chung-Yang Road, Hualien, Taiwan. E-mail: ing.ho@msa.hinet.net

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complex undergoes a rotation of almost 90° before insertion into the calcaneal tuberosity. Hence, the lateral aspect of the Achilles tendon originates from the gastrocnemius muscle, whereas the medial aspect originates from the soleus muscle. As a result of this torsion process, the posterior heel region in the foot and ankle is relatively hypovascular.

The Achilles tendon is primarily composed of strong parallel collagen fibers that are arranged in bundles along the tendon's longitudinal axis. Surrounding the tendon is a layer of the paratenon, which provides a lubricated environment for smooth tendon movement. The Achilles tendon receives its primary blood supply from the paratenon through small-caliber blood vessels. A small portion of vascularity originates from the calf muscle at the proximal end and the calcaneal tuberosity at the distal end. From a broader perspective, the vasculature of the Achilles tendon, positioned 2–6 cm proximal to the calcaneal bone, is predominantly supplied by the peroneal artery laterally, and other parts of the Achilles tendon are from the posterior tibial artery medially. The diameter of the peroneal artery is smaller than that of the posterior tibial artery, indicating that this region serves as a watershed zone for vascularity and is also the area most susceptible to Achilles tendon injuries. Injuries to the Achilles tendon are frequently observed, especially among athletes who engage in sports that involve running and jumping. Such injuries vary in severity, ranging from minor strains to complete tears, which may necessitate surgical intervention for proper repair.

Acute achilles tendon rupture

Etiology

Acute Achilles tendon rupture refers to the sudden tearing of the Achilles tendon, often accompanied by a popping sensation and painful swelling. Patients commonly describe this sensation as akin to being kicked or struck by a stone. The etiology or underlying causes of acute Achilles tendon rupture includes calf muscle and tendon overuse, tendon degeneration, local steroid injection, fluoroquinolone antibiotic administration, diabetes mellitus, hypercholesterolemia, obesity, and rheumatoid arthritis. Muscle and tendon overuse with repeated microtrauma results in tendon weakness and is one of the major causes of Achilles tendon rupture. Therefore, stretching exercises are recommended before sports activities, especially for individuals with Achilles tendinitis. A sudden increase in physical activity, like intense running or jumping, can also exert excessive stress on the Achilles tendon and thus increase the likelihood of its rupture. In addition, age-related changes in tendon texture, characterized by decreased elasticity, may cause the tendon to become more susceptible to injury. In individuals with diabetes mellitus, poorly controlled blood sugar levels are regarded as a risk factor for tendon damage. When the sugar levels increase in the bloodstream, the levels of advanced glycation end products (AGEs) also increase [5,6]. Under typical conditions, the human body produces AGEs in a controlled manner. In terms of tendon metabolism, the synthesis and turnover of collagen and the accumulation of AGEs represent a balanced environment during activities of daily living [7]. However, sudden hyperglycemia disrupts this homeostasis by increasing the levels of AGEs. When AGEs accumulate in the Achilles tendon, they cross-link with the extracellular matrix and destroy the collagen triple-helix structure [8]. This morphological alteration of collagen affects the biomechanical properties of the tendon, thereby increasing its stiffness, decreasing its elasticity, and making it more susceptible to injury even under minor impact forces. In addition, the accumulation of AGEs in the Achilles tendon impairs the tendon's sliding function [9,10]. Overweight or obesity is a detrimental risk factor for Achilles tendinopathy [11]. The underlying mechanism involves a decrease in blood supply to the tendon tissue due to reduced yield of nitric oxide by endothelial cells in the blood vessels, resulting in impaired microcirculation [12]. This reduced local circulation in the Achilles tendon increases the risk of inadequate tendon remodeling [13-15]. Therefore, obesity not only increases the mechanical load on the Achilles tendon but also hampers the tendon's microcirculation. These factors increase the risk of Achilles tendinopathy and tendon rupture.

Physical examination

Evaluating Achilles tendon ruptures requires careful history taking, physical examinations, and imaging studies to confirm the diagnosis. Physical examinations involve several steps, including determining a palpable gap, conducting the Thompson test, evaluating single-leg hopping, and assessing the ankle's range of motion. In most cases, the tendon gap can easily be palpated once leg swelling has subsided, typically 5–7 days after injury. The Thompson test is a highly sensitive test for Achilles tendon rupture. It involves the physician squeezing the calf muscle with the patient in a prone position and observing the movement of the ankle. A lack of ankle plantar flexion is regarded as a positive Thompson test result, indicating an Achilles tendon rupture. However, a negative test result does not necessarily indicate a healthy tendon. In cases of partial rupture, the ankle joint may still exhibit plantar flexion movement during calf muscle squeezing. Therefore, when an Achilles tendon injury is suspected, further evaluation through imaging studies, such as ultrasonography or magnetic resonance imaging (MRI), is recommended. Difficulty of single-leg hopping is another major indicator of Achilles tendon functionality.

Imaging

Imaging studies play a crucial role in confirming a diagnosis of Achilles tendon rupture and evaluating the extent of the injury. Ultrasound and MRI are the most commonly used imaging modalities for this purpose. In cases of Achilles tendon injuries near the calcaneal tuberosity, roentgenography is performed to detect any associated avulsed bony fracture or insertional calcified tendinopathy. Ultrasound is frequently employed in outpatient clinics due to its convenience and ability to provide high-resolution images of soft tissues. It is particularly useful in distinguishing between partial and complete ruptures [Figure 1]. Ultrasonography enables the precise localization of tendon damage, evaluation of injury extent, and visualization of tendon calcification. MRI is a comprehensive imaging modality for soft-tissue injuries.

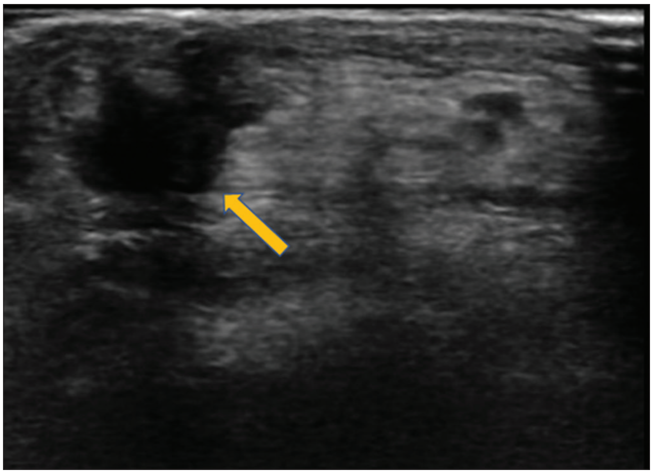

Figure 1: Ultrasonographic visualization of Achilles tendon rupture in the longitudinal view (arrow)

It plays a crucial role in confirming a diagnosis of Achilles tendon rupture, provides information regarding the severity of the injury, and indicates the extent of damage to the surrounding tissues. Notably, the choice of imaging modality depends on factors such as the severity of the injury, the patient's medical history, the availability of the imaging modality, and the preference of the treating physician. In some cases, a combination of imaging modalities may be indicated to confirm the diagnosis and determine the optimal treatment approach.

Management

Conservative treatment

Conservative treatment is a viable option for some patients with Achilles tendon rupture who are not suitable candidates for surgery. These patients include those with a partial rupture and those with underlying medical conditions that increase the risk of complications. Conservative treatment involves a combination of immobilization, rest, and physical therapy.

The first step in conservative treatment involves immobilizing the affected leg with a cast or walking boot in a plantar-flexed position. Serial casting is then performed 3–4 weeks later to achieve a plantigrade foot position. This approach protects the tendon and promotes its healing. The duration of immobilization varies depending on the severity of the injury, typically spanning 2–3 months.

During the 1st month of treatment, patients are advised to refrain from weight-bearing activities. To enhance their mobility during this period, they are advised to use crutches or a walker. After the initial period of immobilization, patients can begin physical therapy to restore their strength, flexibility, and range of motion in the affected leg. Physical therapy involves exercises such as calf muscle stretches, ankle range-of-motion exercises, strengthening exercises for calf muscles, and proprioception training. Supportive devices such as heel lifts or braces can also be used to provide support to the affected leg and reduce the risk of repeated injury after the initial immobilization period. In general, the success rate of conservative treatment for Achilles tendon rupture is lower than that of surgical treatment, particularly for athletes or individuals with high activity levels. However, recent prospective randomized studies have revealed comparable outcomes between conservative treatment and surgical repair [16,17]. Although the rate of rerupture for conservative treatment still exceeds that of surgical treatment, these findings suggest that conservative treatment remains a viable option, particularly when surgical complications and the patient's health are a concern.

Surgery

Surgery is a viable treatment option for individuals with acute Achilles tendon rupture, particularly those who are young and have an active lifestyle. The primary goal of surgery is to repair the torn tendon and restore its function and strength. The surgical approach can be either traditional open repair or minimally invasive repair, depending on the surgeon's preference and the severity of the injury.

Postoperative care plays a critical role in achieving favorable functional outcomes. After surgery, the patient typically wears a cast or brace for a specified duration to protect the repaired tendon and promote its healing. The specific immobilization period and type of device used depend on the chosen repair method and the surgeon's preference.

Physical therapy and rehabilitation exercises are gradually introduced, starting from a few weeks after surgery, to restore the strength and flexibility of the tendon. Surgery for acute Achilles tendon rupture is typically associated with a high success rate, with most patients being able to return to their normal activities within 6–12 months after surgery. However, as with any surgical procedure, Achilles tendon surgery carries the potential for risks and complications – including infection, nerve damage, and localized hematoma – which should be discussed with the patient before they make any decision regarding surgery.

Traditional open repair

Before the 1920s, conservative treatment was the primary choice for Achilles tendon rupture. However, concerns regarding high rerupture rates associated with conservative treatment have since resulted in a shift toward surgical repair. Reports written by Abrahamsen in 1923 and by Qenu in 1929 have contributed to the growing acceptance of operative repair [4,18]. In 1959, Arner and Lindholm presented positive results of surgical repair, further establishing it as a viable treatment option for Achilles tendon rupture [19]. In 1993, Cetti *et al*. conducted a prospective level I study including 111 patients with acute Achilles tendon rupture and treated with open repair. The researchers discovered a lower rate of rerupture in the operative group (4%) than in the nonoperative group (13%), as well as a higher rate of return to previous sports or activities in the operative group than in the nonoperative group (58% vs. 29%, respectively) [20]. However, two patients in that study's open repair group experienced deep wound infections, and one of them later experienced Achilles tendon rerupture. However, despite those complications, that study played a major role in establishing open repair as the standard management for Achilles tendon rupture.

Achilles tendon repair is typically recommended for young or active individuals. During an open repair procedure, a skin incision measuring 6–10 cm is usually made slightly medial to the Achilles tendon to minimize the risk of sural nerve injury. Various tendon repair techniques can then be used, such as the modified Kessler technique, the Bunnell technique, or the Krackow suture technique. Compared with the modified Kessler and Bunnell techniques, the Krackow technique provides higher mechanical strength [21], although no clear clinical superiority has yet been established. In cases where the quality of tendon approximation is uncertain, fascia turndown augmentation can be performed. This technique involves creating two long fascial flaps from the gastrocnemius aponeurosis, which are then turned down (180°) and secured over the sutured stump ends of the tendon for additional reinforcement [22]. Another option is plantaris tendon augmentation; however, this technique is associated with limited tissue availability due to the small diameter of the plantaris tendon [23]. Autografts from the peroneus brevis and flexor hallucis longus have also been proposed for Achilles tendon augmentation in cases of insufficient or poorly textured remnant tissue over the ruptured end [24-26]. These techniques can be used in cases of chronic Achilles tendon rupture with a tendon gap of 2–5 cm; in such cases, the tendon is freed from the insertional site and passed through a bone tunnel in the calcaneal tuberosity. This method is performed using the Pulvertaft tendon weaving, which provides superior mechanical strength for tendon augmentation [27]. Some studies have explored the use of synthetic materials, like polyethylene terephthalate mesh synthetic grafts [28], for Achilles tendon rupture repair; however, although initial reports have revealed promising results in athletes, concerns regarding wound complications, tendon healing problems, infection, and subsequent graft rupture have limited the utilization of synthetic grafts [29]. In the future, biocompatible synthetic tendon grafts that facilitate cell ingrowth may offer a more viable option.

Wound complications are a major concern in acute Achilles tendon repair. Such complications include wound dehiscence, infection, sural nerve injury, and limitations in the ankle's range of motion. In a quantitative study, Wong *et al*. reviewed several surgical and conservative management strategies for Achilles tendon rupture [30]. The researchers analyzed 125 articles encompassing 5370 patients, including 4001 who underwent open repair and 645 who underwent nonoperative treatment. They reported that the nonoperative group had the lowest rate of wound complications (0.5%), whereas the open repair group with long-term immobilization had the highest rate of wound complications (14.6%). They also reported that the open repair and early mobilization group had a lower rate of wound complications (6.7%) compared with their counterparts. Wilkins and Bisson conducted a quantitative systematic review of randomized controlled trials to compare operative and nonoperative treatment for acute Achilles tendon rupture [31]. They analyzed seven level I studies comprising 677 patients who met the inclusion criteria. They reported that the deep wound infection rate was 2.36% in the surgical group. However, they discovered no infections in the nonsurgical group. They also reported that 13.1% of the patients who underwent surgery reported scar discomfort without cosmetic problems. In a meta-analysis, Soroceanu *et al*. discovered a correlation between surgery and absolute increased risk of 15.8% compared with nonoperative management (P = 0.016) for complications including superficial or deep infection, deep vein thrombosis, and sural nerve injury but not for rerupture [32]. In summary, mitigating the risk of complications associated with open surgery, particularly wound infection, is crucial and strongly correlates with the surgical outcome.

Minimally invasive surgery

Minimally invasive surgery (MIS) is an alternative approach to traditional open surgery for Achilles tendon repair. The primary objective of MIS is to minimize the incision size, reduce surgical trauma, and shorten the recovery duration. The indications for MIS of Achilles tendon repair include acute Achilles tendon rupture within 3 weeks, concerns regarding surgical-related infection, and wound complications. Various minimally invasive techniques are available for Achilles tendon repair.

In 1977, Ma and Griffith proposed a percutaneous technique for Achilles tendon repair [33]. However, this technique failed to provide direct visualization of the ruptured end or to evaluate the quality of tendon repair. The technique was also associated with a high rerupture rate (8%) and a high sural nerve injury rate (13%) [34]. In general, this technique involves the creation of six separate medial and lateral paratendinous stab incisions to facilitate needle piercing of the proximal and distal tendon stump. However, it does not indicate the quality of stump approximation during tendon repair, resulting in a lack of exposure at the ruptured end and thus increasing the risk of rerupture. Webb and Bannister proposed a percutaneous technique involving three separate skin incisions [35]. This technique involves placing sutures in the midline portion of the tendon rather than on the bilateral aspect, which is close to the sural nerve, to mitigate the risk of iatrogenic nerve injury. The authors reported no sural nerve injury or rerupture. Carmont and Maffulli proposed a modified technique derived from the technique of McClelland and Maffulli [36,37]. In this technique, a large curvature needle is used to traverse through paratendinous stab incisions in a Bunnell fashion. However, unlike in Ma's technique, a central skin incision is made at the tendon rupture site to expose the ruptured end. Overall, the authors reported no sural nerve injury. Assal *et al*. used an Achillon system to perform minimally invasive Achilles tendon repair [38]. They reported no wound dehiscence, wound infection, or sensory dysfunction in the sural nerve distribution area. However, their technique has some drawbacks. For example, the suture traversing the tendon is assisted by a surgical kit, which does not guarantee its placement at the middle of the tendon in the transverse view, potentially compromising mechanical strength or leading to suture dislodgement during knot tying. Another drawback is that the Achillon jig is excessively prominent, posing a risk of paratenon injury. The paratenon is an outer membranous structure that plays a crucial role in supplying blood to the Achilles tendon. Preserving the paratenon during surgery is of paramount importance for tendon healing and gliding [15]. Aktas and Kocaoglu conducted a comparative study regarding minimally invasive and open repair with an Achillon system. They reported that neither group experienced rerupture or sural nerve injury. They also reported that the open repair group had a deep and superficial infection rate of 20%, whereas the Achillon repair group experienced no wound infection or adhesion [39]. Khan *et al*. conducted a meta-analysis of surgical interventions for Achilles tendon repair [40]. They reported that their percutaneous repair group had a lower complication rate than did their open repair group, with a relative risk of 2.84. They also reported that the open repair group had a higher infection rate (with a relative risk of 4.89), with disturbances in skin sensibility and adhesion. In recent years, novel percutaneous Achilles repair system (PARS) techniques with Kessler-type suture configuration have been introduced. Hsu *et al*. conducted a retrospective study involving 101 patients who were treated using a PARS technique and 169 patients who underwent open repair [41]. They reported no substantial differences in postoperative complications between the two groups. However, they also reported that compared with the non-PARS group, the PARS group was better able to resume their baseline physical activity at 5 months postsurgery.

Recently, endoscopic repair has been introduced for the treatment of Achilles tendon rupture. Chiu *et al*. proposed a technique that involves eight stab incisions medial and lateral to the Achilles tendon [42]. They used a 4-mm arthroscope for suturing with a modified Bunnell configuration. They reported that all 19 patients were able to return to their baseline physical activity levels. However, one patient experienced a superficial infection, and two patients experienced transient numbness over the sural nerve for approximately 1 month. Rungprai and Phisitkul reported that endoscopy-assisted percutaneous Achilles tendon repair is a safe and feasible method that enables a relatively early return to previous activities and satisfactory functional outcomes [43]. They reported that only one of their patients developed a superficial infection (4.3%), with no cases of sural nerve injury or deep-vein thrombosis. Lui emphasized that endoscopy is primarily helpful in the visualization of suture passage through the proximal lateral portal to prevent injury to the sural nerve [44]. However, endoscopy plays no role in tendon repair with percutaneous locking sutures, which aim to reduce the risk of sural nerve injury.

Ultrasound-guided repair is a technique that involves the use of real-time ultrasound imaging to guide the precise placement of sutures and anchors for tendon repair. During the repair process, the surgeon makes a small incision and uses an ultrasound probe to visualize the tendon. Our research group has published several articles on this technique to demonstrate its effectiveness for not only Achilles tendon repair but also Achilles sleeve avulsion and Achilles insertional tendinopathy with retrocalcaneal bursitis [45-47]. For instance, our first publication in 2012 focused on acute Achilles tendon rupture and included 23 patients. Among those patients, only one experienced transient numbness in the lateral foot, which resolved within 2 months. No instances of rerupture, wound infection, or deep-vein thrombosis were observed. To date, this type of surgery has been performed on more than 250 patients, with only one patient experiencing a rerupture due to a slip in the bathroom 1 month postsurgery and requiring subsequent treatment with open repair. Three patients developed superficial wound infections, which resolved after they were prescribed antibiotics. No cases of deep wound infection or deep-vein thrombosis were observed during the follow-up period. However, transient sural nerve neuropathy was observed in 3 (1.2%) patients, which was a low rate compared with other minimally invasive techniques described in the literature [48].

In our procedure, we used a Kessler-type suture configuration with 4–6 core sutures [Figure 2]. We achieved tendon repair through a small incision measuring 0.8–1 cm [Figure 3]. One advantage of ultrasound guidance is that it enables sutures to be accurately placed in the midportion of the Achilles tendon in the transverse view. This technique enables a greater length of suture to be secured within the tendon, resulting in a stronger hold on the tendon stump compared with sutures located in the peripheral region of the Achilles tendon. Another advantage of ultrasound imaging is that it enables the visualization of the tendon's sliding motion and the evaluation of its repair quality. The most powerful advantage of ultrasound imaging is that ultrasonography facilitates the clear depiction of the sural nerve. During percutaneous needle traversal of the tendon, ultrasonography enables the identification of the position of the sural nerve and needle, which aids in the prevention of sural nerve injury. Ultrasonography also allows the hooking device to be positioned beneath the paratenon, thereby further reducing the likelihood of nerve injury during instrument advancement.

In summary, MIS for Achilles tendon repair offers several advantages compared with traditional open surgery [49-51]. These advantages include less postoperative pain, faster recovery times, shorter hospital stays, and lower risk of wound complications [Table 1]. However, not all patients are suitable candidates for MIS. The choice of surgical technique should be based on factors such as the patient's individual condition, the severity of the injury, and the surgeon's expertise.

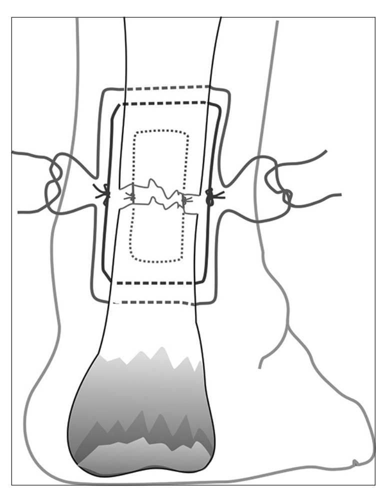

Figure 2: Kessler-type configuration used in minimally invasive Achilles tendon repair guided by ultrasound

Table 1: Complication and recovery performance in different treatment options

	Conservative treatment	Open repair	Traditional minimally invasive repair	Surgical jig-assisted minimally invasive repair	Ultrasound-guided minimally invasive repair
Rerupture	++	+	+	+	+
Stiffness of the ankle	++	++	+	+	+
Paresis of the sural nerve	−	+	++	++	+
Superficial infection	−	++	+	+	+
Deep infection	−	++	+	+	−
Surgical time	−	Long	Short	Short	Short
Time of resume to previous activity	Fair	Fair	Fast	Fast	Fast

Surgical time: Long (>40 min), short (<30 min). Time of resume to previous activity: Fair (>5 months), fast (<5 months). Traditional minimally invasive repair: Achilles tendon repair without surgical jig assisted such as the Ma and Griffith method. [33]
−: Not observed, +: Rare observed, ++: Sometimes observed

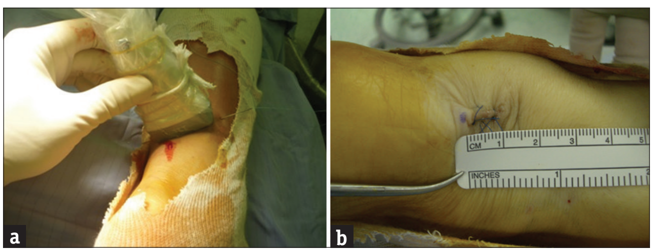

Figure 3: (a) Ultrasound-guided needle positioning for accurate traversal of a suture into the middle portion of the Achilles tendon. (b) Tendon repair achieved through an incision measuring 0.8–1 cm

Conclusion

The choice of treatment scheme for acute Achilles tendon rupture is still a subject of controversy. Recently, conservative treatment has gained renewed attention due to its ability to achieve optimal functional outcomes. However, conservative treatment is associated with an increased risk of rerupture, particularly among active individuals. Open repair offers improved visualization of tendon repair quality but is often accompanied by surgical complications. MIS for Achilles tendon repair has the potential to address these drawbacks associated with open repair and conservative treatment, especially the risk of rerupture and wound complication. However, the possible of nerve injury during needle traversing the Achilles tendon or surgical jig introducing was the concern of traditional MIS and surgical device assisted MIS Achilles tendon repair. Ultrasound-guided MIS method can provide that solutions are found to minimize the risks of subsequent sural nerve injury and wound complication simultaneously.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Nil.

Conflicts of interest

Dr. Chen-Chie Wang and Ing-Ho Chen, the editorial board members at *Tzu Chi Medical Journal*, had no roles in the peer-review process of or decision to publish this article. The other authors declared no conflicts of interest in writing this article.

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