BJR

FOOT & ANKLE

Management of acute Achilles tendon ruptures

A REVIEW

X. Yang,
H. Meng,
Q. Quan,
J. Peng,
S. Lu,
A. Wang

Chinese PLA General Hospital, Beijing, China

Objectives

The incidence of acute Achilles tendon rupture appears to be increasing. The aim of this study was to summarize various therapies for acute Achilles tendon rupture and discuss their relative merits.

Methods

A PubMed search about the management of acute Achilles tendon rupture was performed. The search was open for original manuscripts and review papers limited to publication from January 2006 to July 2017. A total of 489 papers were identified initially and finally 323 articles were suitable for this review.

Results

The treatments of acute Achilles tendon rupture include operative and nonoperative treatments. Operative treatments mainly consist of open repair, percutaneous repair, mini-open repair, and augmentative repair. Traditional open repair has lower re-rupture rates with higher risks of complications. Percutaneous repair and mini-open repair show similar re-rupture rates but lower overall complication rates when compared with open repair. Percutaneous repair requires vigilance against nerve damage. Functional rehabilitation combining protected weight-bearing and early controlled motion can effectively reduce re-rupture rates with satisfactory outcomes. Biological adjuncts help accelerating tendon healing by adhering rupture ends or releasing highly complex pools of signalling factors.

Conclusion

The optimum treatment for complete rupture remains controversial. Both mini-open repair and functional protocols are attractive alternatives, while biotherapy is a potential future development.

Cite this article: *Bone Joint Res* 2018;7:561–569.

Keywords: Functional rehabilitation, Acute Achilles tendon rupture, Nonoperative management

■ X. Yang, MD, Resident Doctor,
■ H. Meng, PhD, Technician,
■ Q. Quan, MD, Resident Doctor,
■ J. Peng, MD, Associate Professor,
■ S. Lu, MD, PhD, Academician of Chinese Academy of Engineering,
■ A. Wang, PhD, Associate Professor, Department of Orthopedic Surgery, Key Laboratory of Musculoskeletal Trauma & War Injuries PLA, Beijing Key Lab of Regenerative Medicine in Orthopedics, Chinese PLA General Hospital, Beijing, China.

Correspondence should be sent to A. Wang; email: aiyuanwang301@126.com

doi: 10.1302/2046-3758.710.BJR-2018-0004.R2

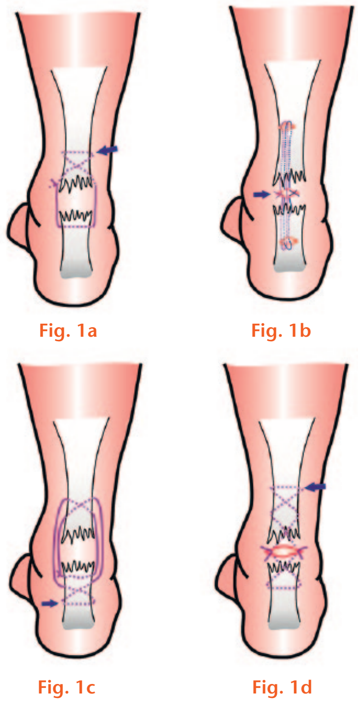
Bone Joint Res 2018;7:561–569.

The Achilles tendon is the strongest tendon in the human body and transmits forces from the gastrocnemius and soleus muscles to the calcaneus, enabling walking, jumping, and running. However, the incidence of Achilles tendon rupture has increased over recent years.[1,2] Although most Achilles tendon ruptures occur during sporting activities,[3] other factors such as gender,[4] drugs,[5,6] intrinsic structural variations,[7] and biomechanical changes related to ageing[2] may all contribute. The process of tendon healing occurs in three distinct phases: inflammation, proliferation, and remodelling.[8] The primary goals of the management of acute Achilles tendon ruptures are to ensure a rapid return to full function and to prevent complications.

The treatment of acute Achilles tendon ruptures can be broadly classified into operative and nonoperative. Clinical assessment involves using objective rating scales[9] and also a patient-reported instrument, the Achilles Tendon Total Rupture Score (ATRS).[10]

Surgical management

The surgical treatment of ruptured Achilles tendon encompasses two distinct elements namely the actual surgical technique and the postoperative regime. The surgical management of a ruptured Achilles can be divided into four categories: open repair, percutaneous repair, mini-open repair, and augmentative repair. In general, operative intervention is usually preferred for younger



Schematic diagram of several minimally invasive suture methods: a) Ma–Griffith repair configuration; b) Webb–Bannister repair configuration; c) Cretnik's repair configuration; and d) Carmont's repair configuration.

patients and those patients who demand greater function.[11,12]

Open repair. The direct open approach is a simple end-to-end procedure using an extended posteromedial incision to expose the rupture site and then to oppose the tendon stumps, using various stitch patterns.[13-15] However, when the defect exceeds 3 cm, augmentation is needed. This is achieved by transplanting tissue matrix,[16] tendon grafts,[17] and performing a turndown flap of the gastrocnemius muscle.[18] However, it needs to be noted that two prospective randomized trials[19,20] have failed to demonstrate any clear advantage of using augmentation.

Wound complications. Open surgery around the Achilles tendon has a wound-related complication rate of between 8.2% and 34.1%,[21-23] of which at least half are due to infection.[24] Wound-related complications are rated as major or minor, depending on their impact on the patient's quality of life.[21,24] The Achilles tendon is more susceptible to infection than other parts of the ankle, owing to its relatively poor blood supply.[25] The retraction of soft tissue during surgery further increases the risk of infection and the use of tourniquets may also be detrimental to wound healing.[26] Corticosteroids, smoking, and diabetes mellitus have been shown to increase the risk of wound complications more than three-fold.[27] While there is no evidence to support the use of prophylactic antibiotics,[28] many surgeons continue to administer prophylactic antibiotics such as cefazolin.[29]

Sutures. All suture materials can cause local immunological and inflammatory reactions.[30] Different sutures with varying properties have different effects on the surrounding tissue and, ultimately, on the rate of wound infection.[28,31] Many surgeons previously advocated nonabsorbable, multifilament sutures. However, these sutures have been shown to develop chronic inflammation,[32,33] and are vulnerable to contamination and infection.[32,34] Yildirim et al[35] have shown that nonbraided and absorbable sutures such as PDS (polydioxanone, Ethicon, Somerville, New Jersey) have sufficient holding capacity and strength. In a biomechanical systematic review[36] of 11 papers using a variety of different suture techniques including the Kessler, Bunnell and Krackow sutures for open repair, the Achillon device (WrightMedical, Memphis, Tennessee), the Ma–Griffith repair technique, the triple bundle technique, and the 'gift box' technique, it was found that the triple bundle technique, in combination with Ethibond sutures (Ethicon, Somerville, New Jersey), performed the best. This finding was later confirmed by Bevoni et al.[37]

Percutaneous repair. The percutaneous method involves suturing the Achilles tendon through multiple small incisions, made under local anaesthesia without directly exposing the rupture site. In 1977, Ma and Griffith[38] described the percutaneous repair of an acute Achilles rupture (Fig. 1a), which had the benefit of a relatively low re-rupture rate, while also reducing the rates of infection and other soft-tissue complications. In a prospective randomized controlled trial (RCT) of 33 patients comparing open and percutaneous methods, Lim et al[39] reported a 21% postoperative infection rate in the open repair group and no wound infection in the percutaneous repair group. The re-rupture rates during the minimum follow-up of six months were 6% and 3%, respectively. Cretnik et al[40] conducted a comparative study of 237 patients and reported that the percutaneous repair group had a lower number of complications (9.7% *vs* 21%; $p = 0.013$). In another prospective RCT of 34 patients, Karabinas et al[41] found that there were no statistically significant differences between the open and percutaneous groups with respect to the time taken to return to activities, the American Orthopedic Foot and Ankle Score (AOFAS), and patient satisfaction. Henríquez et al[42] retrospectively reviewed 32 patients, 17 who had percutaneous and 15 who had open repair, and observed similar values in both groups in terms of muscle strength, ankle range of movement (ROM), and single heel raise tests. The cosmetic appearance, however, was better in the percutaneous group with a smaller mean scar length (2.9 cm *vs* 9.5 cm). In addition, percutaneous repair may be a suitable option for the elderly, producing similar outcomes to those reported for percutaneous repair in younger patients.[43] Percutaneous repair has also been reported to be a good option for elite athletes, allowing for prompt return to sporting activities.[44]

Nerve injury. However, the two main weaknesses of percutaneous repair are the potential risk of sural nerve

Table I. Different types of mini-open operations and the corresponding suture methods

Author	Technology	Cases, n	Results
Keller et al[60]	Dresden mini-open technique	100	Mean follow-up: 42.1 mths Mean time to return to work: 56 days Mean time to return to sports: 18.9 wks Mean AOFAS score: 97.7 Complications: deep vein thrombosis (n=5), re-ruptures (n=2) No sural nerve damage Good isokinetic results
Ng et al[61]	Bunnell-type suture using a double-ended needle	25	Mean follow-up: 65.5 mths No sural nerve damage No re-ruptures Complications: hypertrophic scar (n=1), superficial infections (n=2) Less calf atrophy
Taşatan et al[62]	Achillon	20	Mean follow-up: 58.5 mths Mean AOFAS score: 99.2 at 18 mths No wound problems No re-ruptures No nerve injuries All patients were able to return to work and sporting activities According to the Trillat scores, the outcome was excellent in 19 patients and good in one patient at the 18th postoperative mth
Hsu et al[63]	PARS	101	98% of patients treated with PARS able to return to baseline activities by 5 mths No re-ruptures No nerve injuries Complications: superficial wound dehiscence (n=3), re-operations for superficial foreign-body reaction to FiberWire suture material without concurrent infection (n=2)

AOFAS, American Orthopaedic Foot and Ankle Society; PARS, percutaneous Achilles repair system

injury and the reduced strength of the repair. A nerve injury may result in a slight sensory disturbance, severe pain, or impaired function.[45] The incidence of iatrogenic nerve injuries associated with the percutaneous method was 13% in early studies.[46] In cadavers, high rates of transfixion of the sural nerve have been reported,[47,48] and anatomical variations may exacerbate this rate.[49] In response to these complications, Webb and Bannister[50] developed a percutaneous technique that involved only three midline skin incisions, keeping well away from the lateral side of the tendon, in order to protect the sural nerve (Fig. 1b). Subsequently, Wagnon and Akayi[51] retrospectively reviewed the results of 57 consecutive patients who underwent this improved percutaneous technique and no neurological damage was reported.

Weak strength. The weak initial strength[48] and inadequate apposition of the tendon ends[52] are probably responsible for the relatively high incidence of re-rupture in patients undergoing a percutaneous repair. Using a modified approach (Fig. 1c), Cretnik et al[53] tested 36 cadaveric Achilles tendons to failure and found that their repair technique almost doubled the tendon strength in comparison with the Ma–Griffith method. Furthermore, the Cretnik method had a comparable re-rupture rate to open procedures (3.7% *vs* 2.8%, $p=0.68$).[40] Carmont and Maffulli[54] modified the percutaneous method, using eight strands of suture material with a likely combined ultimate tensile strength in excess of 43 kg, and subsequently treated 73 patients with only one partial re-rupture over the first year. (Fig. 1d).[55]

Endoscopy and ultrasonography. Endoscopy-assisted percutaneous repair allows for direct observation of the stab wounds and controlled juxtaposition of the tendon ends without damaging the paratenon, thereby maintaining the blood supply and enhancing biological recovery.[56] Re-rupture is minimized and early postoperative ankle mobilization and weight-bearing can be carried out. The major advantages of real-time intraoperative ultrasonography are that it allows for the correct positioning of needles and permits accurate stump approximation.[57] It also eliminates the risk of sural nerve injury.[58] Nonetheless, these techniques require skilled and experienced surgeons and the availability of better hardware facilities.

Mini-open repair. The original concept of a limited open procedure was to combine the advantages of both the open and percutaneous techniques,[59] allowing for direct visualization of the ruptured ends using a small incision. Several authors have developed this technique further (Table I).[60-63] Assal et al[64] published the results of a prospective multicentre study using a specially designed instrument, the Achillon device, which guarantees that all sutures are guided externally to the peritendinous region, thereby theoretically avoiding nerve entrapment[60] as well as protecting the paratenon,[65] and facilitating a faster recovery.[66] Unlike the percutaneous technique, where the repair must be undertaken early,[67] limited open repair has been performed up to three weeks after injury.[68] The small skin incision allows for removal of any blood clot and interposed tissue and also reduces the risk of wound infection.[59,64] Visualization enables adequate

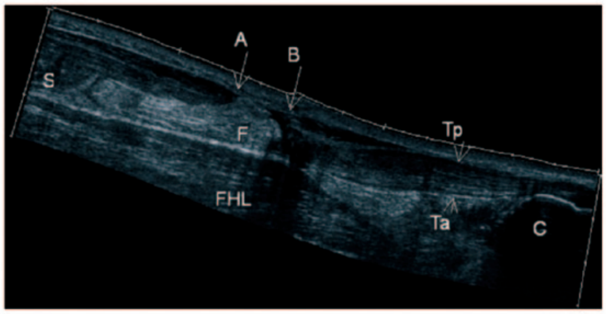


Fig. 2

Ultrasonography. Measurements were performed by identifying the tendon ends on the central part of the tendon on a sagittal scan. The mean of three separate measurements was used as the result value of the gap. A-B, gap of tendon rupture; C, calcaneus; F, fat tissue; FHL, flexor hallucis longus muscle; S, soleus muscle; Ta, anterior tendon surface; Tp, posterior tendon surface. Reproduced from **Westin O, Nilsson Helander K, Gravare Silbernagel K et al.** Acute ultrasonography investigation to predict reruptures and outcomes in patients with an Achilles tendon rupture. *Orthop J Sports Med* 2016;4:2325967116667920.

tendon apposition and increases the repair strength,[69] thus reducing the incidence of re-rupture.[70]

Using a vertical posteromedial incision, the mini-open technique is superior to the percutaneous technique in terms of reducing sural nerve injury and is also better than the classic open technique in decreasing the risk of wound complications while providing sufficient initial strength.

Postoperative management of Achilles tendon repair. The postoperative regime can affect the speed of rehabilitation, of which the main objectives are return to work and return to sporting activity. Functional treatment is important. Various RCTs are listed in Supplementary Table i. Kangas et al[71] compared isolated early ankle movement exercises without early weight-bearing *versus* immobilization and where weight-bearing was initiated three weeks postoperatively. They reported that isokinetic calf muscle strength results were somewhat better in the early movement group, with only one re-rupture in 25 patients. In a RCT comparing two postoperative regimes in 110 patients, Suchak et al[72] showed that two weeks postoperatively weight-bearing improves health-related quality of life in the early phase, with no detrimental effects on recovery and no re-rupture in either groups during the six-month follow-up. Interestingly, in a RCT comparing aggressive with conventional rehabilitation De la Fuente et al[73] demonstrated that 20 patients, who received aggressive therapy based on immediate controlled mobilization combined with weight-bearing from the first day after surgery, had a higher ATRS, a lower verbal pain score, earlier return to work, and higher Achilles tendon strength. The re-rupture rates in both groups was 5% and the rates of other complications were 11% and 15% in the conventional and aggressive groups, respectively. Although aggressive rehabilitation starts immediately after surgery, a period of about two weeks of immobilization and non-weight-bearing may be preferred to allow for soft-tissue healing.

Non-surgical treatment

Conservative treatment consists of immobilization and non-weight-bearing for at least four weeks after surgery. Historically, non-surgical treatment always tended to be offered to older patients and those with reduced functional demands, or who had distinct surgical contraindications. Recently, the decision to treat an acute Achilles tendon rupture non-surgically has improved by dynamic ultrasonography (Fig. 2). Lawrence et al[74] conducted a prospective cohort study of 38 patients and found that patients with a gap $\geq$ 10 mm, with the ankle in the neutral position following nonoperative treatment, had significantly greater peak torque deficit than those with gaps $<$ 10 mm ($p = 0.023$), but there was no difference in ATRS ($p = 0.467$). Regrettably, however, their treatment programme did not involve early mobilization. Using functional nonoperative rehabilitation, Hufner et al[75] reviewed the long-term results of 168 patients who fitted the inclusion criteria of: less than 10 mm of gap with the foot in a neutral position and complete apposition of the tendon stumps in 20° of plantar flexion, as demonstrated on ultrasound examination. The re-rupture rate was 6.4%, and 92 patients (73.5%) achieved good or better results at a mean of 5.5 years after injury. The authors proposed that a repeat ultrasound examination should be performed two to five days after the initial ultrasound to confirm the indications for nonoperative treatment. Also, all patients used a 3 cm hindfoot elevation for eight weeks followed by shoes with 1 cm hindfoot elevation worn for another three months to provide a longer protection for the tendon. Kotnis et al[76] reviewed the role of ultrasound in a group of patients who had a 5 mm gap or more in their Achilles tendon, when the foot was in equinus, who were treated surgically and were compared with a group of patients with a less then 5 mm gap, with the foot in equinus, who were treated conservatively. They reported no difference between operative and nonoperative treatment in the re-rupture rate (1.5% *vs* 3.4%), nor in other complications such as chronic pain (1.5% *vs* 1.7%), numbness (3.0% *vs* 0%), wound infection (3.0% *vs* 0%), or deep vein thrombosis (0% *vs* 1.7%). Moreover, in a cohort study of 45 patients, Westin et al[77] categorized the gap between the two tendon ends as 0 mm to 5 mm, $>$ 5 mm to 10 mm, and $>$ 10 mm. When comparing surgical and non-surgical treatment, they found that, in the non-surgically treated group, three of four patients with a gap of $>$ 10 mm suffered from re-rupture and patients with a gap of $>$ 5 mm had a worse outcome in terms of ATRS ($p = 0.004$) and a lower heel raise height ($p = 0.048$) at 12 months. Therefore, a distance of less than 5 mm is more reliable to confirm adequate apposition of the tendon ends and hence is recommended as the cut-off point for conservative treatment.

Functional rehabilitation

At many medical centres, postoperative and nonoperative functional rehabilitation is similar for Achilles tendon ruptures. The main difference between the two is that the surgical patients begin physical therapy earlier.[78] The most widely used functional protocols combine protected weight-bearing and early controlled movement in an orthosis. This begins with a period of immobilization, gradually progressing from the maximum equinus position to a neutral position, using an elevated heel insert to bring the ends of the tendon closer together.[79,80] There is considerable variation among such protocols in terms of the period of absolute immobilization, the time to initiate weight-bearing and early movement, and the progression of weight-bearing status.

Immobilization *versus* motion

Qureshi et al[81] demonstrated that when a neutral ankle position was replaced with maximal plantar flexion, the mean gap decreased from 12 mm to 5 mm. They reported that this gap distance would further decrease to 2 mm in maximum equinus with the knee in flexion from 0° to 90°. Hence, below-knee cast immobilization with the foot in plantar flexion position was advocated. However, in our experience, eight weeks of immobilization of the limb in this position can have major disadvantages, including soleus muscle atrophy, increased re-rupture rates, deep vein thrombosis, and the loss of coordination and proprioception. On the other hand, immobilizing the ankle in equinus for one to three weeks is important in order to allow the haematoma to consolidate and also to restore the continuity of the tendon.[79] Aspenberg[8] has suggested that early controlled movement of the tendons leads to improved healing through the release of growth factors and animal studies have shown a threefold increase in the strength of the Achilles tendon with dynamic rehabilitation.[71] Tensile loading of the healing tendon by mobilization leads to fundamental changes in the biological process of tendon healing, resulting in accelerated restoration of the load to failure.[82] In a RCT of 35 patients, Schepull and Aspenberg[83] demonstrated that early tensile loading improves the elastic modulus of the healing human Achilles tendon after rupture. Arslan et al[84] evaluated 22 patients after one-sided open repair and found that early postoperative mobilization appeared to have no complications. Majewski et al[85] reviewed 103 patients who underwent percutaneous repair and different postoperative methods of mobilization. They reported that early restricted movement shortened the time taken for return to work from 37 days from 67 days; p = 0.042) with cast immobilization. Moreover, Nilsson-Helander et al[22] randomized 97 patients to either non-surgical or surgical treatment with early mobilization and suggested that early mobilization was beneficial for patients with acute Achilles tendon rupture regardless of whether they were treated surgically or non-surgically. Although the current literature tends to support early functional movement, one survey of orthopaedic specialists in the United Kingdom revealed that the median immobilization period was eight to nine weeks[86] and that functional bracing was not as widely used as below-knee cast immobilization.

Weight-bearing *versus* non-weight-bearing

Protocols using early weight-bearing have two major goals. First, mechanical loading enhances collagen maturation and consequently tendon healing.[8,83] Second, the muscle atrophy associated with prolonged immobilization is prevented.[87] Clearly, however, weight-bearing increases the tension on the Achilles tendon, which may impede its healing. Clinical management therefore requires a balance between protected weight-bearing and functional loading. It has been suggested that weight-bearing has the advantage of convenience,[88] the possibility of an early return to work,[89] the promotion of plantar flexor activity,[82] improvement of coordination during gait and running,[90] and a good functional outcome with an enhanced quality of life.[72] The re-rupture rate for weight-bearing ranges from 0% to 4%, which is similar to operative treatment. Moreover, immediate weight-bearing has no detrimental effect on the outcome or re-rupture rate.[72,88,89] However, there is no consensus on weight-bearing management within the first two weeks.[91] Nevertheless, many centres choose similar weights (15 kg to 20 kg) for their initial partial weight-bearing rehabilitation.

Accelerated dynamic rehabilitation has been an important development in Achilles tendon treatment. In 2007, Twaddle and Poon[92] concluded that obtaining a good functional outcome was dependent on early and prolonged dynamic rehabilitation therapy, regardless of the method for repair that was used, later confirming this in a meta-analyses of RCTs and in a systematic review.[93,94] Previously, authors have argued that functional rehabilitation should begin in the first nine weeks to optimize unidirectional tensile strength.[95] However, recent treatment protocols longer than eight weeks in length have not been shown to improve functional outcomes.[96] Two studies that involved 945 consecutive patients[97] and 17 years of clinician experience[79] confirmed that functional management of the Achilles tendon leads to good outcomes and a low risk of re-rupture. Another study demonstrated that patients treated with functional weight-bearing mobilization showed glutamate upregulation and enhanced production of healing metabolites.[98] However, patient compliance is critical to the success of conservative interventions.[72,88]

Non-surgical *versus* surgical

Historically, nonoperative treatment has been associated with high re-rupture rates (9.7% to 12.6%).[21,80,99] One possible explanation for the difference in re-rupture rate between the non-surgical and surgical methods may relate to the composition of the healed tendon. With primary repair, the gap is minimized and thereby the proportion of the tendon composed of scar tissue is reduced. Achilles tendon scars reach only 57% of the normal maximum stress values after 12 months.[100] However, no significant differences were found between the two treatments in relation to tendon elongation ($p=0.31$).[99] Elongation of the Achilles tendon has a negative effect on the muscle push-off strength,[79] produces gait abnormalities,[101] and lowers the power generation around the ankle.[102] The result is that many surgeons favour operative treatment because of the greater ankle joint range of movement, better quality of life,[15] and shorter time off work.[93,99] However, when functional rehabilitation with early movement and early weight-bearing were adopted, Willits et al[103] found that the re-rupture rates did not differ significantly between surgical and non-surgical patients (2.8% *vs* 4.1%). Furthermore, complications other than re-rupture, such as adhesions, sural nerve damage, and infection, were all higher in the operative group (26.6% *vs* 7.2%).[99] Biomechanically, in an animal model, when early functional activity was coupled with non-surgical treatment, superior fatigue properties were achieved.[104] Nonoperative management may be more suitable for functional rehabilitation than primary repair. However, this remains to be proven in a large RCT.

A retrospective epidemiological study revealed that the best surgical outcomes were achieved in male patients younger than 40 years, while functional bracing was better in female patients over 40 years of age.[105] Although recent high-quality RCTs and meta-analyses support the use of conservative treatment, there remain large discrepancies among different regions. In the United States, an analysis of 12 570 patients found that the ratio of operative to nonoperative treatment from 2007 to 2011 increased from 1.41 to 1.65,[106] while in Canada, a review of 29 531 patients from 2002 to 2014 reported that the operative treatment had significantly declined from 2009 ($p<0.001$).[107]

Biological adjuncts

At present, tendon repair often results in healed tissue with poor structural, mechanical, and functional qualities, which newly emerging adjunct biological therapy may improve. Fibrin sealant, for example, is a blood-derived product that enables anatomical reconstruction with less soft-tissue compromise than suture repair. In a study of 64 patients comparing percutaneous suture and open fibrin glue, Knobe et al[108] reported that no significant difference was found regarding lower leg circumference, disability, or function at a median follow-up of 63 months. However, fibrin glues only provided adhesive properties and they lack signalling factors.[109] Platelet-rich fibrin matrix (PRF) is a second generation of platelet concentrate produced by centrifuging blood. It contains a highly complex pool of signalling factors that are critical to accelerating tendon cell proliferation and healing, which stimulate the synthesis of type I collagen and ensure the growth of healthy tissue. In a retrospective review of 20 patients who had undergone surgical repair with and without PRF, Alviti et al[110] found that the PRF group showed greater functional improvements, in terms of efficiency of movement, at six months. Sánchez et al[111] also achieved promising results in six athletes. Given the low activity and low number of cells in tendons, cell-based therapies for tendon repair seem an attractive proposition. Mesenchymal stem cells (MSCs) improve tendon healing by anti-apoptotic effect, differentiating into tenocytes and producing signalling factors. Stein et al[112] reviewed 28 tendons in 27 patients treated with open repair and bone marrow aspirate concentrate injection, which mainly consists of MSCs and growth factors. They reported excellent results without re-rupture, and only one patient had a superficial wound dehiscence after a mean follow-up of 29.7 months. However, most of these are studies with a low level of evidence and lack systematic functional evaluation. The results regarding the clinical efficacy of platelet-rich plasma (PRP) are contradictory and require validation by further research. PRP is known to contain more than 300 bioactive proteins, such as VEGF, IGF, PDGF, PDEGF, TGFb, and EGF. The resulting pool of growth factors is believed to enhance tendon healing by stimulating an inflammatory response and leading to early collagen deposition. Schepull et al[113] performed a randomized, single-blinded study of 30 patients and found no significant differences in the elastic modulus or functional outcome in the PRP group at 12 months. In a prospective study of 36 patients, Zou et al[114] reported that the PRP group had better isokinetic muscle, a better outcome, with improved ankle movement at three, 12, and 24 months, respectively. Furthermore, Alsousou et al[115] obtained tendon tissue biopsy samples from 20 patients with acute Achilles tendon rupture from the healing area of the Achilles tendon, six weeks after treatment with PRP or placebo controls. They reported PRP samples had an improved histological quality with better collagen I deposition, decreased cellularity, less vascularity, and higher glycosaminoglycan content.

In summary, controversy still exists regarding the best treatment strategy for acute Achilles tendon rupture. Open surgery can significantly reduce the incidence of re-rupture, but the risks of complications are higher. Although percutaneous repair may reduce wound complications, there remains the potential of nerve damage. However, RCTs and meta-analyses have clearly demonstrated the benefits of early functional rehabilitation. In addition, bioactive agents may have the potential to enhance postoperative tendon healing.

It would also be of real interest to investigate the role of mechanical and biological factors in Achilles tendon healing, particularly at the molecular level using genomics, epigenetics, proteomics, and metabolomics.

Supplementary material

A flowchart of the studies in the selection process for this review, a treatment algorithm for management of the acute Achilles tendon rupture, and a table showing functional recovery steps and the corresponding results of different treatment methods in various randomized controlled trials of Achilles tendon rupture.

References

1. **Lantto I, Heikkinen J, Flinkkilä T, Ohtonen P, Leppilahti J.** Epidemiology of Achilles tendon ruptures: increasing incidence over a 33-year period. *Scand J Med Sci Sports* 2015;25:e133-e138.
2. **Ganestam A, Kallemose T, Troelsen A, Barfod KW.** Increasing incidence of acute Achilles tendon rupture and a noticeable decline in surgical treatment from 1994 to 2013. A nationwide registry study of 33,160 patients. *Knee Surg Sports Traumatol Arthrosc* 2016;24:3730-3737.
3. **Huttunen TT, Kannus P, Rolf C, Felländer-Tsai L, Mattila VM.** Acute Achilles tendon ruptures: incidence of injury and surgery in Sweden between 2001 and 2012. *Am J Sports Med* 2014;42:2419-2423.
4. **Vosseller JT, Ellis SJ, Levine DS, et al.** Achilles tendon rupture in women. *Foot Ankle Int* 2013;34:49-53.
5. **Seeger JD, West WA, Fife D, et al.** Achilles tendon rupture and its association with fluoroquinolone antibiotics and other potential risk factors in a managed care population. *Pharmacoepidemiol Drug Saf* 2006;15:784-792.
6. **Pękala PA, Henry BM, Pękala JR, Piska K, Tomaszewski KA.** The Achilles tendon and the retrocalcaneal bursa. *Bone Joint Res* 2017;6:446-451.
7. **Mahieu NN, Witvrouw E, Stevens V, Van Tiggelen D, Roget P.** Intrinsic risk factors for the development of Achilles tendon overuse injury: a prospective study. *Am J Sports Med* 2006;34:226-235.
8. **Aspenberg P.** Stimulation of tendon repair: mechanical loading, GDFs and platelets. A mini-review. *Int Orthop* 2007;31:783-789.
9. **Todorov A, Schaub F, Blanke F, et al.** Clinical assessment is sufficient to allow outcome evaluation following surgical management of Achilles tendon ruptures. *Muscles Ligaments Tendons J* 2015;5:68-72.
10. **Nilsson-Helander K, Thomeé R, Silbernagel KG, et al.** The Achilles tendon Total Rupture Score (ATRS): development and validation. *Am J Sports Med* 2007;35:421-426.
11. **Rettig AC, Liotta FJ, Klootwyk TE, Porter DA, Mieling P.** Potential risk of rerupture in primary Achilles tendon repair in athletes younger than 30 years of age. *Am J Sports Med* 2005;33:119-123.
12. **Bulatović N, Aligrudić V, Dasić Z, Pepić D, Jusković A.** Operative vs. non-operative treatment of acute Achilles tendon rupture. *Acta Chir Iugosl* 2013;60:57-60. (in Serbian)
13. **Sorrenti SJ.** Achilles tendon rupture: effect of early mobilization in rehabilitation after surgical repair. *Foot Ankle Int* 2006;27:407-410.
14. **Krueger H, David S.** The effectiveness of open repair versus percutaneous repair for an acute Achilles tendon rupture: a critically appraised topic. *J Sport Rehabil* 2016;25:404-410.
15. **Lantto I, Heikkinen J, Flinkkila T, et al.** A prospective randomized trial comparing surgical and nonsurgical treatments of acute Achilles tendon ruptures. *Am J Sports Med* 2016;44:2406-2414.
16. **Magnussen RA, Glisson RR, Moorman CT III.** Augmentation of Achilles tendon repair with extracellular matrix xenograft: a biomechanical analysis. *Am J Sports Med* 2011;39:1522-1527.
17. **Maffulli N, Spiezia F, Pintore E, et al.** Peroneus brevis tendon transfer for reconstruction of chronic tears of the Achilles tendon: a long-term follow-up study. *J Bone Joint Surg [Am]* 2012;94-A:901-905.
18. **Corradino B, Di Lorenzo S, Calamia C, Moschella F.** Surgical repair of acute Achilles tendon rupture with an end-to-end tendon suture and tendon flap. *Injury* 2015;46:1637-1640.
19. **Heikkinen J, Lantto I, Flinkkilä T, et al.** Augmented compared with nonaugmented surgical repair after total Achilles rupture: results of a prospective randomized trial with thirteen or more years of follow-up. *J Bone Joint Surg [Am]* 2016;98-A:85-92.
20. **Pajala A, Kangas J, Siira P, Ohtonen P, Leppilahti J.** Augmented compared with nonaugmented surgical repair of a fresh total Achilles tendon rupture. A prospective randomized study. *J Bone Joint Surg [Am]* 2009;91-A:1092-1100.
21. **Khan RJ, Fick D, Keogh A, et al.** Treatment of acute Achilles tendon ruptures. A meta-analysis of randomized, controlled trials. *J Bone Joint Surg [Am]* 2005;87-A:2202-2210.
22. **Nilsson-Helander K, Silbernagel KG, Thomeé R, et al.** Acute Achilles tendon rupture: a randomized, controlled study comparing surgical and nonsurgical treatments using validated outcome measures. *Am J Sports Med* 2010;38:2186-2193.
23. **Pajala A, Kangas J, Ohtonen P, Leppilahti J.** Rerupture and deep infection following treatment of total Achilles tendon rupture. *J Bone Joint Surg [Am]* 2002;84-A:2016-2021.
24. **Saxena A, Maffulli N, Nguyen A, Li A.** Wound complications from surgeries pertaining to the Achilles tendon: an analysis of 219 surgeries. *J Am Podiatr Med Assoc* 2008;98:95-101.
25. **Poynton AR, O'Rourke K.** An analysis of skin perfusion over the Achilles tendon in varying degrees of plantarflexion. *Foot Ankle Int* 2001;22:572-574.
26. **Paavola M, Orava S, Leppilahti J, Kannus P, Järvinen M.** Chronic Achilles tendon overuse injury: complications after surgical treatment. An analysis of 432 consecutive patients. *Am J Sports Med* 2000;28:77-82.
27. **Bruggeman NB, Turner NS, Dahm DL, et al.** Wound complications after open Achilles tendon repair: an analysis of risk factors. *Clin Orthop Relat Res* 2004;427:63-66.
28. **Marican MM, Fook-Chong SM, Rikhraj IS.** Incidence of postoperative wound infections after open tendo Achilles repairs. *Singapore Med J* 2015;56:549-554.
29. **Bratzler DW, Dellinger EP, Olsen KM, et al.** Clinical practice guidelines for antimicrobial prophylaxis in surgery. *Surg Infect (Larchmt)* 2013;14:73-156.
30. **Ratner D, Nelson BR, Johnson TM.** Basic suture materials and suturing techniques. *Semin Dermatol* 1994;13:20-26.
31. **Alexander JW, Solomkin JS, Edwards MJ.** Updated recommendations for control of surgical site infections. *Ann Surg* 2011;253:1082-1093.
32. **Kocaoglu B, Ulku TK, Gereli A, Karahan M, Turkmen M.** Evaluation of absorbable and nonabsorbable sutures for repair of Achilles tendon rupture with a suture-guiding device. *Foot Ankle Int* 2015;36:691-695.
33. **Carr BJ, Ochoa L, Rankin D, Owens BD.** Biologic response to orthopedic sutures: a histologic study in a rabbit model. *Orthopedics* 2009;32:828.
34. **Baig MN, Yousaf I, Galbraith JG, Din R.** Absorbable Polydioxanone (PDS) suture provides fewer wound complications than polyester (ethibond) suture in acute Tendo-Achilles rupture repair. *Ir Med J* 2017;110:566.
35. **Yildirim Y, Saygi B, Kara H, Cabukoğlu C, Esemenli T.** Tendon holding capacities of the suture materials used in repairing Achilles tendon rupture. *Acta Orthop Traumatol Turc* 2006;40:164-168. (in Turkish)
36. **Sadoghi P, Rosso C, Valderrabano V, Leithner A, Vavken P.** Initial Achilles tendon repair strength–synthesized biomechanical data from 196 cadaver repairs. *Int Orthop* 2012;36:1947-1951.
37. **Bevoni R, Angelini A, D'Apote G, et al.** Long term results of acute Achilles repair with triple-bundle technique and early rehabilitation protocol. *Injury* 2014;45:1268-1274.
38. **Ma GW, Griffith TG.** Percutaneous repair of acute closed ruptured Achilles tendon: a new technique. *Clin Orthop Relat Res* 1977;128:247-255.
39. **Lim J, Dalal R, Waseem M.** Percutaneous vs. open repair of the ruptured Achilles tendon–a prospective randomized controlled study. *Foot Ankle Int* 2001;22:559-568.
40. **Cretnik A, Kosanovic M, Smrkolj V.** Percutaneous versus open repair of the ruptured Achilles tendon: a comparative study. *Am J Sports Med* 2005;33:1369-1379.
41. **Karabinas PK, Benetos IS, Lampropoulou-Adamidou K, et al.** Percutaneous versus open repair of acute Achilles tendon ruptures. *Eur J Orthop Surg Traumatol* 2014;24:607-613.
42. **Henríquez H, Muñoz R, Carcuro G, Bastías C.** Is percutaneous repair better than open repair in acute Achilles tendon rupture? *Clin Orthop Relat Res* 2012;470:998-1003.
43. **Maffulli N, Longo UG, Ronga M, Khanna A, Denaro V.** Favorable outcome of percutaneous repair of Achilles tendon ruptures in the elderly. *Clin Orthop Relat Res* 2010;468:1039-1046.
44. **Maffulli N, Longo UG, Maffulli GD, Khanna A, Denaro V.** Achilles tendon ruptures in elite athletes. *Foot Ankle Int* 2011;32:9-15.
45. **Majewski M, Rohrbach M, Czaja S, Ochsner P.** Avoiding sural nerve injuries during percutaneous Achilles tendon repair. *Am J Sports Med* 2006;34:793-798.
46. **Klein W, Lang DM, Saleh M.** The use of the Ma-Griffith technique for percutaneous repair of fresh ruptured tendo Achillis. *Chir Organi Mov* 1991;76:223-228.

47. **Aibinder WR, Patel A, Arnouk J, et al.** The rate of sural nerve violation using the Achillon device: a cadaveric study. *Foot Ankle Int* 2013;34:870-875.
48. **Hockenbury RT, Johns JC.** A biomechanical in vitro comparison of open versus percutaneous repair of tendon Achilles. *Foot Ankle* 1990;11:67-72.
49. **Aktan Ikiz ZA, Uçerler H, Bilge O.** The anatomic features of the sural nerve with an emphasis on its clinical importance. *Foot Ankle Int* 2005;26:560-567.
50. **Webb JM, Bannister GC.** Percutaneous repair of the ruptured tendo Achillis. *J Bone Joint Surg [Br]* 1999;81-B:877-880.
51. **Wagnon R, Akayi M.** The Webb-Bannister percutaneous technique for acute Achilles' tendon ruptures: a functional and MRI assessment. *J Foot Ankle Surg* 2005;44:437-444.
52. **Gigante A, Moschini A, Verdenelli A, et al.** Open versus percutaneous repair in the treatment of acute Achilles tendon rupture: a randomized prospective study. *Knee Surg Sports Traumatol Arthrosc* 2008;16:204-209.
53. **Cretnik A, Zlajpah L, Smrkolj V, Kosanović M.** The strength of percutaneous methods of repair of the Achilles tendon: a biomechanical study. *Med Sci Sports Exerc* 2000;32:16-20.
54. **Carmont MR, Maffulli N.** Modified percutaneous repair of ruptured Achilles tendon. *Knee Surg Sports Traumatol Arthrosc* 2008;16:199-203.
55. **Carmont MR, Silbernagel KG, Edge A, et al.** Functional outcome of percutaneous Achilles repair: improvements in Achilles tendon total rupture score during the first year. *Orthop J Sports Med* 2013;1:2325967113494584.
56. **Chiu CH, Yeh WL, Tsai MC, et al.** Endoscopy-assisted percutaneous repair of acute Achilles tendon tears. *Foot Ankle Int* 2013;34:1168-1176.
57. **Soubeyrand M, Serra-Tosio G, Campagna R, et al.** Intraoperative ultrasonography during percutaneous Achilles tendon repair. *Foot Ankle Int* 2010;31:1069-1074.
58. **Lacoste S, Féron JM, Cherrier B.** Percutaneous Tenolig((R)) repair under intra-operative ultrasonography guidance in acute Achilles tendon rupture. *Orthop Traumatol Surg Res* 2014;100:925-930.
59. **Kakiuchi M.** A combined open and percutaneous technique for repair of tendo Achillis. Comparison with open repair. *J Bone Joint Surg [Br]* 1995;77-B:60-63.
60. **Keller A, Ortiz C, Wagner E, Wagner P, Mococain P.** Mini-open tenorrhaphy of acute Achilles tendon ruptures: medium-term follow-up of 100 cases. *Am J Sports Med* 2014;42:731-736.
61. **Ng ES, Ng YO, Gupta R, Lim F, Mah E.** Repair of acute Achilles tendon rupture using a double-ended needle. *J Orthop Surg (Hong Kong)* 2006;14:142-146.
62. **Taşatan E, Emre TY, Demircioğlu DT, Demiralp B, Kırdemir V.** Long-term results of mini-open repair technique in the treatment of acute Achilles tendon rupture: a prospective study. *J Foot Ankle Surg* 2016;55:971-975.
63. **Hsu AR, Jones CP, Cohen BE, et al.** Clinical outcomes and complications of percutaneous Achilles repair system versus open technique for acute Achilles tendon ruptures. *Foot Ankle Int* 2015;36:1279-1286.
64. **Assal M, Jung M, Stern R, et al.** Limited open repair of Achilles tendon ruptures: a technique with a new instrument and findings of a prospective multicenter study. *J Bone Joint Surg [Am]* 2002;84-A:161-170.
65. **Ding WG, Zhu YP, Yan WH.** Treatment of acute and closed Achilles tendon ruptures by minimally invasive tenocutaneous suturing. *J Foot Ankle Surg* 2013;52:143-146.
66. **Davies MS, Solan M.** Minimal incision techniques for acute Achilles repair. *Foot Ankle Clin* 2009;14:685-697.
67. **Rouvillain JL, Navarre T, Labrada-Blanco O, Garron E, Daoud W.** Percutaneous suture of acute Achilles tendon rupture. A study of 60 cases. *Acta Orthop Belg* 2010;76:237-242.
68. **Elliott AJ, Kennedy JG, O'Malley M.** Minimally invasive Achilles tendon repair using the Achillon repair system. *Tech Foot Ankle Surg* 2006;5:171-174.
69. **Heitman DE, Ng K, Crivello KM, Gallina J.** Biomechanical comparison of the Achillon tendon repair system and the Krackow locking loop technique. *Foot Ankle Int* 2011;32:879-887.
70. **Bartel AF, Elliott AD, Roukis TS.** Incidence of complications after Achillon® mini-open suture system for repair of acute midsubstance Achilles tendon ruptures: a systematic review. *J Foot Ankle Surg* 2014;53:744-746.
71. **Kangas J, Pajala A, Siira P, Hämäläinen M, Leppilahti J.** Early functional treatment versus early immobilization in tension of the musculotendinous unit after Achilles rupture repair: a prospective, randomized, clinical study. *J Trauma* 2003;54:1171-1180.
72. **Suchak AA, Bostick GP, Beaupré LA, Durand DC, Jomha NM.** The influence of early weight-bearing compared with non-weight-bearing after surgical repair of the Achilles tendon. *J Bone Joint Surg [Am]* 2008;90-A:1876-1883.
73. **De la Fuente C, Peña y Lillo R, Carreño G, Marambio H.** Prospective randomized clinical trial of aggressive rehabilitation after acute Achilles tendon ruptures repaired with Dresden technique. *Foot* 2016;26:15-22.
74. **Lawrence JE, Nasr P, Fountain DM, Berman L, Robinson AH.** Functional outcomes of conservatively managed acute ruptures of the Achilles tendon. *Bone Joint J* 2017;99-B:87-93.
75. **Hufner TM, Brandes DB, Thermann H, et al.** Long-term results after functional nonoperative treatment of Achilles tendon rupture. *Foot Ankle Int* 2006;27:167-171.
76. **Kotnis R, David S, Handley R, Willett K, Ostlere S.** Dynamic ultrasound as a selection tool for reducing Achilles tendon reruptures. *Am J Sports Med* 2006;34:1395-1400.
77. **Westin O, Nilsson Helander K, Gravare Silbernagel K, et al.** Acute ultrasonography investigation to predict reruptures and outcomes in patients with an Achilles tendon rupture. *Orthop J Sports Med* 2016;4:2325967116667920.
78. **Frankewycz B, Krutsch W, Weber J, et al.** Rehabilitation of Achilles tendon ruptures: is early functional rehabilitation daily routine? *Arch Orthop Trauma Surg* 2017;137:333-340.
79. **Ecker TM, Bremer AK, Krause FG, Müller T, Weber M.** Prospective use of a standardized nonoperative early weightbearing protocol for Achilles tendon rupture: 17 years of experience. *Am J Sports Med* 2016;44:1004-1010.
80. **Olsson N, Silbernagel KG, Eriksson BI, et al.** Stable surgical repair with accelerated rehabilitation versus nonsurgical treatment for acute Achilles tendon ruptures: a randomized controlled study. *Am J Sports Med* 2013;41:2867-2876.
81. **Qureshi AA, Ibrahim T, Rennie WJ, Furlong A.** Dynamic ultrasound assessment of the effects of knee and ankle position on Achilles tendon apposition following acute rupture. *J Bone Joint Surg [Am]* 2011;93-A:2265-2270.
82. **Palmes D, Spiegel HU, Schneider TO, et al.** Achilles tendon healing: long-term biomechanical effects of postoperative mobilization and immobilization in a new mouse model. *J Orthop Res* 2002;20:939-946.
83. **Schepull T, Aspenberg P.** Early controlled tension improves the material properties of healing human Achilles tendons after ruptures: a randomized trial. *Am J Sports Med* 2013;41:2550-2557.
84. **Arslan A, Çepni SK, Sahinkaya T, et al.** Functional outcomes of repair of Achilles tendon using a biological open surgical method. *Acta Orthop Traumatol Turc* 2014;48:563-569.
85. **Majewski M, Schaeren S, Kohlhaas U, Ochsner PE.** Postoperative rehabilitation after percutaneous Achilles tendon repair: early functional therapy versus cast immobilization. *Disabil Rehabil* 2008;30:1726-1732.
86. **Osarumwense D, Wright J, Gardner K, James L.** Conservative treatment for acute Achilles tendon rupture: survey of current practice. *J Orthop Surg (Hong Kong)* 2013;21:44-46.
87. **Rantanen J, Hurme T, Kalimo H.** Calf muscle atrophy and Achilles tendon healing following experimental tendon division and surgery in rats. Comparison of postoperative immobilization of the muscle-tendon complex in relaxed and tensioned positions. *Scand J Med Sci Sports* 1999;9:57-61.
88. **Young SW, Patel A, Zhu M, et al.** Weight-bearing in the nonoperative treatment of acute Achilles tendon ruptures: a randomized controlled trial. *J Bone Joint Surg [Am]* 2014;96-A:1073-1079.
89. **Costa ML, MacMillan K, Halliday D, et al.** Randomised controlled trials of immediate weight-bearing mobilisation for rupture of the tendo Achillis. *J Bone Joint Surg [Br]* 2006;88-B:69-77.
90. **Barfod KW, Bencke J, Lauridsen HB, et al.** Nonoperative, dynamic treatment of acute Achilles tendon rupture: influence of early weightbearing on biomechanical properties of the plantar flexor muscle-tendon complex-a blinded, randomized, controlled trial. *J Foot Ankle Surg* 2015;54:220-226.
91. **Huang J, Wang C, Ma X, et al.** Rehabilitation regimen after surgical treatment of acute Achilles tendon ruptures: a systematic review with meta-analysis. *Am J Sports Med* 2015;43:1008-1016.
92. **Twaddle BC, Poon P.** Early motion for Achilles tendon ruptures: is surgery important? A randomized, prospective study. *Am J Sports Med* 2007;35:2033-2038.
93. **Soroceanu A, Sidhwa F, Aarabi S, Kaufman A, Glazebrook M.** Surgical versus nonsurgical treatment of acute Achilles tendon rupture: a meta-analysis of randomized trials. *J Bone Joint Surg [Am]* 2012;94-A:2136-2143.
94. **Holm C, Kjaer M, Eliasson P.** Achilles tendon rupture–treatment and complications: a systematic review. *Scand J Med Sci Sports* 2015;25:e1-e10.
95. **Patel VC, Lozano-Calderon S, McWilliam J.** Immediate weight bearing after modified percutaneous Achilles tendon repair. *Foot Ankle Int* 2012;33:1093-1097.
96. **Aujla R, Kumar A, Bhatia M.** Non-surgical treatment of Achilles rupture: does duration in functional weight bearing orthosis matter? *Foot Ankle Surg* 2016;22:254-258.
97. **Wallace RG, Heyes GJ, Michael AL.** The non-operative functional management of patients with a rupture of the tendo Achillis leads to low rates of re-rupture. *J Bone Joint Surg [Br]* 2011;93-B:1362-1366.

98. **Valkering KP, Aufwerber S, Ranuccio F, et al.** Functional weight-bearing mobilization after Achilles tendon rupture enhances early healing response: a single-blinded randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1807-1816.
99. **Jiang N, Wang B, Chen A, Dong F, Yu B.** Operative versus nonoperative treatment for acute Achilles tendon rupture: a meta-analysis based on current evidence. *Int Orthop* 2012;36:765-773.
100. **Bruns J, Kampen J, Kahrs J, Plitz W.** Achilles tendon rupture: experimental results on spontaneous repair in a sheep-model. *Knee Surg Sports Traumatol Arthrosc* 2000;8:364-369.
101. **Don R, Ranavolo A, Cacchio A, et al.** Relationship between recovery of calf-muscle biomechanical properties and gait pattern following surgery for Achilles tendon rupture. *Clin Biomech (Bristol, Avon)* 2007;22211-220.
102. **Silbernagel KG, Steele R, Manal K.** Deficits in heel-rise height and Achilles tendon elongation occur in patients recovering from an Achilles tendon rupture. *Am J Sports Med* 2012;40:1564-1571.
103. **Willits K, Amendola A, Bryant D, et al.** Operative versus nonoperative treatment of acute Achilles tendon ruptures: a multicenter randomized trial using accelerated functional rehabilitation. *J Bone Joint Surg [Am]* 2010;92-A:2767-2775.
104. **Freedman BR, Gordon JA, Bhatt PR, et al.** Nonsurgical treatment and early return to activity leads to improved Achilles tendon fatigue mechanics and functional outcomes during early healing in an animal model. *J Orthop Res* 2016;34:2172-2180.
105. **Gwynne-Jones DP, Sims M, Handcock D.** Epidemiology and outcomes of acute Achilles tendon rupture with operative or nonoperative treatment using an identical functional bracing protocol. *Foot Ankle Int* 2011;32:337-343.
106. **Wang D, Sandlin MI, Cohen JR, et al.** Operative versus nonoperative treatment of acute Achilles tendon rupture: an analysis of 12,570 patients in a large healthcare database. *Foot Ankle Surg* 2015;21:250-253.
107. **Sheth U, Wasserstein D, Jenkinson R, et al.** Practice patterns in the care of acute Achilles tendon ruptures: is there an association with level I evidence? *Bone Joint J* 2017;99-B:1629-1636.
108. **Knobe M, Gradl G, Klos K, et al.** Is percutaneous suturing superior to open fibrin gluing in acute Achilles tendon rupture? *Int Orthop* 2015;39:535-542.
109. **Fortelny RH, Petter-Puchner AH, Glaser KS, Redl H.** Use of fibrin sealant (Tisseel/Tissucol) in hernia repair: a systematic review. *Surg Endosc* 2012;26:1803-1812.
110. **Alviti F, Gurzì M, Santilli V, et al.** Achilles tendon open surgical treatment with platelet-rich fibrin matrix augmentation: biomechanical evaluation. *J Foot Ankle Surg* 2017;56:581-585.
111. **Sánchez M, Anitua E, Azofra J, et al.** Comparison of surgically repaired Achilles tendon tears using platelet-rich fibrin matrices. *Am J Sports Med* 2007;35: 245-251.
112. **Stein BE, Stroh DA, Schon LC.** Outcomes of acute Achilles tendon rupture repair with bone marrow aspirate concentrate augmentation. *Int Orthop* 2015;39: 901-905.
113. **Schepull T, Kvist J, Norrman H, et al.** Autologous platelets have no effect on the healing of human Achilles tendon ruptures: a randomized single-blind study. *Am J Sports Med* 2011;39:38-47.
114. **Zou J, Mo X, Shi Z.** A prospective study of platelet-rich plasma as biological augmentation for acute Achilles tendon rupture repair. *Biomed Res Int* 2016;2016:9364170.
115. **Alsousou J, Thompson M, Harrison P, Willett K, Franklin S.** Effect of platelet-rich plasma on healing tissues in acute ruptured Achilles tendon: a human immunohistochemistry study. *Lancet* 2015;385(Suppl 1):S19.

Funding Statement

- This study was supported by the Beijing Key Laboratory Innovation and development project (Z161100005016059), Key projects of Military Medical Innovation Engineering (16CXZ044), The military's 13th five-year priorities (BWS13C029), and National Natural Science Foundation of China (31640029).

Author Contributions

- X. Yang: Collecting and analyzing the data, Writing and editing the manuscript.
- H. Meng: Collecting, analyzing, and interpreting the data.
- Q. Quan: Collecting the data, Statistical analysis.
- J. Peng: Supervising the study.
- S. Lu: Supervising the study.
- A. Wang: Designing and supervising the study.

Conflict of Interest Statement

- None declared