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ACFAS Clinical Consensus Statement

# ACFAS Clinical Consensus Statement: Acute Achilles Tendon Pathology

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ABSTRACT

Injuries to the Achilles tendon are a challenge to the foot and ankle surgeon. In recent years, research has led to a relative change in the way that many surgeons view acute Achilles tendon rupture. In an effort to fully evaluate these trends, as well as to evaluate all aspects of care for acute Achilles tendon rupture, the American College of Foot and Ankle Surgeons convened a panel of experts to create a clinical consensus statement to address selected aspects of care of the acute Achilles tendon injury.



## Executive Summary

The following work represents a clinical consensus statement on the treatment of Achilles tendon ruptures sponsored by the American College of Foot and Ankle Surgeons. A modified Delphi method was used in an attempt to reach consensus on a series of 13 statements using the best available evidence and clinical experience.

The panel reached consensus that the following statements were "appropriate":

- Patients with increased risk factors for postoperative complications (diabetes, obesity, cigarette smoking) have special considerations with regard to deciding operative versus nonoperative management of the acute Achilles tendon rupture.
- Acute partial Achilles tendon ruptures should be treated nonoperatively.
- Early weightbearing and progressive physical therapy should be used after repair or at initiation of nonoperative management.
- A posteromedial incision or posterior midline incision are both acceptable incision placements for repair of Achilles tendon rupture.

The panel reached consensus that the following statements were "inappropriate":

- Complete acute Achilles tendon ruptures should always be treated surgically with primary repair.
- Advanced imaging should be routinely obtained for suspected Achilles tendon ruptures.
- Augmentation of acute complete Achilles tendon repair with autograft, allograft, and xenograft improves functional outcomes.
- Percutaneous repair results in improved functional outcome compared with traditional open repair.
- Percutaneous repair results in lower rerupture rate compared with traditional open repair.

The panel reached consensus that the following statements were "neither appropriate nor inappropriate":

- Surgical repair of the acute Achilles tendon rupture should occur within 10 days of the injury.
- Percutaneous repair has a lower rate of wound dehiscence and postoperative infection compared with traditional open repair.

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- Percutaneous repair of the Achilles tendon has an increased risk of neurovascular injury.
- Ischemia in the watershed region of the Achilles tendon is a strong factor in the etiology of Achilles tendon rupture.

## Introduction

Clinical consensus statements (CCSs) reflect information synthesized from an organized group of subject matter experts based on available evidence, expert opinion, experience, uncertainties, and minority viewpoints. A CCS is not to establish clinical practice guidelines but rather open the door to discussion on a topic, as opposed to providing definitive answers. Adherence to consensus statements will not ensure successful treatment in every clinical situation, and individual clinicians should make decisions based on all available clinical information, recent evidence, and circumstances with respect to the appropriate treatment of an individual patient. This CCS focuses on general topic of risk factors, etiology, diagnosis, and treatment of Achilles tendon ruptures.

### Methods

A 5-member panel consisting of practicing foot and ankle surgeons, familiar with the treatment and etiology of Achilles tendon ruptures, participated in a face-to-face meeting, several email dialogs, and multiple conference calls. The panel was tasked with developing a series of clinical consensus statements on the topic of Achilles tendon ruptures. Using collective clinical experience, a preliminary list of ~25 specific statements was developed. A preliminary literature search using databases such as Medline, EMBASE, Cochrane database, and CINAHL was conducted to assess the availability of published research on each

**Table 1**
Clinical Consensus Statement Questions and Results

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1. Complete acute Achilles tendon ruptures should always be treated surgically with primary repair. | | | | | | | | |
| 1 | ***2*** | ***3*** | 4 | 5 | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 2.3 | | | | | | | | |
| 2. Patients with increased risk factors for postoperative complications (diabetes, obesity, cigarette smoking) have special considerations with regard to deciding operative versus nonoperative management of the acute Achilles tendon rupture. | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | ***7*** | ***8*** | ***9*** |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 8.4 | | | | | | | | |
| 3. Partial Achilles tendon ruptures should be treated nonoperatively. | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | ***7*** | ***8*** | ***9*** |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 8.4 | | | | | | | | |
| 4. Surgical repair of acute Achilles tendon rupture should occur within 10 days of the injury. | | | | | | | | |
| 1 | 2 | 3 | ***4*** | ***5*** | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 4.4 | | | | | | | | |
| 5. Advanced imaging should be obtained for suspected Achilles tendon rupture. | | | | | | | | |
| **1** | **2** | **3** | 4 | 5 | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 2.0 | | | | | | | | |
| 6. Early weightbearing and progressive physical therapy should be used after repair or at initiation of nonoperative management. | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | ***8*** | ***9*** |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 8.6 | | | | | | | | |
| 7. Augmentation of acute complete Achilles tendon repair with autograft, allograft, and xenograft improves functional outcomes. | | | | | | | | |
| ***1*** | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 1 | | | | | | | | |
| 8. Percutaneous repair has a lower rate of wound dehiscence and postoperative infection compared with traditional open repair. | | | | | | | | |
| 1 | 2 | 3 | ***4*** | ***5*** | ***6*** | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 5.2 | | | | | | | | |
| 9. Percutaneous repair results in improved functional outcome compared with traditional open repair. | | | | | | | | |
| ***1*** | ***2*** | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 1.8 | | | | | | | | |
| 10. Percutaneous repair results in lower rerupture rate compared with traditional open repair. | | | | | | | | |
| ***1*** | ***2*** | ***3*** | 4 | 5 | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 1.6 | | | | | | | | |
| 11. Percutaneous repair has increased risk of neurovascular injury. | | | | | | | | |
| 1 | 2 | 3 | 4 | ***5*** | ***6*** | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 5.6 | | | | | | | | |
| 12. Posteromedial incision or posterior midline incision are both acceptable incision placements for repair of Achilles tendon rupture. | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | ***8*** | ***9*** |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 8.6 | | | | | | | | |
| 13. Ischemia in the watershed region of the Achilles tendon is a strong factor in the etiology of Achilles tendon rupture. | | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Extremely Inappropriate | | | | | | | | Extremely Appropriate |
| Weighted Average: 2.4 | | | | | | | | |

**Table 2**
Evidence Comparison for Operative Versus Nonoperative Repair

| Author | Complications | Rerupture Rate | Functional Outcome | Return to Activity | Notes |
|---|---|---|---|---|---|
| Nilsson-Helander et al (3) | | No difference | No difference | | No difference in patient self-assessment of physical activity at 6 and 12 mo |
| Willits et al (4) | No difference | No difference | No difference | | |
| Keating et al (5) | | No difference | No difference | | |
| Olsson et al (6) | | No difference | No difference | No difference | |
| Lantto et al (7) | | | Trend towards operative management, no statistically significant difference between groups | | |
| Wilkins et al (13) | | Lower rate in operative management | | | |
| Amendola et al (16) | | | | No difference | |
| Van der Eng et al (11) | | No difference | | | |
| Soroceanu et al (12) | | No difference when early functional rehabilitation was utilized | No difference | | |
| Jiang et al (14) | | Favors operative management | | No difference in return to pre-injury sports | Shorter sick leave for operative patients |
| Deng et al (17) | No difference | | No difference | No difference | |

statement. Based on the results of this preliminary review of the literature, a final list of 13 statements was selected for further exploration and discussion (Table 1).

## Consensus Process

A modified Delphi method was used to attain consensus by the members of the panel (1). The panel was asked to review and anonymously rate the appropriateness of each statement. Rating was graded from 1 (extremely inappropriate) to 9 (extremely appropriate) on a Likert scale (2). The results were summarized with basic descriptive statistics, kept anonymous, and distributed back to the panel members for review and discussion. After open discussion of these results, the statements were distributed for a second anonymous rating by the same panel members. The answers were again analyzed using the same method. An attempt was made to reach consensus for all statements, but it was not a requirement. Although this was not a formal systematic review, each panel member conducted a comprehensive review of the literature in an attempt to answer each specific statement. The final draft of the manuscript was submitted to *The Journal of Foot and Ankle Surgery®*.

**Statement 1.** Consensus statement: Complete acute Achilles tendon ruptures should always be treated surgically with primary repair.

The panel reached consensus that the statement was **inappropriate**.

Operative versus nonoperative management of acute Achilles tendon rupture is a controversial topic in the orthopaedic and podiatric surgical communities. The strength of the evidence published over the past 15 years has changed the way the foot and ankle surgeon should view Achilles tendon rupture, with many randomized clinical control trials revealing equivalent long-term outcomes in patients treated nonoperatively compared with those treated with operative management (3–7). Historically, nonoperative management was associated with increased rerupture rate, slower return to sport, and lower functional outcome scores (8). As surgeons began to implement early weightbearing and early functional rehabilitation, many studies began to evaluate whether the outcomes of surgical repair were superior to nonoperative management with accelerated rehabilitation (3–7). Surprisingly, even with evidence supporting nonoperative repair, in the United States 61% of patients continued to be treated with operative management, with the ratio of operative to nonoperative treatment actually increasing from 2007 to 2011 (9). In comparison, the incidence of repair reported in the Canadian literature decreased from 21% to 6.5% from 2010 to 2014 (10). The task of this panel was to review the literature while also taking a practical look at different patient populations when determining the correct treatment course. When reviewing the evidence, the key components that were evaluated when comparing operative versus nonoperative management were (Table 2)

- Complications other than rerupture;
- Rerupture rate;
- Functional outcome; and
- Return to activity.

When looking only at the Level 1 evidence available, there appears to be no difference between operative and nonoperative management with regard to complications, functional outcome, and return to activity. Although the majority of evidence does not reveal a difference in rerupture rate between operative and nonoperative treatment (3–6,11,12), 2 meta-analyses do support that operative management decreases the risk of rerupture (13,14). Of course, the decision for operative versus nonoperative management should always be patient specific, as there is a lack of current high-level studies that evaluate operative versus nonoperative management in high-performance athletes or the military. There are retrospective reviews and Level III studies suggesting that operative intervention will return high-functioning patients to full activity sooner (15), but several other Level I studies do not corroborate these findings (6,14,16,17). It is important to discuss the risks and complications of both operative and nonoperative management with patients and allow for patient input in the decision-making process. However, when taking into consideration the current evidence and the opinion of the panel members, a consensus was achieved that Achilles tendon ruptures should not always be treated with operative intervention.

**Statement 2.** Consensus Statement: Patients with increased risk factors for postoperative complications (diabetes, obesity, cigarette smoking)

have special considerations with regard to deciding operative versus nonoperative management of acute Achilles tendon rupture.

The panel reached consensus that this statement is **appropriate**.

``Multiple factors have been identified as increasing the risk for postoperative complications in patients in general. The panel reviewed literature regarding multiple potential risk factors for complications following Achilles tendon rupture treatment. These include the following.

*Diabetes*

In a study of 7895 patients, the authors found a higher risk of rupture of the Achilles tendon in women with poorly controlled diabetes (15). Additional research suggests that high-glucose diets affect Achilles tendon healing in rats (18). Several other studies involving patients diagnosed with diabetes found that patients developed superficial wound infections after percutaneous repair as well as a mini-open repair. (19,20).

*Obesity*

With regard to obesity, a retrospective review of patients treated both surgically and nonoperatively did not find an increased risk of deep vein thrombophlebitis or pulmonary embolism (21). However, a second retrospective study found that patients with body mass index (BMI) >30 were 2 times more likely to develop a wound infection after Achilles tendon repair then those with BMI <30 (22). Several additional studies found that obese patients displayed statistically significantly higher rates of wound complications, venous thromboembolism, and medical complications (23,24). In contrast, a smaller study did not find that obesity had any effect on the occurrence of adverse events after Achilles tendon repair (25).

*Smoking*

In a retrospective study of 167 cases, Bruggeman et al (26) determined that smoking is a risk factor for developing infections after open Achilles tendon repair. The authors also noted that steroid use and being female were risk factors. Patients with ≥2 risk factors had an even higher rate of complications, 42.1%. In another prospective study of 409 cases of Achilles tendon repair, the authors found that 33% of patients who had a rerupture also abused tobacco (27). Patients >40 years old and male patients did have lower scores. In a 30-day follow-up study of 615 patients by Pean et al (28), 2% had adverse outcomes. Smoking, obesity, and diabetes were not factors. In a study of the medical records of 22 patients with Achilles tendon lacerations, smoking was not found to be a factor in infections (29). Klos et al (30) studied 111 tendons with light spectroscopy to measure microperfusion. Smokers were found to have less blood flow in their Achilles tendons.

**Statement 3.** Consensus Statement: Acute partial Achilles tendon ruptures should be treated nonoperatively.

The panel came to a consensus that this statement is **appropriate**.

The consensus in the literature regarding the treatment of acute partial Achilles tendon ruptures appears to prefer nonoperative treatment, which coincided with the panel's expert opinion and general consensus. It is important to note the specification of acute (versus chronic) in the above statement.

In a 1992 article published in *Clinics in Sports Medicine*, the authors recommended that acute partial Achilles tendon ruptures be treated with casting for 2 to 3 weeks (31). In multiple studies that have been published since then regarding Achilles tendon ruptures, partial tears are excluded and all treated nonoperatively (32–34). Furthermore, there is controversy in the literature regarding nonoperative versus operative treatment in full ruptures. We can extrapolate that data to show that if total ruptures can be treated nonoperatively in lieu of surgery, anything less than a full rupture can be and should be treated conservatively.

**Statement 4.** Consensus Statement: Surgical repair of the acute Achilles tendon rupture should occur within 10 days of the injury.

The Panel came to a consensus that this statement was **neither appropriate nor inappropriate**.

Despite being the most common tendon rupture in the lower extremities, a debate remains on the optimal timing of repair with regard to acute Achilles tendon ruptures. On a cellular level, Type III collagen synthesis and proliferation occur mostly during the first couple of days after injury (35). This phase of the inflammatory process suggests that earlier surgical repair may be most beneficial (36,37). Theoretically, these histologic changes should result in a decreased probability of fibrotic tissue formation as often seen with delayed surgical treatment, thus decreasing the chances of chronic tendinosis and tendon rerupture. Although biocellular studies suggest these processes play an integral role in the outcomes of tendons treated with early surgical intervention, they are combatted by the majority of clinical-surgical data suggesting there is no difference compared with delayed surgical treatment of acute Achilles tendon rupture (38–40). Although surgical outcomes performed within a week of injury have shown exceptional results, it has also been reported that these outcomes are comparable to those treated as far out as ≥4 weeks (39–41).

With contradicting literature about the optimal timing of surgical repair of acute Achilles tendon injury, it is important to take postoperative complications and perioperative risk factors into consideration. With delayed surgical repair of Achilles tendon injuries, there is a significantly increased chance of deep venous thrombosis as well as surgical site infection (29,41,42). Additionally, decreased plantar flexory power of the Achilles tendon has been reported when treated with delayed surgical repair (43). With current findings, it is difficult to formally determine the optimal time frame for surgical repair with regard to acute Achilles tendon injuries. We recommend the treating physician take into account patient expectations, comorbidities, activity levels, and the surgeon's clinical experience and comfort level when determining optimal timing of surgical repair for each patient.

**Statement 5.** Consensus Statement: Advanced imaging should be routinely obtained for suspected Achilles tendon ruptures.

The panel reached the conclusion that this statement was **inappropriate**.

Several diagnostic tests have been described to diagnose Achilles tendon ruptures. The calf squeeze test was described by both Simmonds in 1957 and Thompson in 1962 (44,45). Maffulli (46) reported a sensitivity to diagnose acute tendon rupture of 0.96 and specificity of 0.93 for the calf squeeze test. A false negative for this test is more likely with a neglected rupture, in which hematoma has been replaced with healing tendon tissues. The knee flexion test, also called the passive ankle dorsiflexion test, described by Matles (47) and Maffulli (46), reported a sensitivity of 0.88 and specificity of 0.85. A neglected rupture should still be positive with the knee flexion test, as the tendon will lengthen with hematoma formation and subsequent tendon reconstitution. Maffulli (46) also noted that the diagnosis of subcutaneous Achilles tendon tear can reliably be diagnosed with a combination of the calf squeeze and knee flexion test. Reiman et al performed a systematic review with meta-analysis of the utility of clinical measures for the diagnosis of tendon injuries (48). The calf-squeeze test had a positive likelihood ratio of 13.51 and a negative likelihood ratio of 0.04, giving it the ability to rule in or rule out an Achilles tendon tear to a "large and almost conclusive degree."

The American Academy of Orthopedic Surgeons (2009) (49) requires findings consistent with rupture in ≥2 of the following tests for clinical diagnosis of Achilles tendon rupture: calf squeeze test, palpable gap, knee flexion test, or decreased plantarflexion strength. Garras et al (50) examined the sensitivity of physical exam in comparison to the sensitivity of MRI for diagnosis of acute tendon rupture. In patients with positive calf squeeze test, knee flexion test, and palpable gap, acute tendon rupture was confirmed intraoperatively with 100% sensitivity and with MRI, 90% sensitivity; they recommended that MRI is unnecessary for diagnosis of acute tendon rupture. The AAOS (2009) (49) regards use of imaging modalities including radiograph, ultrasound, and MRI to diagnose acute tendon rupture as "inconclusive," with a lack of compelling evidence to support their use. Imaging may best be performed when diagnosis with clinical findings is equivocal.

**Statement 6.** Consensus Statement: Early weightbearing and progressive physical therapy should be used after repair or at initiation of nonoperative management.

The panel came to a consensus that this statement was **appropriate**.

During the discussion of this statement, the panel agreed that early weightbearing and progressive physical therapy should be performed after an Achilles tendon rupture regardless of surgical or nonsurgical treatment. The panel's opinion corresponded with the most recent data available, which suggest that early weightbearing and range of motion exercise after rupture are critical to long-term outcomes.

Studies that were published before 2005 comparing surgical versus nonsurgical treatment revealed either an increased rate of rerupture with conservative treatment or improved patient outcomes with surgical treatment (51–53). This led researchers to conclude that surgical treatment is the preferred method of addressing acute rupture. Subsequent randomized controlled trials and meta-analyses after 2005, particularly those using functional bracing and dynamic or active rehabilitation, produced results discordant with previous conclusions, including similar or superior outcomes in the non–surgically treated patients (4,54–61). Likewise, they found no difference in rerupture rate (4,58); although there were earlier studies that established some improved outcomes with earlier range of motion and weightbearing (42,62).

Most notably, in 2012, Soroceanu et al (60) performed a meta-analysis including 10 randomized controlled trials. They found that when functional rehabilitation with early range of motion was used, rerupture rates for surgical and nonsurgical patients were equal, without significant statistical difference (absolute risk difference 1.7%; $p = .45$). If such rehabilitation protocols were not used, surgery was favored because of increased rerupture rates in the nonsurgical patients. These functional protocols included immediate weightbearing and mobilization as early as 10 days and stand in stark contrast to traditional conservative treatments of immobilization and nonweightbearing for 6 to 8 weeks. Soroceanu et al (60) noted that if functional rehabilitation is not performed, conservative treatment significantly increased the rerupture rate and concluded that the best available evidence supports conservative intervention for Achilles tendon rupture as the preferred treatment if combined with functional rehabilitation (60).

Similarly, Zhang et al (59) in 2015 published a systematic review of 9 overlapping meta-analyses comparing conservative to surgical treatment. The authors found that when functional rehabilitation was used, conservative intervention was equal to surgical treatment regarding incidence of rerupture, range of motion, calf circumference, and functional outcomes, and that the incidence of other complications was reduced with conservative treatment.

Traditionally, patients with acute Achilles tendon ruptures were immobilized and made non-weightbearing for a prolonged period of time. However, multiple studies have shown that tendon repair is actually stimulated by mechanical loading (63,64). Additionally, passive range of motion after tendon repair has shown enhanced function and increased tensile strength of the repair (64). This effect may be responsible for the decreased rerupture rate when functional rehabilitation protocols are used in conservative care.

Studies reporting on functional rehabilitation protocols for conservative treatment and after surgical intervention exhibit great heterogeneity. They vary in length of time immobilized, time to weightbearing, and orthosis type for functional care. Studies are primarily concerned with nonoperative and operative treatment comparisons, not comparison of rehabilitation programs.

Nevertheless, the panel did discuss its preference regarding treatment protocols. After an Achilles tendon surgical repair, care routinely consists of progressing the patient to weightbearing and rehabilitation an average of 14 to 21 days postoperatively, or ideally, after the sutures heal. For nonoperative treatment protocols, the panel recommends immediate protective weightbearing and daily active plantarflexion.

Regardless of operative or nonoperative treatment, a combination of immediate weightbearing with early ankle mobilization appears to be important for optimum patient recovery. Although there has been some attempt to understand the best course of rehabilitation, research remains to be performed to more clearly guide evidence-based treatment measures in both settings.

**Statement 7.** Consensus Statement: Augmentation of acute complete Achilles tendon repair with autograft, allograft, and xenograft improves functional outcomes.

The panel came to a consensus that this statement was **inappropriate**.

Despite a growing body of literature on the use of a variety of materials to augment Achilles tendon rupture repair, there is inadequate evidence showing that the addition of these materials provides superior outcomes. Although the addition of these materials has not been clearly detrimental, the additional effort and cost do not mandate their use.

In a prospective, randomized trial of 60 patients, Pajala et al (64) evaluated pain, stiffness, subjective weakness, footwear restrictions, ankle joint range of motion tendon elongation, and calf strength at 3- and 12-month intervals. The authors compared end-to-end repair with gastrocnemius turn-down flap augmentation and found that augmented repair held no advantage over end-to-end repair. The same group of patients were once again studied at 14 years of follow-up by Heikkinen et al (65). The authors also noted no advantage in plantarflexion strength, Leppilahti Achilles score, or RAND 36-item health survey for augmentation.

In a case series, Shoaib and Mishra (66) reported on 7 patients with large defects repaired with a synthetic material resulting in satisfactory outcomes. Lee (67) reported on 9 patients receiving repairs using a human acellular dermal matrix, also with satisfactory outcomes. Basiglini et al (68) reported on a case of a long-term inflammatory response in a patient treated with a synthetic graft 11 years after implantation. Ofili et al (69) reviewed 14 cases of delayed repair using allograft, with satisfactory results. Zhang et al, in a meta-analysis (70), compared augmented repair with nonaugmented repair and discovered that no improvement in patient satisfaction, rerupture rate, or infection rate was gained with augmentation. There are several biomechanics studies evaluating xenograft, collagen ribbing, and extracellular matrix; however, there is no high-level evidence to suggest that these tissues improve patient outcomes (71–73).

**Statement 8.** Consensus Statement: Percutaneous repair has a lower rate of wound dehiscence and postoperative infection compared with traditional open repair.

The panel came to a consensus that this statement was **neither appropriate or inappropriate**.

With percutaneous repair of the Achilles tendon gaining traction among foot and ankle surgeons, the hope is that the added expense of

instrumentation as well as the risk of poor visualization of the repair can be mitigated by decreased postoperative complications. One would assume that smaller incisions and less exposure of the tendons would lead to decreased risk of dehiscence and infection. The evidence for this statement, however, is sparse and inconclusive at best. In a Level III retrospective review comparing 101 percutaneous repairs with 169 open repairs, Hsu et al (74) found no statistically significant difference between groups in wound dehiscence, superficial, or deep infection. Yang et al (75) performed a meta-analysis of 815 patients in 5 randomized controlled trials and 7 retrospective cohort studies. The researchers noted a higher rate of deep infection in the open repair group, although the rate was not statistically significant. They also performed a subgroup analysis of the randomized controlled trials only and found no statistically significant difference between groups. Bartel et al (76) performed a systematic review of mini-open Achilles tendon repair, evaluating 8 studies and 253 patients. The overall complication rate was low, with 2% rate of incision problems and 0.8% rate of infection. Although theoretically, smaller incisions and less dissection would likely result in decreased wound complications, a lack of compelling evidence to support that statement prevented the panel from agreeing or disagreeing with the statement.

**Statement 9.** Consensus Statement: Percutaneous repair results in improved functional outcome compared with traditional open repair.

The panel came to a consensus that this statement was **inappropriate**.

Open repair of acute Achilles tendon rupture has traditionally been the preferred method of treatment compared with conservative management. Over the last decade, percutaneous repair of Achilles tendon ruptures has gained momentum, introducing the debate as to which technique produces the best postoperative outcomes. A multitude of studies have compared the functional outcomes of open versus percutaneous repair, with the majority remaining in favor of traditional open methods. American Orthopaedic Foot & Ankle Society scores of Achilles tendons that underwent open repair are higher than or equal to those repaired percutaneously (75,77–81). Achilles Tendon Rupture Scores (ATRS), Modified Thermann total scores, Holz score assessments, and overall patient satisfaction with regard to functional ability also err on the side of open repair (77,78,82–85). Additionally, isokinetic variables have been studied comparing ruptured Achilles tendons repaired both open and percutaneously. These studies not only demonstrated greater concentric and eccentric peak torque with open repair, but also less work needed by the posterior leg muscles to perform peak torques compared with percutaneous surgical management (77,86).

Although some of the recent literature credits percutaneous repair with having fewer postoperative complications, the overall functional outcome remains more favorable when treated via an open technique. Despite postoperative concerns for acute Achilles tendon rupture treated with open repair, it continues to have decreased tendon rerupture rates (75,81,87–89), lower rates of decreased calf circumference (77), and decreased incidence of sural neuritis (77,78,85). Based on the findings from the majority of recent literature published, it is inappropriate to depict percutaneous repair of acute Achilles tendon ruptures as having better overall functional outcomes compared with traditional open repair.

**Statement 10.** Consensus Statement: Percutaneous repair results in lower rerupture rates compared with traditional open repair.

The panel came to a consensus that this statement was **inappropriate**.

Overall, the literature reports rerupture rates that are comparable to open repair. Based on the evidence, we cannot say that percutaneous repair results in decreased rerupture rates.

First, multiple studies have compared complication rates of percutaneous acute tendon repair versus open and reported 0 patients with rerupture in either group (90–95). Lim et al in 2001 (95) found no significant difference between the groups: 1 patient of 33 that had percutaneous repair had a rerupture, and 2 patients of 33 that had open repair had a rerupture. Cretnik et al (96,97) published 2 studies, 1 in 2004 and 1 in 2005. The first study prospectively examined percutaneous Achilles tendon repair with a minimum 2-year follow up. They looked at 134 percutaneous procedures, with 1 complete and 4 partial reruptures, which they stated was comparable to open repairs. The second study compared a percutaneous group to an open repair group and found 3.7% and 2.8% rerupture rates, respectively; 80% of the percutaneous reruptures were partial, and 100% of the open reruptures were complete (97).

A meta-analysis of randomized controlled trials compared open and percutaneous surgical repair throughout a period of 25 years (98). Six studies met their inclusion criteria for a total of 277 patients. When the authors analyzed the data, no significant difference in rerupture rates was found between the 2 groups, with a risk differential of 0.01. Another meta-analysis of multiple databases that included 5 randomized controlled trials and 7 retrospective cohort studies for a total of 815 patients reported no significant difference in regarding rate of rerupture (75).

**Statement 11.** Consensus Statement: Percutaneous repair of the Achilles tendon has an increased risk of neurovascular injury.

The panel reached consensus that the statement was **neither appropriate or inappropriate**.

One major concern with minimally invasive surgery is lack of visualization of adjacent structures that could be damaged during the procedure. With percutaneous Achilles tendon repair, the sural nerve lies adjacent to the Achilles tendon, putting it at risk of puncture or damage during repair. Although cadaveric studies have displayed this risk (82), there is a lack of evidence supporting this finding. Multiple retrospective studies and meta-analyses have evaluated sural nerve injuries comparing open and percutaneous repair, with the incidence ranging between 0% and 5.5%; however, no difference in statistical significance has been identified (74,75,76). This limited evidence supports the theory that the risk is low for sural nerve injury; however, without high-level evidence, the panel could not find this statement to be appropriate or inappropriate.

**Statement 12.** Consensus Statement: A posteromedial or posterior midline incision are both acceptable placements for repair of Achilles tendon rupture.

The panel came to a consensus that this statement was **appropriate**.

Multiple studies published on Achilles tendon repair use the posteromedial incision and consider it to be the standard incision (4,51,99–102). Nistor (103) published a prospective randomized trial in 1981 comparing surgical and nonsurgical treatment of acute Achilles tendon repairs. When analyzing complication rates, 9 of 44 patients who underwent surgical repair had sural nerve injury; in all 9, a lateral incision had been used (103).

Interestingly in 2011, Highlander and Greenhagen (104) performed a systematic review of the literature to analyze wound complications after posterior leg incisions. They found 38 peer-reviewed articles that met their inclusion criteria; however, it is important to note they included any type of surgical procedure that used these incisions, not only Achilles tendon rupture repair. Seven of the articles used a posterior midline incision, and 31 used a posterior medial incision. The posterior medial incision group and the posterior midline incision group had wound complication rates of 8.3% and 7.0%, respectively. They surmised that surgeons avoid the posterior midline incision for unfound reasons (104). The disadvantage to these incisions is that they do not follow skin lines (105). In conclusion, our panel's opinion parallels that published in the literature.

**Statement 13.** Consensus Statement: Ischemia in the watershed region of the Achilles tendon is a strong factor in the etiology of Achilles tendon rupture.

The panel came to a consensus that this statement was **inappropriate**.

As with any tissue, the quality and quantity of vascularization directly affect a tissue's response to trauma and provide the basis for healing. The blood supply to the gastrocnemius and soleus muscles is usually discussed in 3 separate regions: the musculotendinous junction, direct supply to the tendon, and the tendon–bone junction. Blood vessels from these regions originate from the perimysium, mesotenon-paratenon structure, and periosteum.

The most commonly cited understanding of Achilles tendon blood flow is based on cadaveric anatomic research done in the 1950s (106). We have come to regard the midsubstance of the Achilles as relatively ischemic based on this historic cadaveric research. In 1958, a watershed area was identified in the midsubstance of the Achilles tendon through cadaveric injection and analysis of the Achilles peritendinous vessels (106). (The term "watershed" is a geographic concept identifying the point at which 2 bodies of water come together from 2 different directions, or a central zone of land that divides areas drained by different river systems.) It is this watershed that has been proposed as the etiology of an ischemic zone in the tendon and proposed a main determinant in weakness and rupture. The Achilles tendon has been shown to have multiple sources of blood supply originating distal, proximal, and from the peritendinous structures (107,108). The question is, however, does this anatomic distribution of vessels within the tendon tissues cause a true hemodynamic compromise or ischemia?

Hastad et al (109) tested hemodynamic flow in the tendon using a sodium washout technique and noted uniform blood flow throughout the tendon. Astrom et al in 1994 (108) used laser Doppler flow analysis to assess real-time tendon circulation in 28 normal volunteers. Subjects were tested with the Doppler probe inserted into the tendon and hemodynamic flow was assessed at rest, during calf muscle contracture, and after vascular occlusion. Findings showed pulsatile flow synchronous with the heart rate evenly distributed throughout the tendon, with only a slight decrease at the tendon insertion at the calcaneus. Further hemodynamic research in live subjects has further strengthened the notion that blood flow is uniform throughout the tendon including the watershed zone (110–114). Additional research has shown an increase in blood flow in the tendon with exercise (110). Boushel noted that muscle tendon blood flow increased concurrently with exercise without abnormal shunting of blood (111). Kubo reported that both blood volume and oxygen saturation after repetitive muscle contracture did not change, and then found that although oxygen consumption did not change when comparing eccentric to concentric muscle contraction, inflow of blood to the tendon was significantly greater during eccentric compared with concentric contractions (114).

It has been suggested based on work by Cummins in 1946 (115) that the twisting of the Achilles tendon fibers distally is a possible cause of the purported ischemia of the midsubstance of the tendon. This so called "wringing out" of the tendon, as it has been described by many, is based on these anatomic observations. Although this an attractive circumstantial piece of evidence, the effect of this fiber twisting on real-time blood flow in living tissue has not been confirmed through experimentation. The studies that have shown uniform blood flow throughout the tendon at rest, with contracture, and exercise noted previously would argue against this effect. Further research is needed to make the causal connection between the tendon spatial anatomy (twisting) and the blood flow within the tendon at all levels.

## References


1. Dalkey NC, Helmer O. An experimental application of the Delphi method to the use of experts. Management Science 1963;9:458–467.
2. Park RE, Fink A, Brook RH, Chassin MR, Kahn KL, Merrick NJ, Kosecoff J, Solomon DH. Physician ratings of appropriate indications for six medical and surgical procedures. Am J Public Health 1986;76:766–772.
3. Nilsson-Helander K, Silbernagel KG, Thomeé R, Faxén E, Olsson N, Eriksson BI, Karlsson J. 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. 2010.
4. Willits K, Amendola A, Bryant D, Mohtadi NG, Giffin JR, Fowler P, Kean CO, Kirkley A. Operative versus nonoperative treatment of acute Achilles tendon ruptures: a multicenter randomized trial using accelerated functional rehabilitation. J Bone Joint Surg Am 2010;92:2767–2775.
5. Keating JF, Will EM. Operative versus non-operative treatment of acute rupture of tendo Achillis: a prospective randomised evaluation of functional outcome. J Bone Joint Surg Br 2011;93:1071–1078.
6. Olsson N, Silbernagel KG, Eriksson BI, Sansone M, Brorsson A, Nilsson-Helander K, Karlsson J. 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.
7. Lantto I, Heikkinen J, Flinkkila T, Ohtonen P, Siira P, Laine V, Leppilahti J. A prospective randomized trial comparing surgical and nonsurgical treatments of acute Achilles tendon ruptures. Am J Sports Med 2016;44:2406–2414.
8. Cetti R, Christensen SE, Ejsted R, Jensen NM, Jorgensen U. Operative versus nonoperative treatment of Achilles tendon rupture: a prospective randomized study and review of the literature. Am J Sports Med 1993;21:791–799.
9. Wang D, Sandlin MI, Cohen JR, Lord EL, Petrigliano FA, SooHoo NF. 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.
10. Sheth U, Wasserstein D, Jenkinson R, Moineddin R, Kreder H, Jaglal S. 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.
11. van der Eng DM, Schepers T, Goslings JC, Schep NW. Rerupture rate after early weightbearing in operative versus conservative treatment of Achilles tendon ruptures: a meta-analysis. J Foot Ankle Surg 2013;52:622–628.
12. Soroceanu A, Sidhwa F, Aarabi S, Kaufman A, Glazebrook MZ. Surgical versus nonsurgical treatment of acute Achilles tendon rupture: a meta-analysis of randomized trials. J Bone Joint Surg Am 2012;94:2136–2143.
13. Wilkins R, Bisson LJ. Operative versus nonoperative management of acute Achilles tendon ruptures: a quantitative systematic review of randomized controlled trials. Am J Sports Med 2012;9:2154–2160.
14. 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;4:765–773.
15. Spoendlin J, Meier C, Jick SS, Meier CR. Achilles or biceps tendon rupture in women and men with type 2 diabetes: a population-based case-control study. J Diabetes Complications 2016;5:903–909.
16. Amendola A. Outcomes of open surgery versus nonoperative management of acute Achilles tendon rupture. J Sport Med 2014;24:90–91.
17. Deng S, Sun Z, Zhang C, Chen G, Li J. Surgical treatment versus conservative management for acute Achilles tendon rupture: a systematic review and meta-analysis of randomized controlled trials. J Foot Ankle Surg 2017;56:1236–1243.
18. Korntner S, Kunkel N, Lehner C, Gehwolf R, Wagner A, Augat P, Stephan D, Heu V, Bauer HC, Traweger A, Tempfer H. A high-glucose diet affects Achilles tendon healing in rats. Sci Rep 2017;1:780.
19. Maffulli N, Longo UG, Maffulli GD, Khanna A, Denaro V. Achilles tendon ruptures in diabetic patients. Arch Orthop Trauma Surg 2011;131:33–38.
20. Eid A. Miniopen repair of ruptured Achilles tendon in diabetic patients. Int Sch Res Notices 2014;840369.
21. Patel A, Ogawa B, Charlton T, Thordarson D. Incidence of deep vein thrombosis and pulmonary embolism after Achilles tendon rupture. Clin Orthop Relat Res 2012;470:270–274.
22. Marican MM, Fook-Chong SM, Rikraj IS. Incidence of postoperative wound infections after open tendo Achilles repairs. Singapore Med J 2015;56:549–554.
23. Ahmad J, Jones K. The effect of obesity on surgical treatment of Achilles tendon ruptures. J Am Acad Orthop Surg 2017;25:773–779.
24. Burrus MT, Werner BC, Park JS, Perumal V, Cooper MT. Achilles tendon repair in obese patients is associated with increased complication rates. Foot Ankle Spec 2016;9:208–214.
25. Pean CA, Christiano A, Rubenstein WJ, Konda SR, Egol KA. Risk factors for complications after primary repair of Achilles tendon ruptures. J Orthop 2018;15:226–229.
26. Bruggeman, Turner NS, Dahm DL, Voll AE, Hoskin TL, Jacofsky DJ, Haidukewych GJ. Wound complications after open Achilles tendon repair: an analysis of risk factors. Clin Orthop Relat Res 2004;427:63–66.
27. 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;84:2016–2021.
28. Pean, Christiano A, Rubenstein WJ, Konda SR, Egol KA. Risk factors for complications after primary repair of Achilles tendon ruptures. J Orthop 2018;15:226–229.
29. Alhammoud A, Arbash MA, Miras F, Said M, Ahmed G, Al Dosari MAA. Clinical series of three hundred and twenty two cases of Achilles tendon section with laceration. Int Orthop 2016;41:309–313.
30. Klos K, Gueorguiev B, Carow JB, Modabber A, Nebelung S, Kim BS, Horst K, Weber CD, Knobe M. Soft tissue microcirculation around the healthy Achilles tendon: a cross-sectional study focusing on the Achilles tendon and dorsal surgical approaches to the hindfoot. J Orthop Surg Res 2018;13:142.
31. Allenmark C. Partial Achilles tendon tears. Clin Sports Med 1992;11:759–769.
32. Haapasalo H, Peltoniemi U, Laine HJ, Kannus P, Mattila VM. Treatment of Acute Achilles tendon rupture with a standardized protocol. Arch Orthop Trauma Surg 2018;138:1089–1096.

33. Lim CS, Lees D, Gwynne-Jones DP. Functional outcome of acute Achilles tendon rupture with and without operative treatment using identical functional bracing protocol. Foot Ankle Int 2017;38:1331–1336.
34. 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.
35. Sharma P, Maffulli N. Tendon injury and tendinopathy: healing and repair. Curr Conc Rev 2005;87:187–202.
36. Rosenbaum AJ, Wicker JF, Dines JS, Bonasser L, Razzano P, Dines DM, Grande DA. Histologic stages of healing correlate with restoration of tensile strength in a model of experimental tendon repair. HSS J 2010;6:164–170.
37. Woo SL, Hildebrand K, Watanabe N, Fenwick JA, Papageorgiou CD, Wang JHC. Tissue engineering of ligament and tendon healing. Clin Orthop Relat Res 1999;367:312–323.
38. Becher C, Donner S, Brucker J, Daniilidis K, Thermann H. Outcome after operative treatment for chronic versus acute Achilles tendon rupture—a comparative analysis. Foot Ankle Surg 2018;24:110–114.
39. Boyden EM, Kitaoka HB, Cahalan TD, An KN. Late versus early repair of Achilles tendon rupture. Clinical and biomechanical evaluation. Clin Orthop Relat Res 1995:150–158.
40. Park YH, Jeong SM, Choi GW, Kim HJ. How early must an acute Achilles tendon rupture be repaired? Injury 2017;48:776–780.
41. Bullock MJ, DeCarbo WT, Hofbauer MH, Thun JD. Repair of chronic Achilles ruptures has a high incidence of venous thromboembolism. Foot Ankle Spec 2017;10:415–420.
42. Maffulli N, Ajis A. Management of chronic ruptures of the Achilles tendon. Curr Conc Rev 2008;90:1348–1360.
43. Sorrenti SJ. Achilles tendon rupture: effect of early mobilization in rehabilitation after surgical repair. Foot Ankle Int 2006;27:407–410.
44. Simmonds FA. The diagnosis of the ruptured Achilles tendon. Practitioner 1957;179:56–58.
45. Thompson TC. A test for rupture of the tendo Achillis. Acta Orthop Scand 1962;32:461–465.
46. Maffulli N. The clinical diagnosis of subcutaneous tear of the Achilles tendon. Am J Sports Med 1998;26:266–270.
47. Matles AL. Rupture of the tendo Achilles. Another diagnostic sign. Bull Hosp Joint Dis 1975;36:48–51.
48. Reiman M, Burgi C, Strube E, Prue K, Ray K, Elliott A, Goode A. The utility of clinical measures for the diagnosis of Achilles tendon injuries: a sytematic review with meta-analysis. J Athl Train 2014;49:820–829.
49. Kou J. AAOS clinical practice guideline: acute Achilles tendon rupture. J Am Acad Orthop Surg 2010;470:511–513.
50. Garras D, Raikin S, Bhat S, Taweel N, Karanjia H. MRI is unnecessary for diagnosing acute Achilles tendon ruptures. Clin Orthop Relat Res 2012;470:2268–2273.
51. Moller M, Movin T, Granhed H, Lind K, Faxén E, Karlsson J. Acute rupture of tendon Achillis. A prospective randomised study of comparison between surgical and non-surgical treatment. J Bone Joint Surg Br 2001;83:843–848.
52. Bhandari M, Guyatt G, Siddiqui F, Morrow F, Busse J, Leighton RK, Sprague S, Schemitsch EH. Treatment of acute Achilles tendon ruptures: a systematic overview and metanalysis. Clin Orthop Relat Res 2002;400:190–200.
53. Costa ML, MacMillan K, Halliday D, Chester R, Shepstone L, Robinson AH, Donell ST. Randomised controlled trials of immediate weight bearing mobilization for rupture of the tendo Achillis. J Bone Joint Surg Br 2006;88:69–77.
54. 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.
55. Metz R, Verleisdonk EJ, van der Heijden GJ, Clevers GJ, Hammacher ER, Verhofstad MH, van der Werken C. Acute Achilles tendon rupture: minimally invasive surgery versus nonoperative treatment with immediate full weightbearing—a randomized controlled trial. Am J Sports Med 2008;36:1688–1694.
56. Nilsson-Helander K, Silbernagel KG, Thomée R, Faxén E, Olsson N, Eriksson BI, Karlsson J. 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.
57. Wallace R, Heyes G, Michael A. 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;93:1362–1366.
58. Braunstein M, Baumbach S, Boecker W, Carmont MR, Polzer H. Development of an accelerated functional rehabilitation protocol following minimal invasive Achilles tendon repair. Knee Surg Sports Traumatol Arthrosc 2018;26:846–853.
59. Zhang YJ, Zhang C, Wang Q, Lin XJ. Augmented versus nonaugmented repair of acute Achilles tendon rupture: a systematic review and meta-analysis. Am J Sports Med 2018;46:1767–1772.
60. 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. Am J Sports Med 2012;40:2154–2160.
61. Mortensen N, Skov O, Jensen P. Early motion of the ankle after operative treatment of a rupture of the Achilles tendon. J Bone Joint Surg Am 1999;81:983–990.
62. Aspenberg P. Stimulation of tendon repair: mechanical loading, GDFs and platelets. A mini-review. Int Orthop 2017;31:783–789.
63. Lin TW, Cardenas L, Soslowsky LJ. Biomechanics of tendon injury and repair. J Biomech 2004;37:865–877.
64. Pajala A, Kangas J, Siira P, Ohtonen P, Leppilahti J. Augmented compared with non-augmented surgical repair of a fresh total Achilles tendon rupture. A prospective randomized study. J Bone Joint Surg Am 2009;91:1092–1100.
65. Heikkinen J, Lantto I, Flinkkilä T, Ohtonen P, Pajala A, Siira P, Leppilahti J. 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;98:85–92.
66. Shoaib A, Mishra V. Surgical repair of symptomatic chronic Achilles tendon rupture using synthetic graft augmentation. Foot Ankle Surg 2017;23:179–182.
67. Lee DK. Achilles tendon repair with acellular tissue graft augmentation in neglected ruptures. J Foot Ankle Surg 2007;46:451–455.
68. Basiglini L, Iorio R, Vadala A, Conteduca F, Ferretti A. Achilles tendon surgical revision with synthetic augmentation. Knee Surg Sports Traumatol Arthrosc 2010;18:644–647.
69. Ofili KP, Pollard JD, Schuberth JM. The neglected Achilles tendon rupture repaired with allograft: a review of 14 cases. J Foot Ankle Surg 2016;55:1245–1248.
70. Zhang YJ, Zhang C, Wang Q, Lin XJ. Augmented versus nonaugmented repair of acute Achilles tendon rupture: a systematic review and meta-analysis. Am J Sports Med 2018;46:1767–1772.
71. Berlet GC, Hyer CF, Lee TH, Blum BE. Collagen ribbon augmentation of Achilles tendon tears: a biomechanical evaluation. J Foot Ankle Surg 2014;53:298–302.
72. Wisbeck JM, Parks BG, Schon LC. Xenograft scaffold full-wrap reinforcement of Krackow Achilles tendon repair. Orthopedics 2012;35:e331–e334.
73. Magnussen RA, Glisson RR, Moorman CT 3rd. Augmentation of Achilles tendon repair with extracellular matrix xenograft: a biomechanical analysis. Am J Sports Med 2011;39:1522–1527.
74. Hsu AR, Jones CP, Cohen BE, Davis WH, Ellington JK, Anderson RB. Clinical outcomes and complications of percutaneous Achilles repair system versus open technique for acute achilles tendon ruptures. Foot Ankle Int 2015;36:1279–1286.
75. Yang B, Yang L, Kan S, Zhang D, Xu H, Liu F, Ning G, Feng S. Outcomes and complications of percutaneous versus open repair of acute Achilles tendon rupture: a meta-analysis. Int J Surg 2017;40:178–186.
76. Bartel A, 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.
77. Porter KJ, Robati S, Karia P, Portet M, Szarko M, Amin A. An anatomical and cadaveric study examining the risk of sural nerve injury in percutaneous Achilles tendon repair using the Achillon device. Foot Ankle Surg 2014;20:90–93.
78. Buono AD, Volpin A, Maffulli N. Minimally invasive versus open surgery for acute Achilles tendon rupture: a systematic review. Br Med Bull 2013;109:45–54.
79. Karabinas PK, Benetos IS, Lampropoulou-Adamidou K, Romoudis P, Mavrogenis AF, Vlamis J. Isokinetic strength and endurance after percutaneous and open surgical repair of Achilles tendon ruptures. Eur J Orthop Surg Traumatol 2014;24:607–613.
80. Tejwani NC, Lee J, Weatherall J, Sherman O. Acute Achilles tendon ruptures: a comparison of minimally invasive and open approach repairs followed by early rehabilitation. Am J Orthop 2014;43:221–225.
81. Kumar A, Bin LK, Kumar S, Upendra S, Koiri SP, Banaita D. Open versus percutaneous Achilles tendon repair: a review. Int J Sci Invent Today 2018;7:687–692.
82. Carmont MR, Heaver C, Pradhan A, Mei-Dan O, Silbernagel KG. Surgical repair of the ruptured Achilles tendon: the cost-effectiveness of open versus percutaneous repair. Knee Surg Sports Traumatol Arthrosc 2013;21:1361–1368.
83. Khan RJ. Treatment of acute Achilles tendon ruptures: a meta-analysis of randomized, controlled trials. J Bone Joint Surg Am 2005;87:2202.
84. Maele MV, Misselyn D, Metsemakers W, Sermon A, Nijs S, Hoekstra H. Is open acute Achilles' tendon rupture repair still justified? A single center experience and cirtical appraisal of the literature. Injury 2018;49:1947–1952.
85. Maffulli G. Conservative, minimally invasive and open surgical repair for management of acute ruptures of the Achilles tendon: a clinical and functional retrospective study. Muscle Ligaments Tendons J 2017;7:46.
86. Goren D, Ayalon M, Nyska M. Isokinetic strength and endurance after percutaneous and open surgical repair of Achilles tendon ruptures. Foot Ankle Int 2005;26:286–290.
87. Aracil J, Pina A, Lozano J, Torro V, Escriba I. Percutaneous suture of Achilles tendon ruptures. Foot Ankle 1992;13:350–351.
88. Grassi A, Amendola A, Samuelsson K, Svantesson E, Romagnoli M, Bondi A, Zaffagnini S. Minimally invasive versus open repair for acute Achilles tendon rupture. J Bone Joint Surg Am 2018;100:1969–1981.
89. Yilmaz G. Surgical treatment of Achilles tendon ruptures: the comparison of open and percutaneous methods in a rabbit model. Ulus Travma Acil Cerrahi Derg 2014;20:311–318.
90. Aktas S, Kocaoglu B, Nalbantoglu U, Seyhan M, Guven O. End-to-end versus augmented repair in the treatment of acute Achilles tendon ruptures. J Foot Ankle Surg 2007;46:336–340.
91. Gigante A, Moschini A, Verdenelli A, Del Torto M, Ulisse S, de Palma L. 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.
92. Schroeder D, Lehmann M, Steinbrueck K. Treatment of acute Achilles tendon ruptures: open vs. percutaneous repair vs. conservative treatment. A prospective randomized study. Orthopedic Trans 1997;21:1228.
93. Valencia A, Alcala G. Repair of acute Achilles tendon rupture. Comparative study of two surgical techniques. Acta Orthop Mex 2009;23:125–129.
94. Rozis M, Benetos I, Karampinas P, Polyzois V, Vlamis J, Pneumaticos SG. Outcome of percutaneous fixation of acute Achilles tendon ruptures. Foot and Ankle Int 2018;39:689–693.
95. Lim J, Dalai R, Waseem M. Percutaneous vs. open repair of the ruptured Achilles tendon—a prospective randomized controlled study. Foot Ankle Int 2001;22:559–568.
96. Cretnik A, Kosanovic M, Smrkolj V. Percutaneous suturing of the ruptured Achilles tendon under local anesthesia. J Foot Ankle Surg 2004;43:72–81.

97. 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.
98. McMahon S, Smith T, Hing C. A meta-analysis of randomized controlled trials comparing conventional to minimally invasive approaches for repair of an Achilles tendon rupture. Foot Ankle Surg 2011;17:211–217.
99. Ozer H, Ergisi Y, Harput G, Senol MS, Baltaci G. Short-term results of flexor hallucis longus transfer in delayed and neglected Achilles tendon repair. J Foot Ankle Surg 2018;57:1042–1047.
100. Abubeih H, Khaled M, Saleh W, Said GZ. Flexor hallucis longus transfer clinical outcome through a single incision for chronic Achilles tendon rupture. Int Orthop 2018;42:2699–2704.
101. Bradley J, Tibone J. Percutaneous and open surgical repairs of Achilles tendon ruptures. A comparative study. Am J Sports Med 1990;18:188–195.
102. Yotsumoto T, Miyamoto W, Uchio Y. Novel approach to repair of acute Achilles tendon rupture. Early recovery without postoperative fixation. Am J Sports Med 2010;38:287–292.
103. Nistor L. Surgical and non-surgical treatment of Achilles tendon rupture. J Bone Joint Surg Am 1981;63:394–399.
104. Highlander P, Greenhagen R. Wound complications with posterior midline and posterior medial leg incisions. Foot Ankle Spec 2011;4:361–369.
105. Ketterer D, Palladino S. Surgical approaches of the rearfoot and ankle. Clin Podiatr Med Surg 1991;8:401–431.
106. Lagergren C, Lindbom A, Soderberg G. Hypervascularization in chronic inflammation demonstrated by angiography; angiographic, histopathologic, and microangiographic studies. Acta Radiol 1958;49:441–452.
107. Carr AJ, Norris SH. The blood supply of the calcaneal tendon. J Bone Joint Surg Br 1989;71:100–101.
108. Aström M, Westlin N. Blood flow in the human Achilles tendon assessed by laser Doppler flowmetry. J Orthop Res 1994;12:246–252.
109. Hastad K, Larsson LG, Lindholm A. Clearance of radiosodium after local deposit in the Achilles tendon. Acta Chir Scand 1959;116:251–255. PMID: 13636761.
110. Langberg H, Bülow J, Kjaer M. Blood flow in the peritendinous space of the human Achilles tendon during exercise. Acta Physiol Scand 1998;163:149–153.
111. Boushel R, Langberg H, Green S, Skovgaard D, Bulow J, Kjaer M. Blood flow and oxygenation in peritendinous tissue and calf muscle during dynamic exercise in humans. J Physiol 2000;524:305–313.
112. Aström M. Laser Doppler flowmetry in the assessment of tendon blood flow. Scand J Med Sci Sports 2000;10:365–367.
113. Langberg H, Olesen J, Skovgaard D, Kjaer M. Age related blood flow around the Achilles tendon during exercise in humans. Eur J Appl Physiol 2001;84:246–248.
114. Kubo K, Ikebukuro T, Tsunoda N, Kanehisa H. Noninvasive measures of blood volume and oxygen saturation of human Achilles tendon by red laser lights. Acta Physiol (Oxf) 2008;193:257–264.
115. Cummins E, Anson B. The structure of the calcaneal tendon (of Achilles) in relation to orthopedic surgery, with additional observations on the plantaris muscle. Surg Gynecol Obstet 1946;83:107–116.