

# Clinical Outcomes and Cadaveric Biomechanical Analysis of Endoscopic Percutaneous Achilles Tendon Rupture Repair With Absorbable Suture

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## Abstract

**Background:** Percutaneous repair of acute Achilles tendon rupture (ATR) continues to gain in popularity. The primary aim of the study was to review the outcomes of a patient cohort undergoing a novel technique of endoscopic percutaneous Achilles tendon repair with absorbable suture. A secondary purpose of this study was to evaluate the basic biomechanical properties of the technique.

**Methods:** A cohort of 30 patients who underwent percutaneous ATR repair was retrospectively analyzed with Achilles Tendon Rupture Scores (ATRS), complications, and additional outcome measures. For a biomechanical analysis portion of the study, 12 cadaveric specimens were paired and randomized to either novel percutaneous repair or open Kessler repair with absorbable suture. These specimens were subjected to 2 phases of cyclical testing (100 cycles 10-43 N followed by 200 cycles 10-86 N) and ultimate strength testing.

**Results:** In the clinical portion of the study we report excellent patient reported outcomes (mean ATRS 94.1), high level of return to sport, and high patient satisfaction. One partial re-rupture was reported but with no major wound or neurologic complications. In the biomechanical portion of the study we found no significant difference in tendon gapping between percutaneous and open repairs in phase 1 of testing. In phase 2, increased gapping occurred between percutaneous (17.8 mm [range 10.7-24.1, SD 6.4]) and open repairs (10.8 mm [range 7.6-14.9, SD 2.7,  $P = .037$ ]). The ultimate load at failure was not statistically different between the 2 repairs.

**Conclusions:** A percutaneous ATR repair technique using endoscopic assistance and absorbable suture demonstrated low complications and good outcomes in a cohort of patients, with high satisfaction, and excellent functional outcomes including high rates of return to sport. Cadaveric biomechanical testing demonstrated excellent survival during testing and minimal increase in gapping compared with open repair technique, representing sufficient strength to withstand forces seen in early rehabilitation. A percutaneous Achilles tendon repair technique with absorbable suture may minimize risks associated with operative repair while still maintaining the benefit of operative repair.

**Level of Evidence:** Level IV, retrospective case series.

**Keywords:** percutaneous, Achilles, repair, biomechanical, outcomes

## Introduction

Acute Achilles tendon ruptures represent common injuries, occurring most frequently in male recreational athletes with mean reported age ranging from 30 to 47 years of age.<sup>7,15</sup> The incidence of these injuries has been estimated at 31 per 100 000 per year, with evidence of increasing frequency.<sup>5</sup> Acute Achilles tendon ruptures require prompt intervention, as neglected injuries are associated with significant

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functional impairment.<sup>9</sup> Although these injuries can be managed effectively with both nonoperative and operative treatment, there remains debate in the literature as to the optimal treatment.<sup>18,27,37,38</sup> Functional outcomes following nonoperative management have been reported as excellent, especially with more recent accelerated rehabilitation programs.<sup>37</sup>

Despite the reported success of nonoperative management, several randomized controlled trials have demonstrated better strength, lower rerupture rates, and quicker return to work with operative treatment.<sup>18,28,37</sup> Many argue that operative management remains the optimal treatment in the younger, physically active patient.<sup>22</sup> Nonetheless, there remain inherent operative risks and increased costs associated with operative treatment.<sup>29,35,41</sup> Operative repair of Achilles tendon rupture has traditionally involved a posterior ankle incision measuring 4 to 10 cm in most reports.<sup>12,24</sup> One of the primary risks associated with open operative management is potential wound complications,<sup>29</sup> reported to occur in up to 5% to 12% of cases,<sup>1,18,33,37</sup> related to the relatively poor vasculature of overlying soft tissue and the subcutaneous nature of the Achilles tendon.<sup>14,42</sup>

In 1977, Ma and Griffith reported a series of patients who had undergone a novel percutaneous operative repair with good results, thus avoiding some of the potential complications associated with a large posterior Achilles incision.<sup>14,23</sup> Since that time, there have been multiple patient cohorts and various iterations on minimally invasive and percutaneous operative techniques.<sup>3,11,20,21</sup> In exchange for decreased wound complications, increased injury to the sural nerve has been reported as a primary complication of these techniques.<sup>41</sup> Additionally, some report a trend toward higher rerupture rates in percutaneous repair vs open repair.<sup>3</sup> Furthermore, some cadaveric studies report decreased biomechanical strength of percutaneous repair techniques in comparison to traditional open repairs.<sup>2,8,11,34</sup> Although ultimate outcomes remain similar, percutaneous repair has been shown to have decreased complications especially with regard to wound healing.<sup>3,24</sup> The ideal operative treatment is thus one that combines the benefits of operative repair while minimizing associated operative risk. We have implemented a modification on the percutaneous technique that we feel accomplishes this goal. This study is a retrospective review of the clinical outcomes of a patient cohort as well as a biomechanical study of this novel repair technique.

## Methods

### Clinical Outcomes

From 2014 to 2017, 32 patients with an acute Achilles tendon rupture were treated operatively by percutaneous technique by a single fellowship-trained foot and ankle surgeon at an academic medical center. This technique was indicated for acute Achilles rupture, with a goal of operative treatment within 14 days of injury. Distal Achilles avulsion injuries

were not indicated for the technique as it is described. This technique was also not indicated for chronic tears or when tendon augmentation with allograft or tendon transfer is anticipated.

Inclusion criteria were patients age 17 years or older who had elected to undergo operative repair of an acute (less than 14 days) closed Achilles tendon rupture. Patients were excluded if they had previous ipsilateral Achilles tendon surgery or rupture. Diagnosis of acute Achilles tendon rupture was based primarily on clinical examination—a palpable tendon gap, a positive Thompson test, and decreased plantarflexion from the contralateral side. Confirmatory imaging (ultrasonography or magnetic resonance imaging) was available on half of the patients. An informed discussion was had with all patients, and through shared decision making, either nonoperative or operative management was chosen. The operative option presented to all patients in our clinic was the author's preferred technique of percutaneous repair as described. Institutional review board approval was obtained prior to performing retrospective chart review and contacting patients.

A retrospective chart review was performed on all operatively treated patients. The following information was collected: medical history, smoking history, initial management, time to surgery, diagnostic modality, length of surgery, return to sport (if available), and postoperative complications. The average age was 31.6 (range 17-64, SD 10), including 23 men and 7 women (Table 1). Average time to final follow-up was 28 months (range 15-45 months). Eligible patients were contacted via telephone and the following further information collected: Achilles Tendon Rupture Score (ATRS), visual analog scale (VAS) pain scores, satisfaction Likert scale scores, return to sport, and patient-reported complications. The ATRS is a validated outcome measure specifically designed to evaluate functional limitations associated with Achilles tendon injury.<sup>7</sup>

Thirty-two patients were initially included in the clinical portion of this study. Two patients were excluded for intraoperative conversion to a mini-open approach because of technical challenges intraoperatively. Of the 30 patients ultimately included we performed a chart review on all patients and were able to reach 22 (73%) by telephone for interview. Ten percent of the patients (3/30) had significant medical history (1 patient with coronary artery disease and hypertension, 1 with type 1 diabetes, and 1 with asthma). Seven percent of patients used tobacco products (1 patient smoked 5 cigarettes a day; the other smoked 2 cigars a day). Mechanism of injury was basketball in 67%, other sports (football, soccer, cheerleading, tennis, and pickleball) in 30%, and 1 injury while pushing a car (Table 1). Clinical examination findings (as previously described) and a supporting history were considered sufficient for diagnosing acute Achilles rupture in our clinic. Nonetheless, confirmatory imaging of acute Achilles rupture was available for 50% of patients (9 magnetic resonance imaging; 6 ultrasonography). Unremarkable plain radiographs were obtained in 33% of patients

**Table 1.** Patient Demographics, Injury Mechanism, Initial Treatment, Final Follow-up, and Return to Sport.

No.	Age/Sex	Injury Mechanism	Days to OR/Initial Treatment	Final Follow-up, mo	Return to Sport
1	39/M	Basketball	5 (splint)	45.6	No
2	20/M	Basketball	8 (splint)	38.4	Yes
3	17/F	Basketball	9 (splint)	38.4	Yes
4	32/F	Frisbee	4 (splint)	37.2	Yes
5	22/F	Basketball	7 (splint)	36	Yes
6	21/F	Volleyball	3 (splint)	36	Yes
7	21/M	Jumping	7 (splint)	34.8	Yes
8	27/M	Basketball	3 (splint)	34.8	Yes
9	33/M	Basketball	9 (splint)	34.8	No
10	23/M	Football	4 (splint)	34.8	Yes
11	22/F	Cheerleading	5 (splint)	31.2	No (cheerleading)
12	64/M	Pickleball	12 (splint)	30	No
13	33/M	Basketball	4 (splint)	27.6	No
14	25/M	Basketball	5 (splint)	26.4	Yes
15	36/M	Basketball	14 (boot)	25.2	Yes
16	40/M	Basketball	10 (boot)	25.2	Yes
17	18/F	Basketball	7 (splint)	24	Yes
18	28/M	Football	6 (none)	24	Yes
19	40/M	Basketball	2 (splint)	24	Yes
20	42/M	Basketball	10 (boot)	24	Not available
21	28/M	Basketball	4 (splint)	22.8	Yes
22	41/M	Pushing car	13 (splint)	22.8	NA (non-sport)
23	33/M	Basketball	4 (splint)	22.8	Yes
24	31/M	Basketball	4 (splint)	21.6	Yes
25	45/M	Tennis	8 (splint)	21.6	Yes
26	34/M	Basketball	7 (splint)	21.6	Yes
27	18/M	Basketball	5 (splint)	21.6	Yes
28	49/M	Basketball	4 (splint)	20.4	Yes
29	29/M	Basketball	7 (splint)	20.4	Yes
30	23/F	Soccer	2 (splint)	15.6	Yes

Abbreviations: F, female; M, male; NA, not applicable; OR, operating room.

and no imaging in 23% patients. Initial treatment from the emergency department, urgent care, or clinic after injury was splint in 83% of patients and walking boot in 10%, and 7% had no initial immobilization. Mean time from injury to surgery was 6.8 days (range 2-14, SD 3.7).

### Preoperative Planning

Acute rupture of the Achilles must be confirmed preoperatively, either via reliable clinical examination or imaging study such as ultrasonography or magnetic resonance imaging. The senior author finds these imaging studies to be helpful, but not required, depending on the clinical history and examination. Imaging can be helpful in evaluating the quality of the tendon and extent of any retraction prior to surgery. The surgeon must be able to identify the location of the tear, which is typically easily palpated, in order to accurately place the transverse rupture site incision. Imaging studies may also be used to assist in this endeavor if it is not obvious clinically.

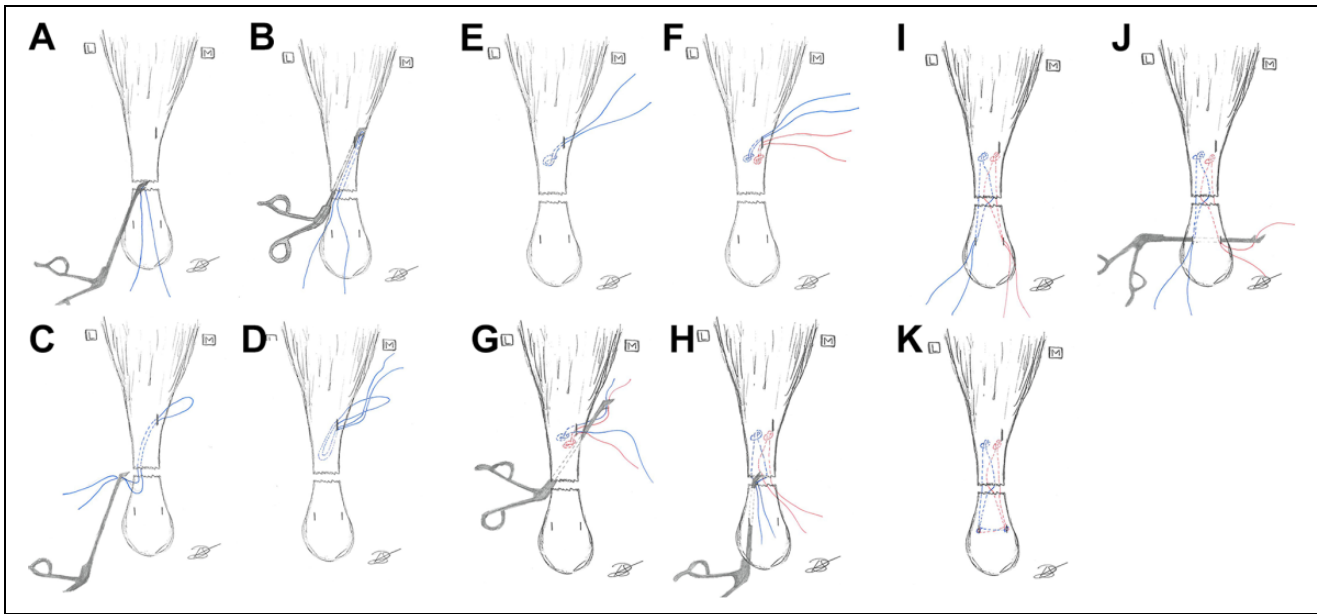
Prone positioning is required for the surgery, and thorough preoperative medical evaluation is recommended to

ensure that the patient has no cardiovascular or pulmonary contraindications to this positioning.

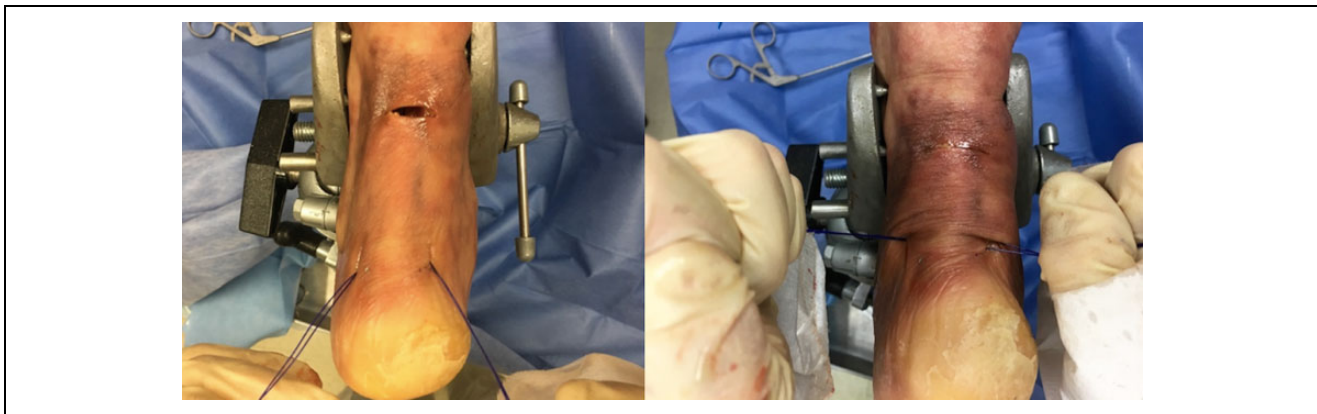
### Technique

**Operative Technique.** All patients are placed into the prone position with a pneumatic thigh tourniquet in place. The operative leg is then elevated and the tourniquet inflated to 250 mmHg. Two portals are made at the level of the tendon insertion onto the calcaneus, and a single transverse 1-cm incision at the level of the palpable rupture. Using the blunt entry trochar, a 4.0-mm arthroscope is placed in the distal lateral portal and used to visualize the ruptured tendon, using the shaver through the incision at the level of the rupture to debride the rupture site.

A Kocher is placed inside the sheath to grasp the proximal tendon. A sharp pointed suture passer is then used to pass a loop of no. 1 polydioxanone absorbable suture into the rupture site transverse incision (Figure 1A), through the tendon, and out a proximal medial incision at the level of the distal posteromedial gastrocnemius belly (Figure 1B). The suture passer is removed and then inserted again through the transverse rupture incision site with the 2 tails of the suture loop,



**Figure 1.** (A-K) Percutaneous repair technique.



**Figure 2.** Cadaveric pictures of the final step of the procedure securing the repair and thus bringing the ankle in plantarflexion.

and up through the same proximal medial incision (Figure 1C). Outside the proximal medial incision, the tails are passed through the loop and cinched tightly (Figure 1D, E). A second suture is passed in the same manner, creating a second cinch (Figure 1F). No proximal lateral incision is made so as to minimize risk to the sural nerve.

The suture passer is passed again from distal at the transverse incision site to the proximal medial incision and the previously passed sutures will be pulled distally in a crossed manner, pulling one suture from each cinch in 2 separate passes (Figure 1G). The arthroscope is removed at this point. Through the distal lateral incision at the tendon insertion, the suture passer is placed, grasping 2 sutures after they are crossed again. The same passing is then performed through the distal medial incision (Figure 1H, I). One suture from each pair, performing the third and final crossing of sutures, is passed to the other side transversely using the suture

passer across the 2 distal poke holes (Figure 1J). The sutures are then tied together on each side, pulling the foot into plantarflexion (Figures 1K and 2). The foot is held by an assistant in a plantarflexed position, and the skin is closed with nylon suture. The patient is then placed into a well-padded plantarflexion resting splint for 10-14 days prior to beginning early mobilization rehabilitation.

### *Postoperative Management*

The rehabilitation program used in this study involved early protected weightbearing and is adapted from that reported by Willits et al<sup>37</sup> in 2002. This is summarized in Table 2 and involves a 2-week nonweightbearing period followed by slow advancement of motion, weightbearing, weaning of a heel lift, and strengthening throughout the rehabilitation period. Traditional rehabilitation protocols have involved

**Table 2.** Summary of Rehabilitation Protocol.<sup>a</sup>

Time Frame	Activity
0-2 wk	Nonweightbearing with crutches; splint immobilization postoperatively
2-4 wk	Protected weightbearing with crutches Walking boot with total height 3-cm heel lift Active plantar flexion and dorsiflexion to neutral.
4-6 wk	Weightbearing as tolerated in boot Remove 1 cm/wk of heel lift until none at 6 wk Continue active plantar flexion and dorsiflexion to neutral
6-8 wk	Careful dorsiflexion stretching Continued weightbearing as tolerated in boot Begin careful resistance training
8-12 wk	Wean off boot Advance strength and range of motion
>12 wk	Power and resistance training Return to sport training

<sup>a</sup>Adapted from Willits et al.<sup>37</sup>

long periods of cast immobilization from 6 to 8 weeks.<sup>4</sup> In multiple studies, early progressive weightbearing and ankle motion has proven to be of benefit in both operative and nonoperative treatment and thus is used in our practice for both operative and nonoperatively managed Achilles tendon rupture.<sup>17,32</sup> Patients are typically followed for 6-9 months postoperatively, until they have completed rehabilitation and are starting to return to athletic activities.

**Biomechanical strength testing technique.** As a separate analysis of the operative technique, a small cadaveric biomechanical trial of the technique was performed. We obtained a total of 12 fresh-frozen lower extremity cadaver specimens (midtibia to toes). The mean age of the specimens was 71.5 years (range 48-49). These were age and sex matched for 4 female pairs and 2 male pairs. One specimen from each pair was randomly assigned to either an open (n=6) or percutaneous (n=6) repair group. The Achilles tendon in all 12 specimens underwent complete transverse tenotomy through a small, 1-cm transverse incision 6 cm proximal to the calcaneal insertion. Each specimen was then repaired by either open or percutaneous technique. The open repair procedure was an open Kessler repair performed through a 5-cm midline incision centered over the rupture site with 4 strands crossing the tenotomy (Figure 3). The same suture (no. 1 polydioxanone) was used for both the open Kessler and percutaneous repairs.

Each specimen was mounted to the materials testing system (8500 plus, Instron Inc, Norwood, MA). Each specimen was then pretensioned with 10 N force. A medial and a lateral differential variable reluctance transformer (DVRT; M-DVRT-9, Lord Corporation, Williston, VT) were placed spanning the tenotomy to record

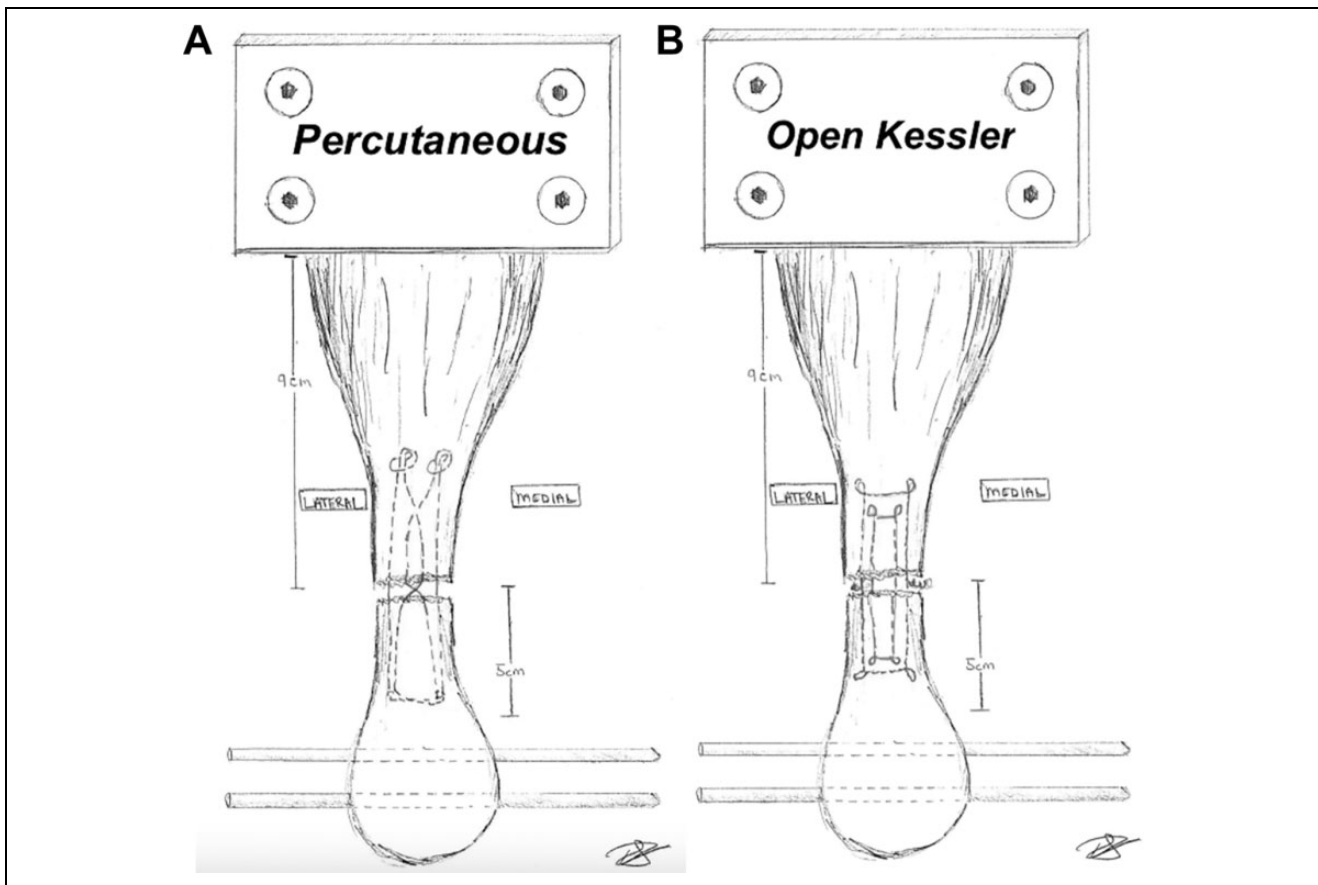
displacement during cycling (Figure 4). During phase 1 of testing, the specimens were subjected to 100 cycles of loading between 10 and 43 N at a frequency of 0.5 Hz. During phase 2 of testing, they were then subjected to 200 cycles of loading between 10 and 86 N at the same frequency. These values were selected based on estimates of stress encountered during postoperative rehabilitation.<sup>25</sup> Once displacements exceeded the range of DVRTs, secondary displacement was recorded via actuator displacement. Following the final phase of testing, the ultimate failure load and displacement at ultimate load of each tendon was determined by applying distraction at a rate of 6 mm/s until gross failure occurred. DVRT and actuator displacements and loads were recorded at 100 Hz during testing. A paired Student *t* test was used to compare the cyclic gap displacements and tensile failure properties of the percutaneous repairs to the open repairs.

## Results

### Clinical Study

Mean tourniquet time was 25 minutes (range 15-40 minutes, SD 6.5). There was no significant correlation ( $R = 0.26$ ,  $P = .17$ ) between time to surgery and length of procedure. Final VAS scores were available on all patients with an average postoperative score of 0.3 (range 0-2, SD 0.6), 95% reported being very satisfied with their outcome and 5% reported being somewhat satisfied. Mean ATRS was 94.1 (range 81-100, SD 4.8) and did not show any significant correlation between patient age, time to surgery, tourniquet times, or length of follow-up. Eighty-two percent of patients returned to the sports that caused their injury. One patient sustained a nonsporting injury and for 1 patient return to sport information was not available. Four of the 5 patients who did not return to their prior sport reported a fear of rerupture, and 1 of the 6 was no longer involved in that activity (cheerleading).

**Biomechanical study.** All 12 cadaveric specimens survived initial phase 1 testing of 100 cycles of loading between 10 and 43 N, and 11 of 12 specimens survived the phase 2 testing of 200 cycles of loading between 10 and 86 N. During phase 1, the mean gapping of the percutaneous specimens is reported in Table 3. The mean combined (medial and lateral DVRTs) phase 1 displacement was 2.25 mm in the percutaneous repair and 3.65 mm in the open repair. During phase 2, there was increased displacement in the percutaneous repair group (Table 3) ( $P = .038$ ). One of the 6 percutaneous specimens had early failure, with gapping exceeding 30 mm. Failure in this specimen was due to suture pullout of the proximal tendon. In testing to failure, the percutaneous specimens exhibited a mean ultimate load of 210 N (range 118-432 N, SD 128), and the open specimens exhibited a mean ultimate load of 224 N (range 130-256 N, SD 49). The final gapping at ultimate load was 23.1 mm



**Figure 3.** (A) Percutaneous repair testing setup, and (B) 4-strand Kessler repair setup.

(range 14-29.2 mm, SD 6.5) in the percutaneous specimens and 15.7 mm (range 9.6-16.5 mm, SD 5.7) ( $P = .139$ ) in the open group. The mechanism of failure in the percutaneous group was pullout of the proximal suture fixation in the majority of specimens (5/6) and suture failure in one. The mechanism of failure in the open group was suture breakage in the majority (5/6) and pullout of the proximal suture fixation in one.

**Abbreviation:** DVRT, differential variable reluctance transformer.

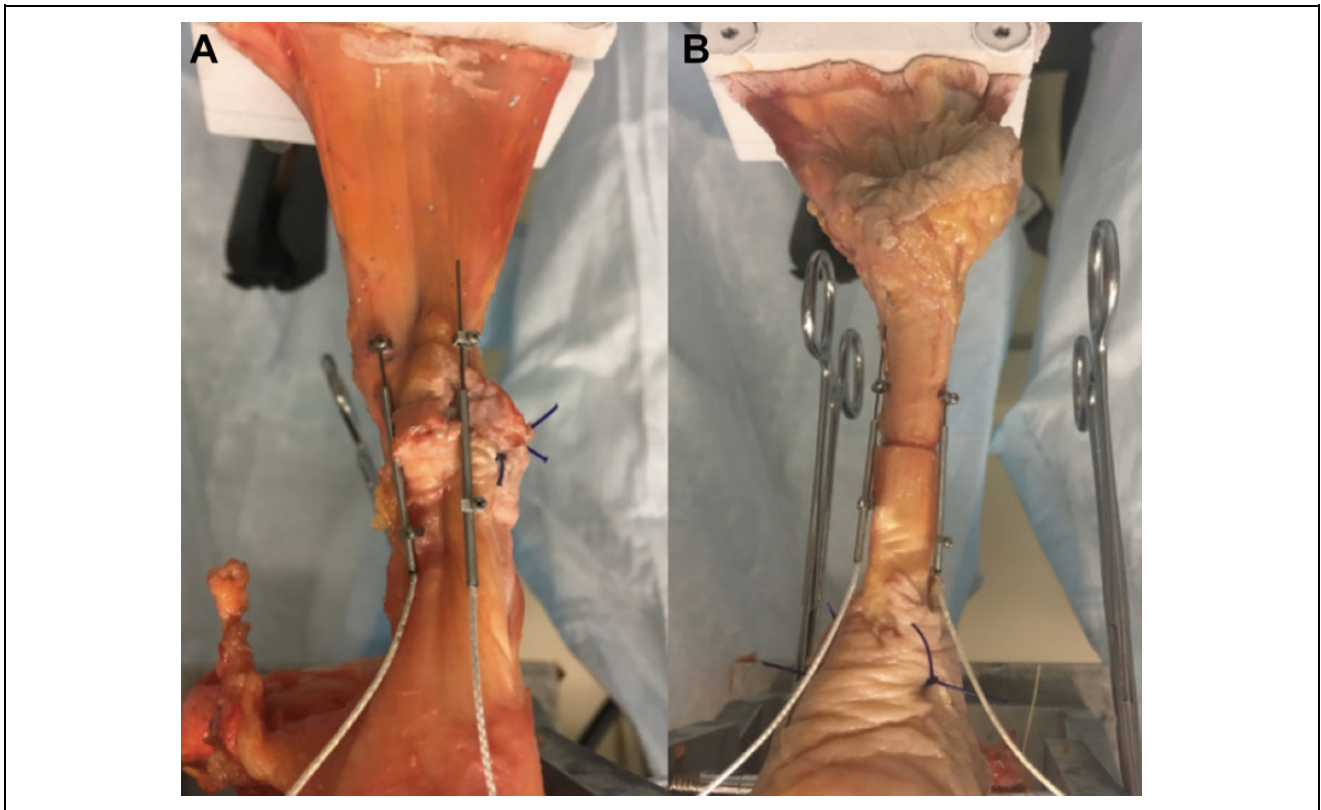
### Complications

We report an overall complication rate of 6.5% (2/30). We had 1 partial rerupture (confirmed on ultrasonograph to involve less than 50% of tendon width) that occurred 2 months postoperatively during physical therapy. After being given operative and nonoperative options for the rerupture, this patient was treated nonoperatively with the same rehabilitation protocol with a good outcome. Additionally, 1 patient had mild drainage from the distal portal site, which responded promptly to oral antibiotics. No DVTs or sural nerve injuries were recorded.

### Discussion

Although percutaneous repair of acute Achilles tendon rupture has gained in popularity, the ideal treatment remains controversial. Some continue to advocate for an open repair because of concerns of inferior biomechanical strength with percutaneous techniques, whereas others report good outcomes with nonoperative management and early motion rehabilitation.<sup>37</sup> In light of the continued controversy, operative treatments should seek to minimize complications while still optimizing function. Our study sought to do that in all aspects, from operative technique to choice of suture.

The aim of the clinical portion of this study was to review a cohort of patients having undergone this novel repair and assess outcomes and complications. The most important finding of our study was the excellent functional outcomes and high return to sport in patients undergoing this novel method of endoscopically assisted percutaneous repair. Patient-reported outcomes in our cohort equal or exceed many of those in similar cohorts with an average ATRS score of 94.1 (81-100, SD 4.8).<sup>4</sup> Additionally, we saw a high rate of return to sport, even in collegiate athletes. Three perfect scores (ie, 100) were collected, demonstrating ceiling effect of the ATRS in 10% (3/30) of the cohort. Two of these 3 were in high-level athletes and truly



**Figure 4.** Testing setup on the materials testing system with medial and lateral differential variable reluctance transformers in the (A) percutaneous and (B) open repairs.

**Table 3.** Displacement Data (mm) of the Percutaneous and Open Repairs in Phase I and Phase 2 of Testing.

	Percutaneous, Mean (Range, SD)	Open, Mean (Range, SD)	P Value
Phase I (10-43 N × 100 cycles)			
Medial DVRT	2.5 (0.3-5.2, 2.1)	3.9 (2.8-4.5, 0.8)	.159
Lateral DVRT	17.8 (10.7-24.1, 6.4)	10.8 (7.6-14.9, 2.7)	.138
Phase 2 (10-867 N × 200 cycles)			
Actuator displacement	17.8 (10.7-24.1, 6.4)	10.8 (7.6-14.9, 2.7)	.037

endorsed “normal” function. Of note, although the ATRS is a validated outcome measure, it provides only patient-reported outcomes and thus is not equipped to directly assess the biomechanical properties of the tendon repair such as pullout strength or tendon elongation.<sup>35</sup> These metrics may only be assessed indirectly through patient reports of push-off strength, for example, and thus are better evaluated through the biomechanical portion of this study as described below.

Our rerupture rate of 3% is comparable to generally reported rates for operative management.<sup>5,28,38</sup> Those using the original percutaneous technique of Ma and Griffith<sup>23</sup> reported higher rerupture rates of up to 10%.<sup>5,6</sup> As more modifications have been made on the percutaneous technique, rerupture rates are generally reported as equal to that

of open repair.<sup>4</sup> Sural nerve injury has also been reported as a unique complication in percutaneous repair. There were no cases of sural nerve injury in this cohort as we avoid using a proximal lateral incision. Prior to the study period, the senior author used a similar technique that included a proximal lateral incision, which resulted in 2 patients with sural nerve injuries. The current technique includes only a proximal medial incision, and we have thus subsequently avoided sural nerve injury. In line with results from a recent meta-analysis showing a significantly decreased risk ratio of 0.21 for complications after minimally invasive surgery, this study adds to a growing body of evidence that percutaneous or minimally invasive treatment of Achilles tendon ruptures provides excellent outcomes with significantly fewer complications than open repair.<sup>3,8</sup>

As even more percutaneous techniques are reported with good results and low complications, the regular use of an open repair may be increasingly less desirable.<sup>24</sup> Though this is a relatively small patient cohort, we believe this study establishes basic biomechanical properties of this repair technique as well as convincing evidence for its clinical safety and efficacy.

The aim of the cadaveric portion of this study was to establish the basic biomechanical properties of our described technique. We chose the double Kessler repair for the control group as this suture configuration best reflects what we are attempting to accomplish with our percutaneous configuration. Many suture configurations for open repair have been tested for their biomechanical strength in the treatment of acute Achilles tendon rupture.<sup>2,8,13,26</sup> McCoy et al found the double Kessler repair equivalent in strength to both the Krackow and Bunnell suture configurations in a human cadaveric model.<sup>26</sup> Despite this, some express concerns that the multiple locking suture loops (as in a Krackow repair) can jeopardize tendon vascularity when compared to other techniques such as a Kessler suture.<sup>24,36</sup> The percutaneous technique avoids this concern.

The use of an absorbable suture such as no. 1 polydioxanone has been shown in several studies to be associated with lower wound complications.<sup>19</sup> Kocaoglu et al<sup>20</sup> prospectively assigned 48 patients with acute Achilles ruptures to absorbable vs nonabsorbable suture fixation and found significantly lower complications in the absorbable group with equal functional outcomes.<sup>19</sup> Additionally, there are multiple reports of significant complications related to the use of nonabsorbable sutures including late sinus tract formation.<sup>1,16</sup> One potential downside of an absorbable suture such as polydioxanone is an estimated 50% lower ultimate strength compared with some commonly used nonabsorbable polyblend sutures of similar size.<sup>40</sup> Nonetheless, it maintains a single-strand strength greater than 150 N, which was independently validated in our study.<sup>34</sup> In previous studies using polydioxanone, the modified double Kessler suture has shown similar results to other repair techniques though with failure occurring via suture pullout rather than suture breakage.<sup>13,34</sup> This type of failure might justify the use of an absorbable, though biomechanically weaker, suture in percutaneous repair. We thus advocate for the use of an absorbable suture for its proven role in further decreasing wound complications without obvious detriment to clinical outcome.

The strength of many percutaneous repair techniques has been tested and in some cases is equivalent to open repairs whereas in others it is biomechanically inferior.<sup>2,11</sup> In the ultimate strength testing of our specimens, we did not find a statistically significant difference in ultimate strength between the percutaneous repair group and the open modified double Kessler repairs. We did find increased variability in the percutaneous group (ultimate load 118–442 N). This finding has been reported in other percutaneous techniques as well.<sup>2,8</sup> In our study, we attribute this to both the

percutaneous nature of the procedure as well as the lack of endoscope visualization in the cadaveric specimens. Though many percutaneous techniques might be considered a “blind” procedure, we feel the use of an endoscope helps mitigate this downside. This technique of endoscopically assisted repair is not novel to our series and has been reported in previous studies with favorable results.<sup>3,10,30,31</sup> Halasi et al<sup>11</sup> reported a large series of percutaneous repairs with and without endoscopic control and had fewer reruptures in the endoscopic group, thus concluding that this technique allows for a more thorough evaluation of tendon apposition after repair.<sup>10</sup> Though reasonable, we do not routinely do this with our technique.

Tendon gapping after repair is also commonly reported, and was similarly found in our cadaveric study. Both the percutaneous and open repairs gapped, although the extent of gapping was not significantly different between groups. Thus, although the percutaneous technique appeared to be noninferior compared with the open technique with regard to gapping, we cannot advocate for the percutaneous technique’s superiority in this metric.

The force parameters used in our study represent previously reported values thought to be encountered during early rehabilitation.<sup>25</sup> Whether operatively sutured or treated nonoperatively, tendon apposition can typically be achieved with little to no stress by maintaining minimal plantarflexion of the foot.<sup>37,39</sup> With this in mind, it is possible that the ultimate benefit of operative management is maintenance of closer tendon apposition without actually providing full strength to withstand near maximal loading. Although the necessary strength of repair to withstand early rehabilitation remains debatable, the endurance of our specimens throughout the testing using previously established force parameter guidelines suggests adequate strength to endure typical early postoperative rehabilitation protocols. Because establishing discrete force parameters encountered during typical rehabilitation protocols was beyond the scope of this study, interpretation of the repair strength in the clinical context of rehabilitation remains limited by prior knowledge.

A major limitation of the current clinical study is lack of randomization and lack of a control group. The lack of a clinical control group limits our ability to perform a side-by-side comparison of the 2 techniques, controlling for confounding variables, and instead requires comparison to the literature to contextualize our results. Although the complication rate identified in this study is comparable to studies performed by other investigators, without a control group, its results should be interpreted cautiously. Second, the number of cadaveric specimens included in the biomechanical portion of this study was small, and our analysis may be underpowered in identifying further differences between repair methods. The biomechanical study also has no way to address active early motion and weightbearing, with the healing of tissues that occurs in the first 2 weeks of immobilization in the rehabilitation protocol. Finally, though we believe that this procedure is technically straightforward and



reproducible, there remains an associated learning curve as it relates to the endoscope and percutaneous passing of the sutures. This learning curve could potentially limit its widespread implementation for those who are less familiar with endoscopic and percutaneous techniques.

We are left to consider the discordance between the inferior biomechanical cadaveric findings of the biomechanical repair and the high functional outcomes in the clinical study. If one assumes that postoperative tendon elongation is an important clinical factor, and that the ATRS is both sensitive enough and without ceiling effect to show clinical differences, a conclusion could be that initial early healing, unmeasurable in a cadaver, is critical to the clinical outcome. A percutaneous technique with apparently weaker time 0 suture strength thus relies on the known ability of the body to heal an Achilles rupture, having been demonstrated in the nonoperative treatment literature.

In conclusion, this combined biomechanical and clinical pilot study reports on a novel technique that delivers the advantages of operative treatment while minimizing potential risks. The percutaneously repaired cadaveric specimens demonstrated equivalent strength to an open repair control group, though with increased interspecimen variability. The clinical cohort undergoing the novel method of percutaneous fixation demonstrated excellent functional outcomes, low pain scores, high return to activity, and low complications.

### Ethics Approval

Ethical approval for this study was obtained from UNC Chapel Hill Biomedical Institutional Review Board, Study # 17-2011.

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

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