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Proximal and Distal Failure Site Analysis in Percutaneous Achilles Tendon Rupture Repair

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Abstract

Background: Different techniques have been described for percutaneous Achilles tendon rupture repair, but no biomechanical evaluation has been performed separately for proximal and distal suturing techniques. The purpose of this study was to biomechanically analyze proximal versus distal percutaneous Achilles suture configurations during cyclic loading and load to failure.

Methods: A simulated, midsubstance rupture was created 6 cm proximal to the calcaneal insertion in fresh-frozen cadaveric Achilles tendons. Fifteen proximal specimens were divided into 3 groups: (A1) triple locking technique, (A2) Bunnell-type technique, and (A3) double Bunnell-type technique. Twelve distal specimens were divided into 2 groups: (B1) triple nonlocking technique and (B2) oblique technique. Repairs were subjected to cyclic testing and load to failure. Load to failure, cause of failure, and tendon elongation were evaluated.

Results: None of the proximal specimens and 7/12 of the distal ones failed in cyclic testing. The proximal fixation groups demonstrated significantly more strength than the distal groups ($P = .001$), achieving up to 710 N of failure load in Group A3. Groups B1and B2 failed on average at 380 N with no difference between them ($P > .05$). The majority of all repairs failed in the suture-tendon interface. Distal groups had more elongation during cyclic testing (13.7 mm) than proximal groups (9.4 mm) ($P = .02$).

Conclusion: The distal fixation site in this Achilles tendon repair was significantly weaker than the proximal fixation site. A proximal modified suture configuration increased resistance to cyclic loading and load to failure significantly.

Clinical Relevance: A modification can be suggested to improve strength of the Achilles repair.

Keywords: Achilles tendon, Achilles tendon rupture, Achilles percutaneous repair, minimally invasive Achilles repair, biomechanical analysis, cyclic loading

Introduction

Achilles tendon rupture is a frequent condition,[2,10] especially in middle-aged men during recreational activities. Different treatment options have been proposed. Nonoperative management is a viable option for nonactive adults who can tolerate to be immobilized for long periods[22]; surgical repair is often preferred in active and healthy patients hoping to achieve a better return to sports activity.[8] There is no consensus on the best surgical repair approach, either open or percutaneous.[6,13,17] Recent research suggests that percutaneous techniques combine a reduced operating time, low complication rates, and improved wound healing, but also possess an increased risk of iatrogenic sural nerve damage.[9,17,20] Open and percutaneous repairs also present differences in biomechanical comparisons. Some studies have reported percutaneous repairs to be stronger than open repairs, whereas others have demonstrated percutaneous

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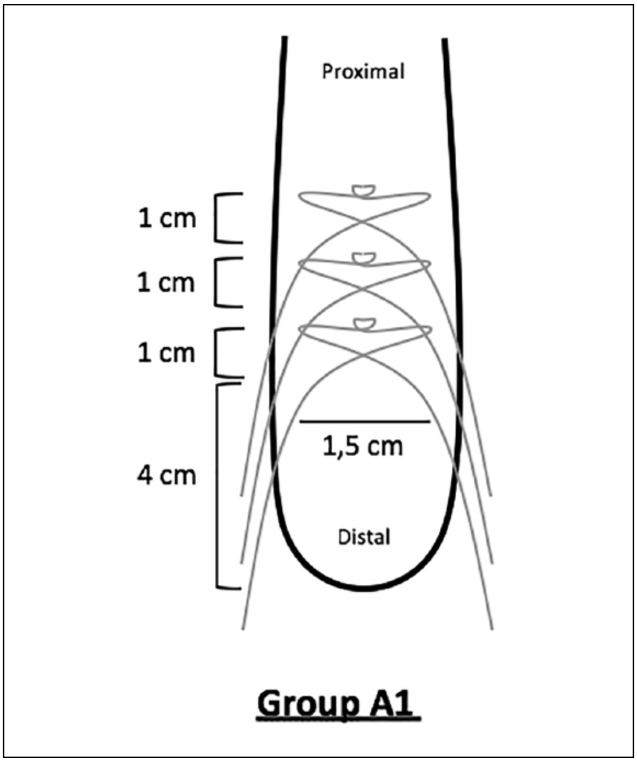

Figure 1. Diagram of a proximal Achilles stump sutured with the triple locking technique (group A1). Three sutures are tied to the stump starting distally in a crisscross fashion. Five half-knots were created for each stitch and each knot was separated by 1 cm. The repair construct started 4 cm proximal to the rupture site.

repairs to be weaker and more susceptible to elongation.[12,16,18] A limitation of all biomechanical cadaveric studies is that they only represent what happens at time zero in vivo because there is no healing process in a cadaver study; what happens in the postoperative period regarding repair performance is not possible to accurately estimate. Another limitation of most studies is that no separate analysis has been performed comparing distal and proximal fixation site strengths. Every construct is analyzed and tested as a unit with no specific analysis on where different constructs specifically fail. Therefore, it is not possible to identify the specific weaknesses and failure areas of the available techniques. By isolating the different components of a repair, improvement of the available techniques is possible.

The main purpose of this biomechanical study was to separately analyze different proximal and distal fixation site suture configurations of a mini-open Achilles tendon repair during a cyclic-load and load-to-failure test. Our first hypothesis was that distal fixation site repairs would prove to be stronger than proximal fixation site repairs. Our second hypothesis was that a double Bunnell-type technique would be stronger than the triple locking technique (modified Dresden).

Methods

Fifteen fresh-frozen cadaveric Achilles tendons were used. All specimens belonged to individuals younger than 65 years without previous surgery or visible pathology. A simulated, midsubstance rupture was created 6 cm proximal to the calcaneal insertion in each tendon with a scalpel, resulting in 15 proximal tendon stumps (including the whole gastrocsoleus complex) and 15 distal tendon stumps (dissected off the calcaneus). Of the 15 distal stumps, 3 had to be discarded because of poor tissue quality.

Surgical technique

A total of 27 specimens were separated into 2 groups. Group A had 15 proximal Achilles specimens that were separated into 3 sections with different suturing techniques: (group A1, 5 specimens) triple locking technique (modified Dresden); (group A2, 5 specimens), Bunnell-type technique and (Group A3, 5 specimens) double Bunnell-type technique. Group B had 12 distal specimens that were separated into 2 sections: (group B1, 6 specimens) triple nonlocking technique (modified Dresden and (group B2, 6 specimens) oblique technique. All surgical repairs were performed by the same foot and ankle fellowship-trained orthopedic surgeon using Number 2 FiberWire suture (Arthrex, Naples, FL). The samples were continuously hydrated with saline solution to prevent desiccation and preserve tissue resiliency.

The classic Dresden technique for Achilles tendon rupture repair is performed using a straight needle for passing 2 sutures through the distal stump of the Achilles tendon. For this technique, the first suture is placed 1 cm proximal to the calcaneal insertion of the tendon, and the second suture is placed parallel and 1 cm proximal to the first. The sutures are then placed into the proximal stump 2 cm and then 3 cm proximal to the gap in a crisscross fashion. The sutures are secured using a single surgeon's knot and 4 simple half-hitches.

For this study, a triple locking technique or modified Dresden technique was used for the A1 group. Three sutures were placed into the proximal stump of the Achilles tendon starting distally, in a crisscross fashion. Five half-knots were created for each stitch, and each knot was separated by 1 cm (Figure 1). Group A2 differed from A1 in that the first of the 3 sutures was tied in a Bunnell fashion (Figure 2). Group A3 differed from A2 by 1 additional suture (4 in total) with a double Bunnell configuration (Figure 3). In all groups, the sutures were placed in the central 1.5 cm of the tendon, to simulate a clinical repair. The total distance of the suturing was 3 cm for groups A1 and A2 (Figures 1 and 2) and 4 cm for group A3 (Figure 3). For group B1, 3 sutures were passed through the distal stump 1 cm apart in a "U" fashion, starting 2 cm distal to the rupture site (Figure 4). In group B2, the 3 sutures were modified such that the 2 distal sutures traversed in an oblique direction to the distal stump (Figure 5).

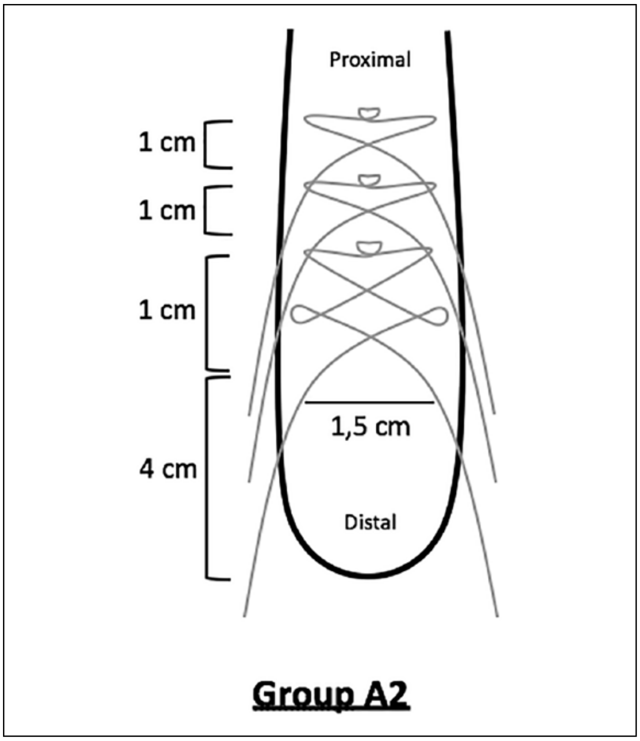

Figure 2. Diagram of a proximal Achilles stump sutured with a Bunnell-type technique (group A2). The difference with group 1 is that the first of the 3 sutures was tied in a Bunnell fashion.

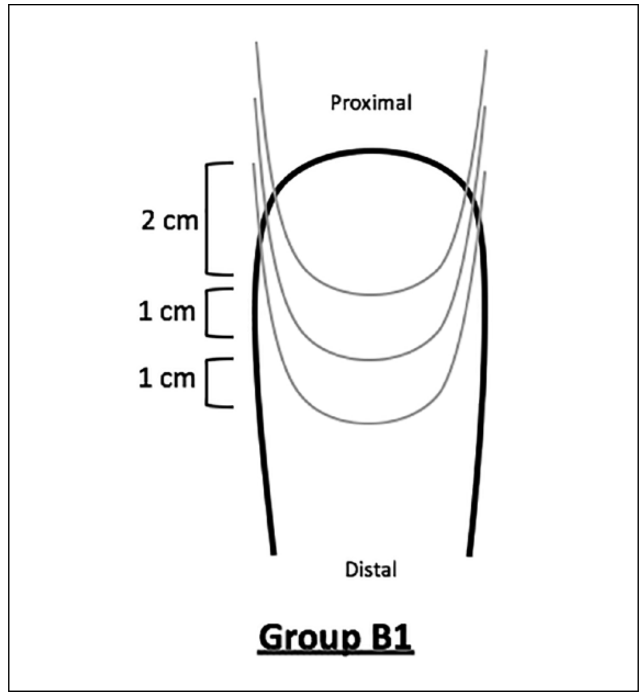

Figure 4. Diagram of a distal Achilles stump sutured with a triple nonlocking technique. Three sutures are passed in a U-fashion through the distal Achilles stump, starting 2 cm distal to the rupture site.

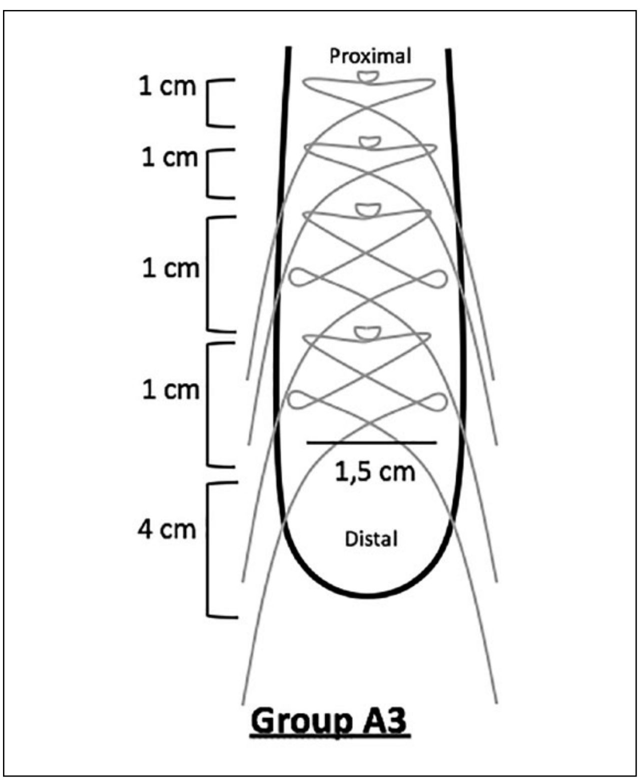

Figure 3. Diagram of a proximal Achilles stump sutured with a double Bunnell-type technique (group A3). The difference with group 2 is that a fourth suture was added with a Bunnell configuration.

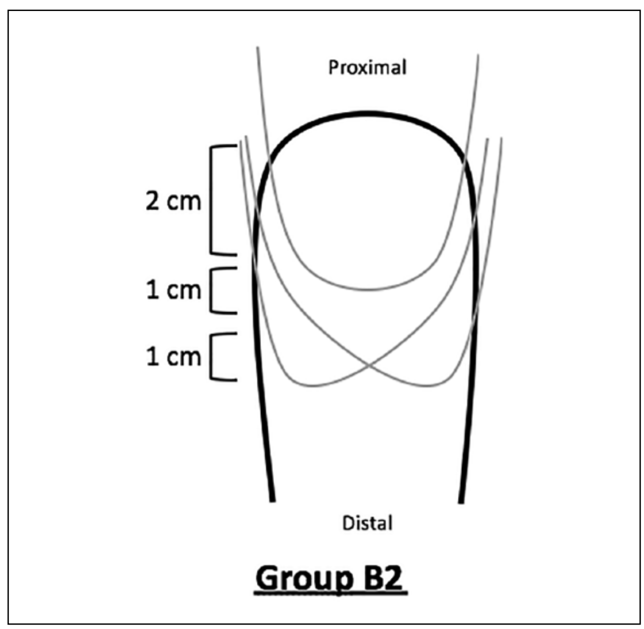

Figure 5. Diagram of a distal Achilles stump sutured with an oblique technique. The 2 distal sutures traverse the distal Achilles tendon stump in an oblique direction.

Biomechanical testing. Every construct was tested in a dynamic tensile testing machine (Kinetecnics, Santiago, Chile) with the aid of 2 specifically designed clamps separated by 7 cm (Figure 6). The proximal clamp attached the

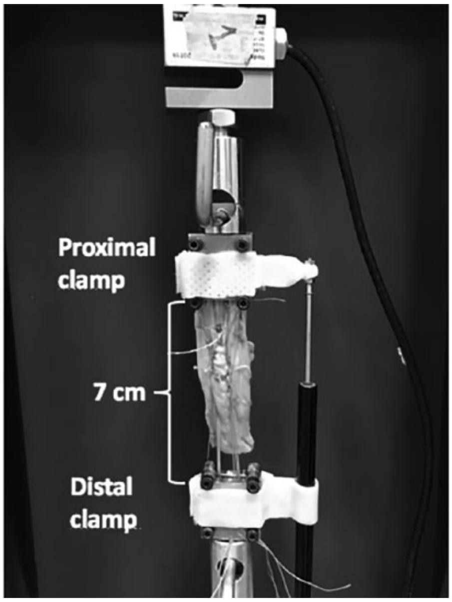

Figure 6. Figure depicting a proximal Achilles stump being tested in a dynamic tensile testing machine (Kinetecnics, Santiago, Chile). The proximal clamp attached the tendon body directly, and the distal clamp grabbed the sutures coming out from the tendon. An electronic tensile cell was mounted on the proximal clamp, and an electronic strain-measuring device was attached to the distal clamp.

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Each specimen was subjected to a loading protocol comprising 1000 cycles of 50 to 200 newtons (N). Constructs surviving all cyclic loading were then loaded to failure. Cyclic loads were selected to mimic load ranges experienced by the Achilles tendon during passive ankle flexion (20-100 N) and walking in a cam walker with a 1-inch heel lift.[1,4] Load to failure (in newtons), tendon elongation (in mm), and cause of failure (anatomic location) were evaluated in every case. Failure was defined as catastrophic when a tear at the suture-tendon interface, suture rupture (any suture), or repair elongation of more than 1 cm happened during testing.

Statistical analysis. Statistical analysis was performed using Kruskal Wallis, Mann Whitney, and Fisher test depending on the analysis performed. Differences were deemed to be statistically significant for $P < .05$.

A post hoc power analysis was performed taking the main hypothesis as the primary outcome. A power of 100% was obtained. A statistician performed all analysis.

Table 1. Table Showing Cyclic Testing Survival, Load to Failure, Elongation, and Type of Failure for Groups A1, A2, and A3.

	Group A1	Group A2	Group A3	*P* Value[a]
Cyclic testing, failures	None	None	None	–
Load to failure, N	598	587	710	**.035**
Elongation, mm	9.6	9.4	9.1	.45
Interphase failure	4	3	3	–
Suture failure	1	2	2	–

[a]Boldface indicates statistically significant.

Table 2. Table Showing Cyclic Testing Survival, Load to Failure, Elongation, and Type of Failure for Groups B1 and B2.

	Group B1	Group B2	*P* Value
Cyclic testing, failures	3 of 6	4 of 6	–
Load to failure, N	416	351	.24
Elongation, mm	10.8	17.6	.8
Interphase failure	3	2	–
Suture failure	0	0	–

Results

Every proximal repair survived the cyclic testing (1000 cycles, 50-200 N). The average load to failure in groups A1, A2, and A3 was 598, 587, and 710 N, respectively, with group A3 being statistically stronger than A1 and A2 ($P = .035$). A1 vs A2 were not significantly different ($P = .1$). No difference was found between groups A1, A2, and A3 regarding elongation under cyclic or load-to-failure testing. A total of 10 repairs failed in the suture-tendon interphase (per group: A1, 4/5; A2, 3/5; and A3, 3/5) and 5 repairs failed by suture rupture (per group: A1, 1/5; A2, 2/5; and A3, 2/5) (Table 1).

Regarding the distal repair groups (B1) and (B2), 3/6 and 4/6 samples failed during cyclic testing respectively. Three of six tendons (B1) and 2/6 tendons (B2) survived the cyclic phase and were suitable to load-to-failure testing and elongation analysis. No significant differences were observed between groups in load-to-failure testing (average 380 N) or in elongation under cyclic or load-to-failure conditions. All repairs failed at the suture-tendon interface by sutures tearing through the tendon (Table 2).

When comparing the strength of the repair between proximal groups (15/15 specimens) and distal groups (5/12 specimens that did not fail in cyclic testing) using the load-to-failure average, proximal groups were significantly stronger than distal groups, 638 vs 380 N ($P = .001$). In addition, distal groups had more elongation during cyclic testing (13.7 mm) than proximal groups (9.4 mm) ($P = .02$).

Discussion

Controversy still exists when comparing minimally invasive Achilles rupture repair techniques and more traditional open techniques. Heitman et al[12] compared repairs using traditional Krackow locking loop technique to the Achillon device technique (Integra Life Sciences Corporation) and concluded that Achillon repairs can be stronger than Krackow locking loop repairs (178 and 128 N, respectively). Both groups had different failure mechanisms, as Achillon repairs failed because of suture cutout through the tendon, whereas Krakow repairs failed because of suture breakage. Clanton et al[4] showed that simulated, midsubstance Achilles ruptures repaired with an open technique survived a mean of 439 ± 122 cycles before failure, compared with minimally invasive percutaneous repairs where Achillon repairs survived 362 ± 113 cycles and PARS repairs survived 424 ± 203 cycles.[4] It has been reported that soft tissue complications can be as high as 34% in open Achilles repair[15] and as low as 0% in minimally invasive options.[7,14] Therefore, according to the literature it can be accepted that percutaneous techniques provide a biomechanically reasonable alternative to open techniques based on their repair strength (load to failure and cycles to failure), and on the advantage of avoiding soft tissue complications.

It is worrisome that many Achilles repairs end up with a lengthened musculotendinous unit, with the consequent compromise in performance, with reported deficits up to 18% less plantarflexion torque after a minimum of 14 years' follow-up.[11] As we increasingly try to speed up the recovery and shorten rehabilitation periods, especially in the young athletic population, the need of a better repair that ensures a correct functional unit is paramount. One area of improvement is finding a reliable way of fixing our distal and proximal tendon stumps, thus achieving stronger repairs biomechanically resulting in a higher load-to-failure resistance, higher number of cycles before failure, and, we hope, with a low elongation rate. When analyzing recent published results about percutaneous Achilles repair techniques, PARS (Arthrex) and Achillon (Integra Life Sciences Corporation),[4] during cyclic testing failed at 362 and 429 cycles and their load to failure was 385 and 299 N, respectively. The biggest limitation in these studies was that the failure site was not identified, as they were analyzed as a whole construct. These results are not entirely satisfactory if we consider that the number of steps in a regular postoperative period can be estimated to be in the 1000s[21], and therefore an equivalent number of cycles should be attained in cadaveric studies before failure. Regarding the load sustained by the Achilles tendon walking in a cam walker with and without a 1-inch heel lift, it has been estimated to be 190 and 369 N, respectively.[1] For this reason, it would be logical to aim for a cyclic resistance of minimum 190 N in 1000 cycles in our Achilles repair constructs. To have a high load to failure helps too to avoid construct failures that result in a lengthened tendon. Manegold et al[19] showed that 23% of 118 patients had an elongated Achilles tendon after the classic Dresden repair which was correlated with worse functional scores, calf muscle atrophy and subjective functional limitations. This correlation has been shown by other authors.[3,11,18]

When we analyze our results of the proximal suturing techniques, they proved to be statistically significantly stronger than the distal ones. They all survived the cyclic testing, not failing after 1000 cycles between 50 and 200 N. This resistance widely surpasses the cyclic resistance already mentioned for other minimally invasive techniques. Relative to the load to failure, the double Bunnell technique group (Group A3) was significantly stronger than the other 2 proximal constructs (710 N vs 598 and 587 N), and stronger than the published resistance of any other construct. On the other hand, the distal constructs were significantly weaker, as more than half of our distal samples failed during cyclic testing. The difference between the distal and proximal suturing technique strengths probably relies on the tissue and suture configuration. The distal constructs (3 nonlocking sutures) were significantly weaker constructs where only 1 passage of the suture through the tendon per suture limb occurred. There is no suture grabbing the tendon, no locking or tying on top of it as in the proximal group where an increased soft tissue friction and load sharing occurs (Figures 4 and 5). Some authors like Cottom et al[5] have recognized this limitation and proposed the use of anchors to reinforce the distal suture.

Regarding elongation, on average, all of our constructs elongated 10 mm in the cyclic testing. In the distal groups, 7/12 samples failed during cyclic testing, so no elongation could be calculated for those. These results are similar to what was shown by Clanton et al[4] as he found that percutaneous techniques elongate 10 mm. Although this fact could not be controlled with our suture configurations, it can be compensated intraoperatively. We recommend pretensioning the repair and achieving a slightly shortened (5 degrees of additional ankle equinus) musculotendinous length with the repair compared to the other side. We also think that this apparent drawback when performing minimally invasive Achilles techniques is overly compensated by the decreased rate of soft tissue complications found[9,14] compared to open techniques.

Based on our results, we reject our first hypothesis (distal configuration stronger than proximal) and we accept our second hypothesis that the double Bunnell technique is stronger than the triple-locking technique (modified Dresden).

The present investigation has the following limitations. First, all samples came from human cadavers of different age, ethnicities, and lifestyle, which could have affected their quality. Second, the described cadaveric model presents a simplified time zero representation of the biomechanical characteristics of each of the Achilles repair techniques.

Third, variations in the technique across the specimens may hinder finding true differences in the resistance or failure type. However, the significantly different results we found between the proximal and distal configurations lead us to believe the actual strength of these repairs is appropriately represented by them.

In summary, the double Bunnell-type technique was significantly stronger in cyclic loading and load to failure than the other proximal techniques tested. Regarding the distal techniques, both constructs tested were significantly weaker than the proximal techniques and not strong enough to confidently allow weight bearing in a walker boot. If an accelerated and active postoperative rehabilitation protocol is important for the surgeon's practice, a modification in the Achilles tendon suturing technique should be considered. The authors' current practice is to perform the double Bunnell-type technique proximally and to use 2 percutaneous suture anchors into the calcaneus as part of the distal repair.

Declaration of Conflicting Interests

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