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

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, mid-substance rupture was created 6 cm proximal to the calcaneal insertion in fresh-frozen cadaveric Achilles tendons. Fifteen proximal specimens were divided in three groups: (A1) classic Dresden technique, (A2) modified Dresden, (A3) double modified Dresden. Twelve distal specimens were divided in two groups: (B1) classic Dresden technique and (B2) modified Dresden. Repairs were subjected to cyclic testing (1000 load cycles between 50-200 N) 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, achieving up to 710 N of failure load in Group A3. Groups B1and B2 failed on average at 416 N and 351 N respectively. The majority of all repairs failed in the suture-tendon interphase. No difference was found for elongation between groups.

Conclusion: The distal fixation site in the Dresden percutaneous Achilles tendon repair is 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 Dresden repair.

Keywords: Achilles tendon; Percutaneous Repair; Proximal; Distal; Cyclic loading.

INTRODUCTION

Achilles tendon rupture is a frequent condition [1,2], especially in middle-aged men during recreational activities. Different treatment options have been proposed, being non-operative management a viable option for non-active adults that can tolerate to be immobilized for long periods [3]; instead surgical repair is often preferred in active and healthy populations hopefully to achieve a better return to sports activity[4].

Actually, there is no consensus on the best surgical repair approach, either open or percutaneous [5,6.] 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 [7-9]. Open and percutaneous repairs also present differences in biomechanical comparisons. Some studies have reported percutaneous repairs to be stronger than open repairs, while others have demonstrated percutaneous repairs to be weaker and more susceptible to elongation [10-12]. A limitation of all biomechanical cadaveric studies is that they only represent what happens at time 0 in vivo. As 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. Only isolating the different components of a repair, deep analysis and 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 Dresden percutaneous 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 modified proximal and distal fixation repair would be stronger than the classic Dresden construct.

METHODS

Fifteen fresh- frozen cadaveric Achilles tendons were used. All specimens belonged to individuals under 65 years old without previous surgeries or visible pathology. A simulated, mid-substance 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 gastrosoleus complex) and 15 distal tendon stumps (dissected off the calcaneus). Of the 15 distal stumps, 3 had to be discarded given bad tissue quality.

Surgical technique

15 proximal (Group A) and 12 distal (Group B) specimens were separated in three and two groups respectively depending on the suturing technique utilized: (Group A1) classic Dresden suture: 5 specimens; (A2) modified Dresden suture: 5 specimens; and (A3) double modified Dresden suture: 5 specimens; (B1) classic Dresden suture: 6 specimens; and (B2) modified Dresden suture: 6 specimens. All surgical repairs were performed by a single foot and ankle fellowship trained orthopedic surgeon. Every specimen was sutured with Fiberwire® nº2 (Arthrex, Naples, FL). The samples were continuously hydrated with saline solution to preserve physical properties.

1) <u>Proximal and distal Achilles suturing technique</u>

In Group A1, three threads were sutured to the proximal stump of the Achilles tendon, from distal to proximal, in a criss-cross fashion, with 5 half-knots for each thread and separating each knot by 1 cm (classic Dresden, figure 1). Group A2 differs from A1 in that the first of the three threads is tied in a Bunnel fashion, as shown in figure 2 (modified Dresden). Group A3 differs from A2 that it adds one additional suture (4 in total) with a Bunnel configuration (figure 3) (double modified Dresden). In all groups, the workspace for the sutures was centrally located in the tendon, spanning 1.5 cms in width to resemble the technique as close as possible to a real-life situation. Regarding length, the suture technique spanned a distance of 3 cm for group A1 and A2 (figure 1 and 2) and 4 cm for Group A3.

In group B1, three threads were passed through the distal stump separated by 1 cm in a "U" fashion, starting 2 cm distal to the rupture (figure 4). In group B2, the same three threads were used, with the modification that the two distal threads traverse in a criss-cross fashion the distal stump, as shown in figure 5.

2) <u>Biomechanical testing</u>

Every construct was tested in a dynamic tensile testing machine (Kinetecnics, Santiago, Chile) with aid of two specifically designed clamps separated by 7 cms (figure 6). 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.

Each specimen was subjected to a loading protocol consisting in 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 [13,14]. 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.

3) Statistical analysis

Statistical analysis was performed using Kruskal Wallys, Mann Whitney and Fisher's test depending on the analysis performed. Differences were deemed to be statistically significant for $P < 0.05$.

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.

RESULTS

Every proximal repair survived the cyclic testing (1000 cycles, 50-200N). The average load to failure in groups A1, A2 and A3 was 598 N, 587 N and 710 N respectively, with group A3 being statistically stronger than A1 and A2 ($p=0.035$). A1 and A2 were not statistically different ($p=0.1$). No difference was found between groups A1, A2 and A3 regarding elongation under cyclic or load to failure testing. 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 (50-200N) respectively. Three out 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 in the suture- tendon interphase 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 N vs 380 N, p value=0.001. In addition, distal groups had more elongation during cyclic testing (13.7mm) than proximal groups (9.4mm) (p=0.02).

DISCUSSION

Controversy still exists when comparing minimally invasive Achilles rupture repair techniques and more traditional open techniques. Heitman et al [10] compared repairs utilizing 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, while Krakow's repairs failed because of suture breakage. Clanton et al[14] 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[14].

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[16,17]. 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 worrysome that many achilles repairs end up with a lengthened musculotendinous unit, with the consequent compromise in performance, with reported deficits up to 18% less plantar flexion torque after a minimum of 14 years follow up (Heikkinen J, Lantto I, Piilonen J, Flinkkilä T, Ohtonen P, Siira P, Laine V, Niinimäki J, Pajala A, Leppilahti J. Tendon Length, Calf Muscle Atrophy and Strength Deficit After Acute Achilles Tendon Rupture: Long-Term Follow-up of Patients in a Previous Study. J Bone Joint Surg Am. 2017 Sep 20;99(18):1509-1515). As we increasingly try to speed up recovery and shorten up rehabilitation periods, especially in young athletic population, the need of a better repair which assures a correct functional unit is paramount. One area of improvement is finding a reliable way of fixing our distal and proximal tendon stumps, achieving stronger repairs, with a higher load to failure resistance, higher number of cycles before failure, and hopefully with a low elongation rate. When analyzing recent published results about percutaneous Achilles repair techniques, PARS® (Arthrex, Naples, FL) and Achillon ® (Integra Life Sciences Corporation)[14] , during cyclic testing, they fail at 362 and 429 cycles and their load to failure is 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. In our study we show that most probably the failure first happens distally, as more than half of our distal samples failed during cycles, with an average load to failure of 397 N in the specimens which survived the cyclic testing. These results are not entirely satisfactory if we consider that the number of steps in a regular postoperative period can be estimated in 1000[18] , 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 [13]. For this reason, it would be logical to aim for a load to failure above 369 N in our Achilles repair constructs. To have a high load to failure helps too to avoid construct failures that end up in a lengthened tendon. Manegold et al [19] showed that 23% of 118 patients ended up with an elongated Achilles tendon after the classic Dresden repair which was correlated to worse functional scores, calf muscle atrophy and subjective functional limitations. This correlation has been shown by other authors too [20,21].

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 20 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 modified Dresden group was significantly stronger than the other 2 proximal constructs (710N vs 598N and 587N), and clearly more resistant than the published resistance of any other construct. The difference between the distal and proximal suturing technique strengths probably relies on the tissue and suture configuration. The distal constructs (3 non locking sutures) are significantly weaker constructs where only one passage of the suture through the tendon per thread occurs. 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 (see Figure 4-5). Some authors like Cottom et al[22] have recognized this limitation and proposed the use of anchors to reinforce the distal suture.

Regarding elongation, in average, all of our constructs elongated 10 mm in the cyclic testing. In the distal groups, 7/12 samples failed during cycles, so no elongation could be calculated for those. These results are similar to what was shown by Clanton et al[14] as he found that open techniques elongate 5 mm and 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. 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 [16,17], compared to open techniques.

As the reader can interpret, we reject our first hypothesis (distal configuration stronger than proximal) and we accept our second hypothesis relative to the fact that the modified proximal configuration is stronger than the classic Dresden.

The present investigation has the following limitations. First, all samples came from human cadavers of different age, ethnicities and life style which could have modified results. 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. Having said this, the difference and p value of the results between the proximal and distal configurations is highly significant, and therefore we think the difference is present and significant.

In summary, the double modified proximal suture configuration 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 even 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 Dresden Achilles tendon suturing technique should be considered. The authors current practice is to perform the double modified suture technique proximally and to use 2 percutaneous suture anchors to the calcaneus as a distal repair.

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