Biomechanical Head-to-Head Comparison of 2 Sutures and the Giftbox Versus Bunnell Techniques for Midsubstance Achilles Tendon Ruptures

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Background: Acute midsubstance Achilles tendon ruptures are a common orthopaedic problem for which the optimal repair technique and suture type remain controversial. Head-to-head comparisons of current fixation constructs are needed to establish which stitch/suture combination is most biomechanically favorable.

Hypothesis: Of the tested fixation constructs, Giftbox repairs with Fiberwire will exhibit superior stiffness and strength during biomechanical testing.

Study Design: Controlled laboratory study.

Methods: Two biomechanical trials were performed, isolating stitch technique and suture type, respectively. In trial 1, 12 transected fresh-frozen cadaveric Achilles tendon pairs were randomized to receive either the Giftbox-modified Krackow or the Bunnell stitch with No. 2 Fiberwire suture. Each repair underwent cyclic loading, oscillating between 10 and 100 N at 2 Hz for 1000 cycles, with repair gapping measured at 500 and 1000 cycles. Load-to-failure testing was then performed, and clinical and catastrophic failure values were recorded. In trial 2, 10 additional paired cadaveric Achilles tendons were randomized to receive a Giftbox repair with either No. 2 Fiberwire or No. 2 Ultrabraid. Testing and data collections protocols in trial 2 replicated those used in trial 1.

Results: In trial 1, the Bunnell group had 2 failures during cyclic loading while the Giftbox had no failures. The mean tendon gapping after cyclic loading was significantly lower in the Giftbox repairs (0.13 vs 2.29 mm, $P = .02$). Giftbox repairs were significantly stiffer than Bunnell (47.5 vs 38.7 N/mm, $P = .019$) and showed more tendon elongation (5.9 ± 0.8 vs 4.5 ± 1.0 mm, $P = .012$) after 1000 cycles. Mean clinical load to failure was significantly higher for Giftbox repairs (373 vs 285 N, $P = .02$), while no significant difference in catastrophic load to failure was observed (mean, 379 vs 336 N; $P = .61$). In trial 2, there were no failures during cyclic loading. The Giftbox + Fiberwire repairs recorded higher clinical load-to-failure values compared with Giftbox + Ultrabraid (mean, 361 vs 239 N; $P = .005$). No other biomechanical differences were observed in trial 2.

Conclusion: Simulated early rehabilitation biomechanical testing showed that Giftbox-modified Krackow Achilles repair technique with Fiberwire suture was stronger and more resistant to gap formation at the repair site than combinations that incorporated the Bunnell stitch or Ultrabraid suture.

Clinical Relevance: A more in-depth understanding of the biomechanical properties of the Giftbox repair will help inform surgical decision making because stronger repairs are less likely to fail during accelerated postoperative rehabilitation.

Keywords: Achilles rupture; tendon repair; Achilles repair; tendon biomechanics

Achilles tendon ruptures are a common problem that many orthopaedic surgeons encounter.[7,12] The rate of midsubstance Achilles ruptures has nearly doubled in the past 50 years, reaching its current incidence of 18 injuries per 100,000 people.[6,17] Changes in population demographics such as increased age and elevated body mass index have been shown to be risk factors.[20]

Operative versus nonoperative management of midsubstance Achilles ruptures continues to be debated. Surgical repair has been associated with decreased rerupture rates and trends toward faster return to work, but with increased risk for complications.[23] Suboptimal outcomes are common with both operative and nonoperative management.[21]

Overlengthening of the Achilles tendon secondary to suture stretching or loss of fixation at the suture-tendon

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interface is a key issue responsible for poor functional outcomes.[18] Even after precise intraoperative tensioning and apposition of the tendon ends, a gap of even 5 mm can lead to significantly worse outcomes.[15] A second consideration is the high rate of postoperative wound dehiscence and tendon necrosis, leading some to hypothesize that increased suture bulk and prominence may act as a nidus for adhesion.[10]

Historically, there has been debate over several repair techniques, including the Kessler, Bunnell, triple bundle, and Krackow.[11,24] The recent meta-analysis by Sadoghi et al[22] of Achilles repair techniques noted trends in the strength differences between stitches but concluded that the compiled data were too heterogeneous to allow for an endorsement of any single repair technique. The Krackow stitch has been a staple of treatment, and its strength and durability has been shown to be superior to several other stitches.[5,25] In 2009, the Giftbox modification of the Krackow was introduced and demonstrated superior biomechanical properties in comparison to the original Krackow.[14] The triple-bundle technique is touted as the strongest in biomechanical studies, but there are clinical concerns regarding disruption of the vascularity of the tendon due to large amounts of suture employed.[11,14] Finally, repairs using the Bunnell stitch have exhibited the greatest tensile strength of the commonly used techniques, outperforming the Kessler and Krackow by a significant margin.[22]

Several studies have compared different types of braided nonabsorbable sutures, finding Fiberwire (Arthrex) to be superior when compared with other conventional sutures.[3,5,8] However, none of these trials used cyclic loading in human cadavers.

This study reports on a series of 2 head-to-head biomechanical comparisons of matched cadaveric Achilles repairs with different fixation constructs. We hypothesized that (1) locked stitches with more strands of suture crossing the repair site will minimize gap formation between the repaired tendon ends and (2) stiffer suture will lead to less gap formation.

METHODS

Experimental Design

This study was designed to isolate 2 surgery-specific variables that could affect the biomechanical properties of Achilles tendon repairs. Trial 1 compared 2 stitch techniques, the Bunnell and the Giftbox, using No. 2 Fiberwire suture for all repairs in this trial. Trial 2 compared 2 proprietary, nonabsorbable braided sutures, with all repairs in this trial receiving a Giftbox stitch.

Trial 1: Comparison of Giftbox Versus Bunnell Repairs

Twelve pairs of cadaveric gastrocsoleus complexes were harvested, wrapped in saline-soaked gauze to prevent tissue damage, and fresh frozen. They were thawed for 12 hours at room temperature and kept moist until immediately prior to testing. The harvested Achilles tendons were trimmed to a length of 15 cm proximal to the tendon insertion and each Achilles tendon transected with a scalpel 4 cm proximal to its insertion, consistent with previous studies.[11,14,16] The proximal tendon was then placed in a tissue grip with the proximal-most end against the top of the grip. The calcaneous was placed in a custom jig, and 2 Steinman pins were drilled through the pretapped holes in the jig for distal fixation.

Each Achilles pair was randomized to receive a Giftbox-modified Krackow or a Bunnell repair (Figures 1 and 2, respectively). The Giftbox modification of the traditional Krackow stitch changes how the suture tails are managed and where the final knots are placed. After the Krackow stitch is completed, the suture tails are passed across the rupture site and traverse in a buried fashion through the central portion of the opposing tendon. One suture tail is brought out of the superficial tendon surface before reaching the crossing arm of the opposing Krackow (Figure 3). The second suture tail exits beyond the crossing arm, capturing the crossing arm between the 2 suture tails. This procedure is repeated for the suture tails of the opposing Krackow. Both sets of tails are then tagged, and an epitendinous repair is completed with 3-0 polypropylene suture to help reapproximate the tendon ends and achieve appropriate tension before the final core knots are tied.[26] A No. 2 nonabsorbable braided suture made of ultrahigh-molecular-weight polyethylene (UHMWPE) (Fiberwire) was used for all repairs.

After a single surgeon completed all 24 repairs, a cyclic loading protocol adapted from prior similar studies was performed.[2,6] The calcanei were mounted on a materials testing machine (EnduraTEC Systems Corp) with the Achilles placed at a 30° angle to simulate the physiologic stress of early heel rise (Figure 4). The samples were on the machine for 8.5 minutes of cyclical testing, with approximately 3 additional minutes during and after testing to measure gapping.

After preconditioning the tendon at 10 N for 1 minute, cyclic loading was then performed from 10 to 100 N at 2 Hz for 1000 cycles in a sinusoidal waveform. Calipers with 1/10 mm accuracy were used to measure any gapping between the tendon ends after 500 and 1000 cycles. Any specimen that exhibited over 5 mm of gapping was considered a failure. Those specimens, along with their matched

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Ethical approval for this study was obtained from the Miami Valley Hospital (study # 14-0106C).

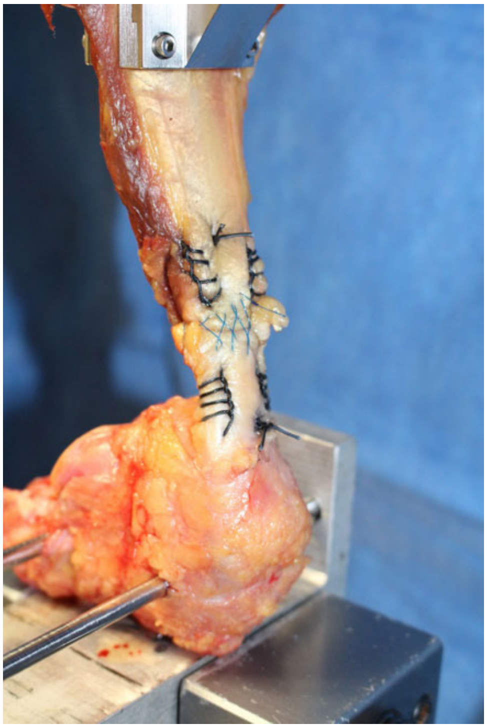

Figure 1. An example of the Giftbox repair in a cadaveric Achilles tendon.

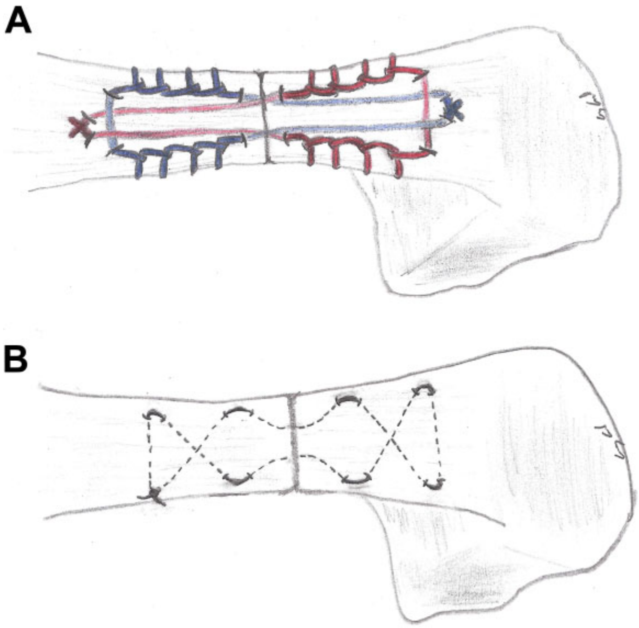

Figure 3. A schematic illustrating the stitch patterns for the (A) Giftbox and (B) Bunnell repair techniques.

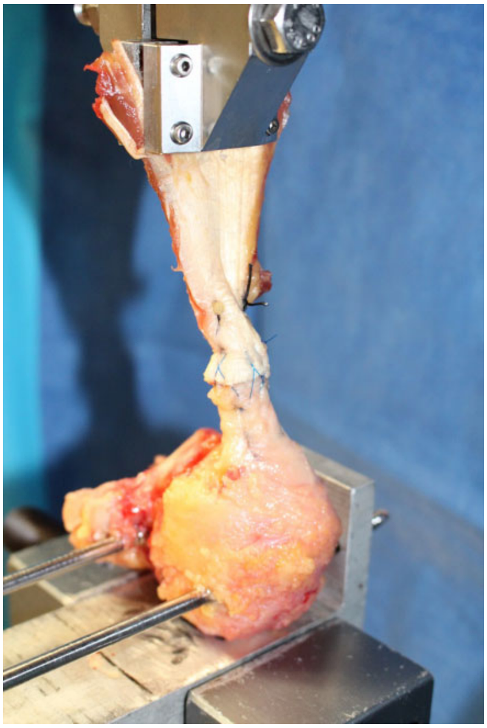

Figure 2. An example of the Bunnell repair in a cadaveric Achilles tendon.

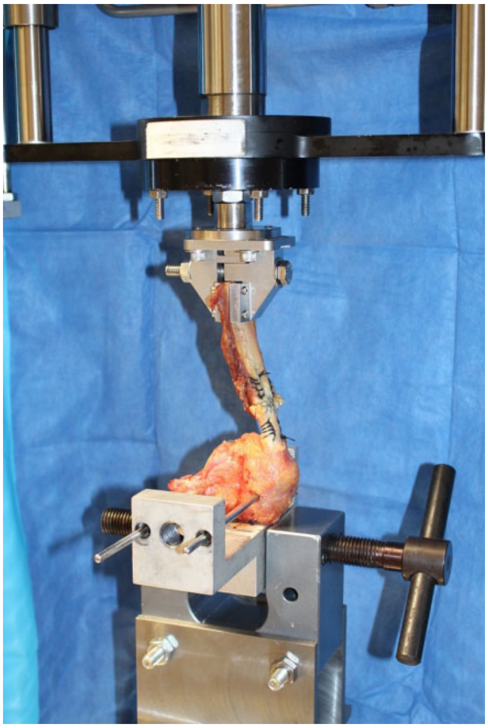

Figure 4. A photograph of the mechanical testing system configuration used for evaluating the Achilles tendon repairs.

TABLE 1
Cyclic Loading Data[a]

	Repair Technique and Suture Combination	No. of Failures During Cyclic Loading	No. of Specimens With Measureable Gapping	Mean Gapping of Repairs After 1000 Cycles, mm	Elongation Over 1000 Cycle, mm	Stiffness After 1000 Cycles, N/mm
Trial 1 (n = 12 matched pairs)	Giftbox + Fiberwire	0	1	0.13 ± 0.5	5.8 ± 0.8	47.5 ± 5.5
	Bunnell + Fiberwire	2	6	2.29 ± 2.6	4.5 ± 1.0	38.7 ± 9.2
		P = .48	*P* = .059	***P* = .02**	***P* = .012**	***P* = .019**
Trial 2 (n = 10 matched pairs)	Giftbox + Fiberwire	0	0	0	6.1 ± 1.1	38.8 ± 5.5
	Giftbox + Ultrabraid	0	0	0	6.8 ± 1.9	39.2 ± 5.9
					P = .34	*P* = .83

[a]Boldfaced *P* values indicate statistical significance.

TABLE 2
Load-to-Failure Data[a]

	Repair Technique and Suture Combination	Load to Failure, N: Clinical Failure	Load to Failure, N: Catastrophic Failure
Trial 1 (n = 10 matched pairs)	Giftbox + Fiberwire	373 ± 110	379 ± 103
	Bunnell + Fiberwire	285 ± 74	336 ± 77
		***P* = .02**	*P* = .61
Trial 2 (n = 10 matched pairs)	Giftbox + Fiberwire	361 ± 118	415 ± 124
	Giftbox + Ultrabraid	239 ± 58	356 ± 100
		***P* = .005**	*P* = .16

[a]Boldfaced *P* values indicate statistical significance.

contralateral specimen, were not included in load-to-failure testing. All remaining specimens underwent load-to-failure testing at a rate of 0.2 mm/s. Clinical load to failure was defined as 5 mm of tendon gapping. Catastrophic load to failure was recorded when complete loss of fixation was observed.

Trial 2: Comparison of 2 Nonabsorbable Sutures Using the Giftbox Repair

Ten pairs of fresh-frozen cadaveric gastrocsoleus complexes were harvested and transected in the same manner as in trial 1. Each Achilles pair was repaired using the Giftbox technique with 1 of 2 nonabsorbable sutures. The right and left tendons of each pair were randomized to have either a No. 2 Fiberwire or a No. 2 UHMWPE suture with a unique braid pattern (Ultrabraid, Smith & Nephew). All Achilles tendons also had an epitendinous repair with 3-0 polypropylene suture to appose the tendon ends.

After the designated repairs were completed, the constructs were tested with the same parameters and procedures as in trial 1. Statistical analysis was performed using SAS Software 9.4 (SAS Institute Inc).

RESULTS

In trial 1, no failures were observed after 500 cycles, and 2 failures were observed after 1000 cycles, both in the Bunnell group. The Bunnell group also had 4 other specimens in which a gap ranging from 2.0 to 4.9 mm was measured after 1000 cycles (Table 1).

Only 1 gap was observed in the 12 Giftbox repairs after 1000 cycles, measuring 1.5 mm. The mean amount of gapping after cyclic loading was 0.13 mm for the Giftbox group and 2.29 mm for the Bunnell group (*P* = .02). After 1000 cycles, the Giftbox group was significantly stiffer than the Bunnell and also showed more tendon elongation during cyclic loading. After removal of the failed constructs, 10 pairs were available to undergo load-to-failure testing. The Giftbox group withstood significantly higher forces than the Bunnell group before reaching clinical load to failure (Table 2).

Catastrophic load-to-failure values were not significantly different for the 2 groups. All failures were at the knot-tendon interface, with the knot slipping through the tendon a small amount then failing catastrophically with knot failure.

In trial 2, no failures occurred during cyclic loading, and after 1000 cycles, no gapping between the repaired ends was observed in either group. There was no significant difference in stiffness or elongation found between the trial 2 groups (Table 1). During load-to-failure testing, the Giftbox + Fiberwire repairs withstood significantly higher force before clinical failure. Mean catastrophic load to failure showed no significant difference between the trial 2 groups. The mechanism of failure for all constructs was at the knot-tendon interface, with the knots pulling through the tendon a small amount, then completely cutting out, leading to catastrophic failure.

The Giftbox + Fiberwire groups exhibited similar clinical load-to-failure values in both trial 1 and trial 2, recording values of 373 and 361 N, respectively. Only 1 of the 22 repairs with this stitch/suture combination exhibited tendon gapping after cyclic loading. There was no significant difference in the age or sex of the cadaveric specimens between the 2 trials (74.3 vs 73.9 years, $P = .94$).

DISCUSSION

Many Achilles repair techniques are described in the literature; however, there is no consensus on the best techniques and materials. Despite extensive research, determinants of Achilles tendon repair effectiveness have not been clearly established.[22] As rehabilitation protocols have become much more aggressive, emphasizing early motion and controlled stress at the repair site, knowledge of the strongest and most durable repair construct is needed. The purpose of this study was to analyze suture pattern (Giftbox vs Bunnell) and suture type (Ultrabraid vs Fiberwire). Testing protocols historically used in the literature were employed for consistency.

In the analysis of pattern, Giftbox repairs were biomechanically superior to Bunnell repairs with regard to both gap resistance and strength ($P = .02$ for both). In the analysis of suture type, Fiberwire Achilles repairs were found to be statistically significantly stronger than matched Ultrabraid repairs during load to failure.

Our experimental design incorporates aspects of many previous Achilles biomechanical studies. High-repetition, high-force cyclic loading is thought to most accurately model current trends for postoperative rehabilitation protocols that stress early range of motion, early weightbearing, and early light-resistance stressing of the repair.[2] Our testing method revealed biomechanical differences that may not be apparent with only single-trial displacement-driven load-to-failure testing, reproducing a more physiologic load nearing what has been proposed for early weightbearing with a shoe lift in place.[1] Traditional displacement-driven single load-to-failure trials were also included as a subsequent step to allow for comparison of our results with many previous studies.[2,3,14,25]

The chosen repair techniques and "failure" definitions were driven by the most recent articles and guidelines.[15,18] Fiberwire was selected for inclusion primarily because it has been shown to lead to stronger tendon fixation than Ethibond (Ethicon) and many other suture types.[2-4] Second, the only previous biomechanical study of the Giftbox used a much less studied suture (Hi-Fi, ConMed Linvatec), which made comparison with other construct combinations difficult.[14]

Our 2 trials address key elements of Achilles repair and Achilles research. Trial 1 and trial 2 both contained Giftbox + Fiberwire groups. These identical groups exhibited similar clinical load-to-failure values, reinforcing the consistency and reproducibility of our testing protocol. Second, catastrophic load-to-failure values in our study occurred when the tendon ends were already gapped greater than 1 cm, hence we considered this outcome measure less clinically relevant, a conclusion that has been alluded to in other studies.[15] Finally, the clinical load-to-failure strength of Giftbox + Ultrabraid repairs was lower (239 N) than the Bunnell + Fiberwire (285 N), but the Bunnell group exhibited failures during cyclic loading and the Giftbox + Ultrabraid did not. Hence, stitch technique may affect the stiffness of Achilles repairs and their ability to resist gapping more than suture type. Given this finding, load-to-failure values in isolation should be interpreted with caution, as they did not always correlate with the overall integrity and durability of the repairs in our study.

Weaknesses of this study include its use of cadaveric tendons as a model for in vivo tendons. Many studies have noted limitations with regard to cadaver-related, suboptimal tissue integrity secondary to early decay and advanced age when compared with the typical patient population that sustains this injury.[9,14,19] Heterogeniety in the cadaveric tissue quality between the 2 trials may explain the difference in stiffness observed between the Giftbox + Fiberwire groups in trials 1 and 2. Additionally, the tissue shredding that occurs at the ruptured tendon ends in vivo was not accurately represented by the simple transection used in our procedures. However, the repair techniques span the shredded portion of tendon, with the first core suture passes traversing the tendon 2 to 3 cm away from the rupture site. These limitations could significantly alter the biomechanical properties of the tendon and the repairs.

The ultimate construct for Achilles tendon rupture fixation remains to be seen; however, the Giftbox + Fiberwire method outperformed the other tested constructs in this study. This combination minimizes suture bulk particularly around the repair junction, increases the number of strands across the rupture site, and keeps the knots away from the diseased portion of tendon. It also allows for accurate tensioning of the tendon ends because any shortening of the repaired segment can be directly visualized and adjusted as the knots are tightened down on the tendon. The Giftbox + Fiberwire constructs showed minimal displacement with intensive cyclic loading, and exhibited higher clinical load-to-failure values than any other construct to date except the triple bundle, whose increased suture bulk and prominence has led to concern about tendon adherence and wound healing.[14,26] To our knowledge, only 1 clinical study, which was retrospective in nature, has included the Giftbox technique, reporting increased strength compared with the Krackow.[13] Further outcome-focused, prospective clinical research is needed to confirm the superior characteristics of this repair and compare it head to head with other well-studied repair techniques.

CONCLUSION

The combination of a Giftbox-modified Krackow Achilles repair technique and Fiberwire suture with an epitendinous repair is stronger and stiffer than constructs that combined the Bunnell technique with Fiberwire suture and the Giftbox with Ultrabraid. It also outperformed all other previously published fixation combinations except the triple bundle, although direct comparison is limited by different testing conditions and study protocols. We recommend the Giftbox stitch with Fiberwire in combination with an epitendinous repair for the operative fixation of midsubstance Achilles tendon ruptures.

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