Biomechanical Comparison of Parallel and Crossed Suture Repair for Longitudinal Meniscus Tears

Charles Milchteim,* MD, Eric A. Branch,* MS, Ty Maughon,* Jay Hughey,* MD, and Adam W. Anz,*† MD

Investigation performed at the Andrews Research and Education Foundation, Gulf Breeze, Florida, USA

Background: Longitudinal meniscus tears are commonly encountered in clinical practice. Meniscus repair devices have been previously tested and presented; however, prior studies have not evaluated repair construct designs head to head. This study compared a new-generation meniscus repair device, SpeedCinch, with a similar established device, Fast-Fix 360, and a parallel repair construct to a crossed construct. Both devices utilize self-adjusting No. 2-0 ultra–high molecular weight polyethylene (UHMWPE) and 2 polyether ether ketone (PEEK) anchors.

Hypothesis: Crossed suture repair constructs have higher failure loads and stiffness compared with simple parallel constructs. The newer repair device would exhibit similar performance to an established device.

Study Design: Controlled laboratory study.

Methods: Sutures were placed in an open fashion into the body and posterior horn regions of the medial and lateral menisci in 16 cadaveric knees. Evaluation of 2 repair devices and 2 repair constructs created 4 groups: 2 parallel vertical sutures created with the Fast-Fix 360 (2PFF), 2 crossed vertical sutures created with the Fast-Fix 360 (2XFF), 2 parallel vertical sutures created with the SpeedCinch (2PSC), and 2 crossed vertical sutures created with the SpeedCinch (2XSC). After open placement of the repair construct, each meniscus was explanted and tested to failure on a uniaxial material testing machine. All data were checked for normality of distribution, and 1-way analysis of variance by ranks was chosen to evaluate for statistical significance of maximum failure load and stiffness between groups. Statistical significance was defined as $P < .05$.

Results: The mean maximum failure loads ± 95% CI (range) were 89.6 ± 16.3 N (125.7-47.8 N) (2PFF), 72.1 ± 11.7 N (103.4-47.6 N) (2XFF), 71.9 ± 15.5 N (109.4-41.3 N) (2PSC), and 79.5 ± 25.4 N (119.1-30.9 N) (2XSC). Interconstruct comparison revealed no statistical difference between all 4 constructs regarding maximum failure loads ($P = .49$). Stiffness values were also similar, with no statistical difference on comparison ($P = .28$).

Conclusion: Both devices in the current study had similar failure load and stiffness when 2 vertical or 2 crossed sutures were tested in cadaveric human menisci.

Clinical Relevance: Simple parallel vertical sutures perform similarly to crossed suture patterns at the time of implantation.

Keywords: failure load; meniscus; longitudinal tear; repair

Our understanding of the role of the meniscus has significantly evolved in recent years. Currently, it is widely accepted that meniscal preservation is preferred over meniscectomy to prevent the development of degenerative changes in the knee.[2,4,13,16,25,27] This is in part due to the meniscus' role in force transmission as well as anterior-posterior stability in the knee.[21,28] Numerous meniscal repair techniques have been developed in recent years, but the ideal repair technique remains to be determined.

To decrease potential morbidity associated with open inside-out repair, all-inside techniques have become increasingly popular. Early meniscal repair devices such as screws, darts, and arrows have proven inferior to modern suture-based repair devices.[3,5-7,9,12,22] The

†Address correspondence to Adam W. Anz, MD, Andrews Research and Education Foundation, 1040 Gulf Breeze Parkway, Gulf Breeze, FL 32561, USA (email: anz.adam.w@gmail.com).

*Andrews Research and Education Foundation, Gulf Breeze, Florida, USA.

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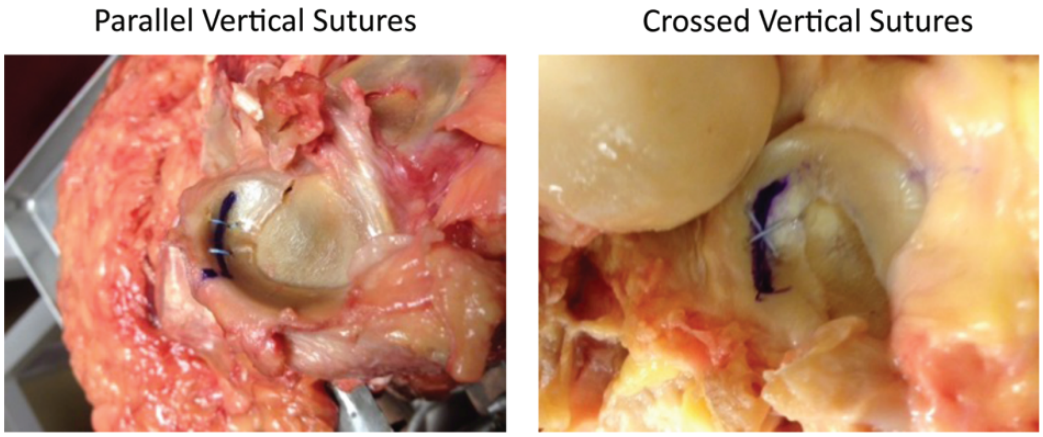

Figure 1. Meniscus repair constructs.

evolution of repair device design and increasing familiarity has made it possible to safely accomplish more complex patterns of repair.[1,8,10,11,18-20]

The objective of this study was to assess the strength of 2 different repair constructs, a parallel vertical repair and crossed vertical repair, and to compare 2 available devices that utilize No. 2-0 ultra–high molecular weight polyethylene (UHMWPE) suture and polyether ether ketone (PEEK) anchors. We hypothesized that repair construct failure loads will vary based on suture construct, postulating higher failure loads with a crossed repair. Evaluation of the failure load and stiffness for different meniscal repair constructs will aid the clinician in decisions regarding the optimal meniscal repair technique and in developing appropriate postoperative rehabilitation plans.

METHODS

Thirty-two menisci were utilized from 16 human cadaveric knee specimens. The mean specimen age was 63.5 ± 4.3 years, with a range of 55 to 67 years. Twenty menisci were from female donors and 12 menisci were from male donors. Four medial menisci and 4 lateral menisci were used for each group. We selected 8 specimens per group as this has proven a sufficient sample size in previous biomechanical in vitro studies on meniscus suture techniques.[3,11,26] Additionally, on power analysis, it was determined that a sample size of 8 specimens per study group would yield at least 80% power to detect the minimal between-group difference in maximum failure load of 20 N, assuming a nonparametric comparison of 4 groups, a group standard deviation $\leq$15 N, and a type I error probability of .05.

To expose the meniscal tissue for testing, the cadaveric knees were thawed the day prior to testing, and the tibial shaft was dissected for the specimen to be mounted on a 2-hole clamp. The specimens were then dissected using a medial parapatellar arthrotomy. The anterior and posterior cruciate ligaments were incised to disarticulate the knee joint. Dissection was then carefully continued posteriorly with care to preserve the posterior capsule of the knee. Specimens exhibiting meniscal degeneration or meniscal tears involving Cooper zones 0, 1, and/or 2, that is, the peripheral two-thirds of the meniscus, were excluded from the study.[23] Two menisci were excluded due to macroscopic degeneration on initial arthroscopic evaluation.

With the menisci still in their native position on the tibia, a meniscal tear was created utilizing a No. 11 blade surgical scalpel. A 1-cm complete, longitudinal, full-thickness tear was created in each meniscus 3 mm from the peripheral rim to simulate this commonly encountered tear pattern. The tears were then repaired with 1 of 2 devices. The implants were deployed using the protocol recommended by the respective manufacturer. After tear creation, meniscus repair was performed with the menisci still attached on the tibia. Four repair groups were studied utilizing 2 meniscal repair devices, the SpeedCinch (Arthrex) and the Fast-Fix 360 (Smith & Nephew). Both devices feature an all-inside repair technique utilizing small PEEK implants with pretied knot tensions and allow low-profile vertical or horizontal suture repairs. Two repair constructs were evaluated: 2 parallel vertical sutures and 2 crossed vertical sutures (Figure 1).

Evaluation of 2 repair devices and 2 repair constructs created 4 groups: 2 parallel vertical sutures Fast-Fix (2PFF), 2 crossed vertical sutures Fast-Fix 360 (2XFF), 2 parallel vertical sutures SpeedCinch (2PSC), and 2 crossed vertical sutures SpeedCinch (2XSC). After repair, the menisci were explanted using sharp dissection. Tears were further elongated utilizing an 11-blade surgical scalpel on each side of the repair to ensure the repair sutures were the sole contributor to calculated repair strength and not residual intact meniscal tissue. Individual meniscus specimens were then mounted onto the uniaxial material testing machine and tested. Specimen mounting involved two 5-mm Mersilene Tapes (Ethicon), which were passed between the repair sutures in opposing directions and secured to opposing screw side-action grip specimen clamps.[22] This arrangement allowed initial force application to be in parallel with the repair construct, thus perpendicular to the created tear (Figure 2). Specimens were kept moist using saline solution and were tested within 1 hour of suture construct placement.

The tensile testing protocol has been previously described.[3] It included a preload period for 10 seconds, a

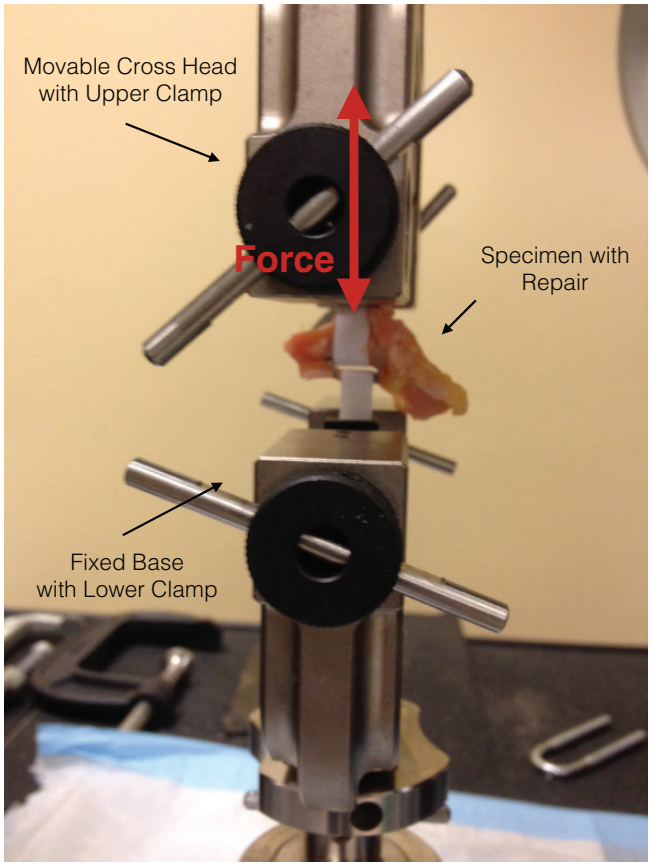

Figure 2. Uniaxial testing construct.

preconditioning period with cyclic loading, and a period of load to failure. Throughout testing, tensile load and displacement were recorded at 10 Hz. The preconditioning period involved 20 cycles from 5 to 30 N at 0.5 mm/s, and the load-to-failure period involved an increase in force at a rate of 0.5 mm/s until failure. The values were chosen for continuity with previous testing techniques for both radial and longitudinal meniscal tear repair strength testing. Through the entire testing process, actuator force and displacement was captured and a displacement curve generated using mechanical testing software (Bluehill 2; Instron Corp). Maximum failure load was defined as the first loss of structural integrity illustrated by the initial peak on the displacement curve. Specimens were monitored closely to ensure that slip of meniscus tissue within the clamp did not occur. Stiffness for each construct was determined by calculating the slope of the displacement curve during the load-to-failure period. Specimens were monitored for slip within the clamp visually during testing as well as on posttest analysis of the displacement curve. Methodology is similar to previously published longitudinal meniscal repair studies.[5,6,22]

All data were checked for normality of distribution, and 1-way analysis of variance by ranks was chosen to evaluate for statistical significance of maximum failure load and stiffness between groups. Statistical significance was defined as $P < .05$.

TABLE 1
Maximum Failure Load and Stiffness for Each Construct[a]

	Maximum Failure Load, N	Stiffness, N/mm
Fast-Fix		
Parallel vertical sutures	89.6 ± 16.3 (125.7-47.8)	18.2 ± 6.63 (40.4-7.84)
Crossed vertical sutures	72.1 ± 11.7 (103.4-47.6)	16.5 ± 6.34 (33.2-5.25)
SpeedCinch		
Parallel vertical sutures	71.9 ± 15.5 (109.4-41.3)	17.1 ± 4.69 (31.7-6.75)
Crossed vertical sutures	79.5 ± 25.4 (119.1-30.9)	11.3 ± 2.89 (21.5-7.62)

[a]Results are reported as mean ± %95 CI and range (maximum-minimum).

RESULTS

The mean maximum failure loads ± 95% CI (range) were 89.6 ± 16.3 N (125.7-47.8 N) (2PFF), 72.1 ± 11.7 N (103.4-47.6 N) (2XFF), 71.9 ± 15.5 N (109.4-41.3 N) (2PSC), and 79.5 ± 25.4 N (119.1-30.9 N) (2XSC). Interconstruct comparison revealed no statistical difference between all 4 constructs regarding maximum failure loads ($P = .49$). Stiffness values were also similar, with no statistical difference on comparison ($P = .28$) (Table 1). The failure mechanism for all specimens tested was meniscal tissue suture pull-through.

DISCUSSION

This study evaluated the failure properties of suture constructs placed in an open fashion mimicking repair of a longitudinal meniscus tear to aid the clinician regarding suture repair options. It also compared a new meniscus repair device to an established device. To our knowledge, this is the first study to compare the newer generation SpeedCinch and Fast-Fix 360. In comparing failure load and stiffness, no statistical significance was found between a parallel suture repair pattern and a crossed suture repair pattern; additionally, no difference was illustrated between repair devices.

Early meniscus repair devices were rigid, absorbable polymers deployed intra-articularly into meniscus tissue. Newer implants contain rigid polymer anchors deployed intra-articularly through the meniscus and capsule tissue to the outside of the joint, anchoring self-adjusting UHMWPE intra-articular suture components. Older rigid implants have performed inferiorly in biomechanical studies.[3,5-7,9,12,22] Modern suture material, UHMWPE, has also been found to improve repair strength when compared with older suture material.[17] Additionally, repair devices utilizing UHMWPE and PEEK anchors have performed better than all-inside devices utilizing suture material alone.[22]

In addition to different implant properties, the configuration of the repair pattern has potential implications for meniscal healing. Several biomechanical studies have

shown that vertically oriented repairs have superior load-to-failure characteristics than horizontally placed sutures.[14,24] Kohn and Siebert[17] demonstrated that vertically oriented placed sutures within the vascular zone captured more collagenous fibers and thus provided more stability to the repair. Rimmer et al[24] demonstrated that a double vertical loop and a single vertical loop had twice the mean failure strength than a single horizontal loop. However, more recent studies have suggested that more complex repair patterns fared even better than simple patterns.[3,9,15] Abdelkafy and colleagues[1] proposed that a "cruciate" repair pattern failed at 110 N whereas a simple vertical suture failed at 67 N. Although the technique relied only on spinal needles, it was time consuming and the clinical applicability was not fully tested. Regarding longitudinal tears, this current study found no difference between a more complex crossed pattern and a simple parallel repair pattern.

Similar to a previous study comparing the SpeedCinch and Fast-Fix, we found no difference between the 2 tested devices.[5,22] To our knowledge this is the first study to compare the newer generation of the devices. The results are not surprising given that both devices utilize sutures made of similar material (UHMWPE) and size. Both of these suture properties have been found to be important factors in the ultimate load-to-failure strength of repaired constructs.[17]

Although the biomechanical model utilized in this study has been validated in previous publications, it still has several weaknesses. First, the menisci are tested at a time point "zero," which fails to account for any meniscal healing. Second, it represents a "worst-case scenario" as the repair constructs are tested in tension only and fail to account for the more complex forces that occur physiologically. Third, the mean age of the specimens tested may not reflect the actual characteristics of meniscal repairs performed in clinical practice.

CONCLUSION

The newer generation of hybrid all-inside meniscal repair devices containing UHMWPE sutures and PEEK anchors performed similarly in the model tested. The decision of which device to use should be based on the surgeon's familiarity with the device. Further studies comparing the device's ease of use should be performed.

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