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Biomechanical Comparison of All-Suture, All-Inside Meniscus Repair Devices in a Human Cadaveric Meniscus Model

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Abstract

Objective. Newer all-suture, all-inside meniscus repair devices utilize soft suture anchors. The purpose of this study was to compare the biomechanical performance of 4 meniscus repair devices in human cadaver menisci: the JuggerStitch (all-suture, all-inside), the FiberStitch (all-suture, all-inside), a polyether ether ketone (PEEK) all-inside, and an inside-out device. *Design*. Forty human cadaver menisci were tested after creating 20 mm longitudinal tears in the posterior meniscus. Each knee was randomized to 1 of 4 meniscus repair groups: JuggerStitch (all-suture, all-inside), FiberStitch (all-suture, all-inside), FAST-FIX 360 (PEEK-based anchor all-inside), and inside-out (with Broadband$^{\text{TM}}$ tape meniscus needles). For each meniscus, 2 devices were used to prepare vertical mattress repair construct. The specimens were tested by pre-conditioning 20 cycles between 5 N and 30 N and then the tear diastasis was measured, followed by distraction to failure phase after imposing a displacement at a rate of 0.5 mm/s. *Results*. Ten menisci were tested in each of the 4 groups. After pre-conditioning, there was no significant difference in the gap formation among groups ($P = 0.212$). The average failure load for the JuggerStitch, FiberStitch, PEEK all-inside, and inside-out was 384 N, 311 N, 207 N, and 261 N, respectively, with a significant difference between groups ($P = 0.034$). *Post hoc* analysis showed the JuggerStitch failure load was higher than the PEEK all-inside and inside-out ($P = 0.005$, and $P = 0.045$, respectively). There was no significant difference between the failure load of the JuggerStitch and FiberStitch ($P = 0.225$). *Conclusion*. The JuggerStitch all-suture device, FiberStitch all-suture device, PEEK all-inside, and inside-out devices have similar biomechanical properties for gapping and stiffness. The JuggerStitch all-suture, all-inside device has superior failure load compared with the PEEK all-inside and inside-out repair for longitudinal meniscus tear repair.

Keywords
biomechanics, general, knee meniscus, repair, all-inside

Introduction

Recent studies have highlighted the importance of meniscal preservation in the treatment of meniscal tears.[1-6] The menisci play an important role in dynamic load distribution, shock absorption, joint congruity, joint lubrication, and proprioception.[7-9] Assuming successful healing, meniscal repair offers preservation of the above-mentioned functions of the menisci. Degenerative changes in the knee have been shown to develop following meniscectomy.[10,11] As a result, many advances have been made in meniscus repair techniques and technology.[3,12]

Many techniques have been developed for meniscus repair, including inside-out, outside-in, and all-inside techniques. The inside-out technique has long been considered the gold standard of meniscus repair.[12] However, the all-inside all-arthroscopic technique avoids the technical demands and morbidity associated with open surgery required of inside-out and outside-in techniques.[13] In addition, multiple studies have found no difference in clinical healing between all-inside versus inside-out repairs.[12,14-16] Significant advances have been made for all-inside

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meniscus repair devices leading to increasing indications for meniscal repair.[17-19] All-inside devices with PEEK (polyether ether ketone) anchors have been shown to have similar biomechanical properties and clinical healing to inside-out repairs.[12] While many all-inside devices utilize PEEK-based anchors, a recent study demonstrated increased meniscal cyst formation with all-inside PEEK anchor devices compared with inside-out repairs.[20] Newer all-suture, all-inside anchors have subsequently been developed. Unlike PEEK anchor devices, these newer all-suture devices utilize soft anchors made of suture material. These newer all-suture, all-inside devices are deployed posterior to the capsule and expand when the repair is tensioned.

The purpose of this study was to compare the biomechanical performance of 4 meniscus repair devices in human cadaver menisci: the JuggerStitch (all-suture, all-inside), the FiberStitch (all-suture, all-inside), a PEEK all-inside, and an inside-out device. The hypothesis was that the biomechanical properties would be similar among all-suture, all-inside devices, a current PEEK anchor all-inside meniscal device, and inside-out meniscus repair in response to cyclic loading and load to failure testing.

Materials and Methods

The Institutional Review Board (IRB) approved this study. After IRB review, 24 human cadaver knees were dissected leaving only the tibia, the posterior capsule, and the medial and lateral menisci with roots still attached to the tibia. The menisci were not removed from the tibia during the biomechanical testing performance. Cadaver knees were excluded from the study if they had a previously existing meniscus tear. Four knees were found to have a meniscus tear. This yielded 40 menisci total (20 medial, 20 lateral). The following meniscal dimensions were obtained: length, width, mid body width, and thickness. The average age of the cadavers was 67 years old ± 13 (SD) (range, 23-81). The weight and side of each cadaver knee was recorded. Posterior horn longitudinal full-thickness cuts were simulated 4 mm from the capsule, 20 mm in length.

Each knee was designated to 1 of 4 meniscus repair groups: FiberStitch all-inside (Arthrex, Naples, FL), JuggerStitch all-inside (Zimmer-Biomet, Warsaw, IN), PEEK all-inside (FAST-FIX 360, Smith and Nephew, Andover, MA), and inside-out with Broadband tape (Zimmer-Biomet, Warsaw, IN) meniscus needles. The FiberStitch is constructed of a 2-0 coreless FiberWire (polyester and ultra-high-molecular-weight polyethylene [UHMWPE]) suture with a pre-tied knot, anchored by 2 suture sleeves, that are deployed by a 1.8 mm, 12° up curve hollow needle. The curved JuggerStitch uses 2 soft polyester suture sleeve anchors connected by a 2-0 UHMWPE adjustable locking suture that is deployed with a meniscal repair device that uses a 1.6-mm hollow needle with a beveled tip. The FAST-FIX 360 curved meniscal repair device deploys 2 PEEK anchors (1 mm × 5 mm and 1.5 × 5 mm) that are adjoined by number 2-0 braided UHMWPE suture that has a pre-tied locking and sliding knot. These PEEK anchors are deployed through a hollow 1.5-mm needle which has a beveled tip. The Broadband tape meniscus needles were made of a 30″ tape (1.0 mm) that transitions to 2-0 suture connected to 10″ long 0.6-mm solid needles.

Both the FiberStitch and JuggerStitch are all-inside devices that are anchored with a polyester sleeve which expands when the suture is tensioned. For each meniscus, 2 longitudinal repairs were performed with 10-mm horizontal spacing between the repairs. The 2 separate repairs were performed with separate devices composed of the same implants for each group. For each all-inside repair, the first anchor was inserted in the inner meniscus to a depth of 18 mm and anchor deployed behind the capsule, then the second anchor was placed into the periphery close to the menisco-capsular junction to a depth of 18 mm and second anchor deployed behind the meniscus rim and capsule as well. The inside-out repairs were performed similarly, in a vertical mattress configuration, with the knots tied on the capsular side with a surgeon's knot and 6 half hitches. All knots were reduced and tied by a single, board-certified orthopedic surgeon who completed a fellowship in sports medicine (P.A.M.). The tension to cinch all of the knots for repair was measured using a dynamometer (Mark-10, Copiague, NY) and recorded. This was done by attaching a dynamometer to the all-inside meniscus devices single suture stand for final tensioning. For the inside-out, this was done by attaching the dynameter to the post, when tying a surgeon's knot. Following a previously developed protocol,[21] polyester fiber tapes (Mersilene, Ethicon, New Brunswick, NJ) 5 mm wide were placed in the center of the cut with one posterior loop and one anterior loop to load the meniscus after repair.

Mechanical testing was performed with a custom-built attachment made for the Instron 8874 biaxial servohydraulic fatigue testing system (Instron, Norwood, MA), with linear-torsion testing of ±25 kN and ±100 Nm of torque capacity. The attachment converted the axial displacement of the Instron actuator in the symmetrical distraction of the meniscal cut along the medial/lateral axis. In order to obtain a pure distraction of the cut, the tibia was mounted on an X-Y stage allowing free movement in the transverse plane and a custom apparatus pulled symmetrically on the Mersilene tapes (see **Fig. 1**).

A baseline load of 10 N was applied with the apparatus and baseline gapping was measured. Measurements were obtained including gapping at baseline, gapping after preconditioning, and the failure load. Following a previously published protocol,[1] the specimens were pre-conditioned

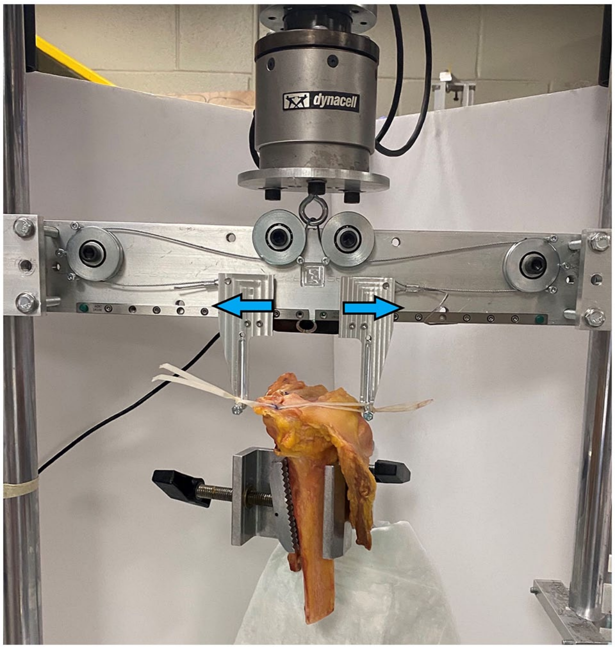

Figure 1. Testing apparatus. Left tibia medial meniscus with a simulated 2 cm longitudinal meniscus tear is mounted on the x-y stage that allowed free movement while the longitudinal meniscus tear is symmetrically distracted by the custom-made fixture mounted on the Instron 8872 frame. The x-y stage allows for 2 degrees of freedom. The blue arrows represent the symmetric pull of the Mersilene tape by the Instron machine.

imposing initially a sinusoidal load in amplitude ranging between 10 N and 30 N for 20 cycles and followed by a distraction to disruption. The amount of 20 cycles was chosen based on a previous biomechanical study on meniscus repair.[22] The cut gapping was measured before and after the cycling phase through the measure of the maximal distance in correspondence of the cuts measured an imaging program called ImageJ (Oracle, Redwood Shores, CA) on calibrated images acquired with a 12MP camera. Gapping distances were obtained averaging the distances across the longitudinal cuts in correspondence of the middle and the margins of the Mersilene tape, similar to a previously described method (see **Fig. 2**).[23]

The repair site distraction was performed imposing a displacement at a rate of 0.5 mm/s while acquiring load-displacement data at 100 Hz. During the distraction phase, peak load was measured, and failure load was defined as the sudden load reduction greater than 10%. Modes of failure were considered to be device pullout, suture breakage, suture pull-through, and suture slippage. They were evaluated and recorded immediately after experimentation. Stiffness of the construct was measured trough the angular coefficient of the linear regression fitting the linear portion of the load-displacement curve.

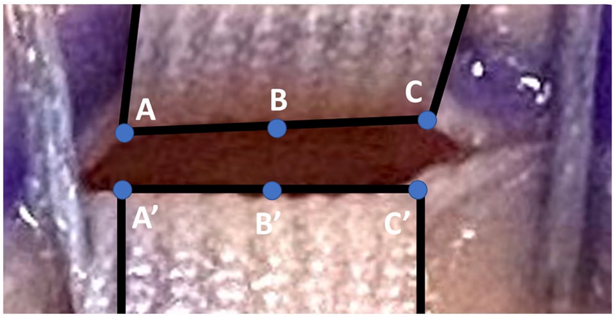

Figure 2. Gap measuring illustration. The gaps can be appreciated between the vertical mattress sutures as distraction forces are applied by the anterior and posterior Mersilene tapes. Gapping distances were obtained averaging the distances across the longitudinal tears in correspondence of the middle (distance from B to B') and the margins of the Mersilene tape (distance from A to A' and C to C', respectively).

Statistical Analysis

For comparison of numerical data such as the dimensions of the meniscus, load to failure, and gapping, an analysis of variance (ANOVA) was performed. Statistical analysis was performed with SPSS version 29 (IBM, Armonk, NY). A significance level of 0.05 was set for all comparisons. After ANOVA, *post hoc* testing was performed with Fisher's least significant difference test. For comparing categorical data such as the mode of failure, a chi-square was done.

In order to determine the number of specimens for each group, *a priori* power analysis was performed after a small sample of specimens was tested. After 5 samples were tested in each group, there was an average failure load of $\mu1 = 406$ N, $\mu2 = 197$, $\mu3 = 183$, and $\mu4 = 288$ (for the JuggerStitch, FiberStitch, PEEK all-inside, and inside-out groups, respectively), with a pooled SD of 132. For a $1 - \beta$ or power of 0.8, a sample size needed was calculated to be 7 for each group. To provide a buffer, it was determined that 10 menisci in each group were selected for a total of 40 menisci.

Results

After removing 4 knees from the study due to previous meniscus tears, 20 knees with 40 intact menisci were utilized. There were 5 medial meniscus and 5 lateral menisci tested in each group. When comparing the medial menisci length, width, mid body width, and thickness, there was no difference in dimensions across all 4 groups ($P = 0.27$, $P = 0.14$, $P = 0.98$, and $P = 0.89$, respectively, see **Table 1**). When comparing the lateral menisci length, width, mid body width, and thickness, there was no difference in dimensions across all 4 groups ($P = 0.75$, $P = 0.69$, $P = 0.5$, and $P = 0.91$, respectively, see **Table 2**). There was

Table 1. Medial Meniscus Dimensions of 4 Groups.

Group	Length	SD[a]	Width	SD	Mid-Body Width	SD	Thickness	SD
JuggerStitch	43.6	4.8	31.8	2.6	9.6	0.5	5.6	0.9
FiberStitch	45.2	3.2	34.2	2.8	9.4	1.5	5.8	0.4
FastFix360	40.6	2.6	30.8	2.3	9.4	2.4	5.6	1.1
InsideOut	43.6	3.4	30.8	2.2	9.8	1.9	5.4	0.5
P-value	0.27		0.14		0.98		0.89	

SD = standard deviation.

Table 2. Lateral Meniscus Dimensions of 4 Groups.

Group	Length	SD[a]	Width	SD[a]	Mid-Body Width	SD	Thickness	SD
JuggerStitch	36.8	4.6	29.6	1.7	10.8	0.8	5.8	1.6
FiberStitch	36.2	1.5	30.6	5.2	9.4	2.1	6.2	1.3
PEEK all-inside	35	1.2	28.2	0.4	9.4	1.9	5.6	1.1
InsideOut	35	4	29	3.4	10.8	2.7	5.8	1.3
P-value	0.75		0.69		0.5		0.91	

PEEK = polyether ether ketone; SD = standard deviation.

also no difference in the age, weight, or side among the 4 groups ($P = 0.85$, $P = 0.9$, and $P = 0.66$, respectively, see **Table 3**).

A *post hoc* analysis showed a non-significant small correlation between increasing age and increasing load to failure (r = 0.14, $P = 0.413$) and no correlation between age of cadaver and gapping after cycling (r = 0.04, $P = 0.842$). There was a difference in the force required to reduce the peripheral side implant ($P = 0.001$). *Post hoc* analysis showed the peripheral FiberStitch required a force to reduce it higher than the PEEK all-inside, inside-out, and JuggerStitch ($P = 0.001$, $P < 0.001$, and $P = 0.009$, respectively). There was also a difference in the force required to reduce the root-sided implants (the suture closer to the posterior root of the meniscus) among the 4 groups ($P = 0.002$). *Post hoc* testing showed that the root-sided FiberStitch required a higher force to reduce than the PEEK all-inside and inside-out ($P = 0.033$ and $P < 0.001$, respectively). The root-sided JuggerStitch had a different tension required compared to the inside-out ($P = 0.018$, see **Table 4**).

After pre-conditioning the menisci, there was no significant difference in the gap formation among groups ($P = 0.212$, see **Fig. 3**).

The average failure load for the JuggerStitch, FiberStitch, PEEK all-inside, and inside-out was 384 N, 311 N, 207 N, and 261 N, respectively, with a significant difference between groups ($P = 0.034$, see **Fig. 4**).

Post hoc analysis showed the JuggerStitch failure load was higher than the PEEK all-inside and inside-out ($P = 0.005$, and $P = 0.045$, respectively). The FiberStitch failure load was no different than the JuggerStitch, PEEK all-inside, or inside-out groups ($P = 0.225$, 0.089, 0.405, respectively). There was no difference with stiffness among the 4 groups ($P = 0.468$). The failure loads, stiffness, and gapping data are summarized in **Table 5**. Fifty-eight percent of all specimens failed due to suture cutout. No difference in stiffness could be demonstrated among the 4 groups ($P = 0.346$, see **Table 6**).

Post hoc power analysis for the failure load showed that with a sample size of 10 for each of the 4 groups and an effect size (η^2) of 0.221, there was an estimated power of 0.742.

Discussion

All-inside meniscus repair devices and techniques have advanced significantly. The PEEK anchor all-inside meniscus repair devices have been shown to have biomechanical and clinical results comparable to the traditional inside-out techniques.[3,12,24] This study compared the biomechanical properties of these newer all-suture anchored devices to a traditional PEEK anchor device and inside-out repair. The 2 all-suture all-inside devices had comparable biomechanical properties to each other. The JuggerStitch all-inside device has higher failure load than the PEEK all-inside and the inside-out device for longitudinal meniscus repair ($P = 0.005$ and $P = 0.045$, respectively). There was no difference in failure load between the 2 all-suture all-inside devices. No difference was found among the 4 devices with respect to gapping or stiffness.

Table 3. Demographic Data of Cadaver Specimens.

			Side	
Device	Age (Years)	Weight (kg)	L	R
JuggerStitch	62.5	91.5	3	2
FiberStitch	70.0	82.6	2	3
PEEK all-inside	69.2	82.0	3	2
Inside-out	67.2	79.5	2	3
P value	0.85	0.90	0.66	

PEEK = polyether ether ketone.

Table 4. Force to Reduce Peripheral Side and Root Side Sutures of 4 Different Repair Devices.

Device	Peripheral Side Sutures (*N*)	SD[a]	Root Side Sutures (*N*)	SD[a]
JuggerStitch	20.5	4.5	22.5	5.6
FiberStitch	25.3	4.3	25.4	2.8
PEEK all-inside	19.1	4.1	21.5	4.4
Inside-out	18.4	2.3	18.1	1.8
P-value	0.001		0.002	

PEEK = polyether ether ketone; SD = standard deviation.

These devices can be used to repair longitudinal meniscus tears without the need for open incisions to tie knots on the capsule. The next advancement of all-inside meniscus devices has led to the development of all-suture anchored devices. These devices utilize a suture sleeve anchor technology, with a suture material that expands after being deployed on the extra-articular side of the knee capsule. Inside-out meniscus repair for longitudinal meniscus tears has long been considered the gold standard for a reliable repair.[25] All-inside devices such as the PEEK all-inside were subsequently developed and have shown comparable results both clinically and biomechanically.[3,12,24] A recent systematic review demonstrates no difference in failure rate and clinical outcomes between inside-out or all-inside repair.[12] All-suture anchors with similar technology have been utilized for repair of soft tissue such as the labrum and rotator cuff with promising clinical and biomechanical results.[26,27] These all-suture anchors have shown high failure loads in bone and have the advantage of being placed in a smaller hole in the meniscus, then expanding after deployment.[26] The current study specifically focused on comparing the biomechanical data of 4 devices: the JuggerStitch, FiberStitch, PEEK all-inside, and inside-out repair.

Previous studies have evaluated the failure load, gapping, and stiffness of inside-out and all-inside devices with helpful comparisons.[3,28,29] While many of these studies separated the whole meniscus from the capsule, this study preserved the capsule peripheral to the meniscus. Many of these devices are designed to anchor behind the capsule and these devices are typically deployed behind the capsule in the clinical setting. Barber *et al.*[3] compared the FAST-FIX to inside-out, with a failure load of 68.1 N versus 95.8 N, respectively. The authors showed the OrthoCord (Depuy Synthes Mitek, Raynham, MA) inside-out had a higher failure load than the FAST-FIX 360. Another study by Masoudi *et al.*[28] compared the FAST-FIX to the NovoStitch (Smith and Nephew, Andover, MA) and inside-out. They showed the FAST-FIX had a failure load of 82.4 N, while the inside-out had a failure load of 118.3 N and NovoStitch had a failure load of 111.4. There was a higher failure load for the inside-out and NovoStitch over the FAST-FIX 360. In addition, a study showed the inside-out and newer Omnispan (Depuy Synthes Mitek, Raynham, MA) had higher failure loads than the FAST-FIX 360.[29] Many of these previous studies were done with a single repair device in a longitudinal meniscus cut with the peripheral capsule removed, while this study utilized 2 parallel repairs for each group with an intact peripheral capsule. It was chosen to model this testing with preservation of the peripheral capsule in this manner to better simulate the actual anatomy of the knee and to preserve the attachments of the native meniscus as many times these repair devices are deployed posterior to the intact capsule. This may explain the failure load average of 207 N for the PEEK all-inside group which is approximately double these previous studies. In addition, the meniscus roots and capsule were kept providing more realistic testing of the meniscus.

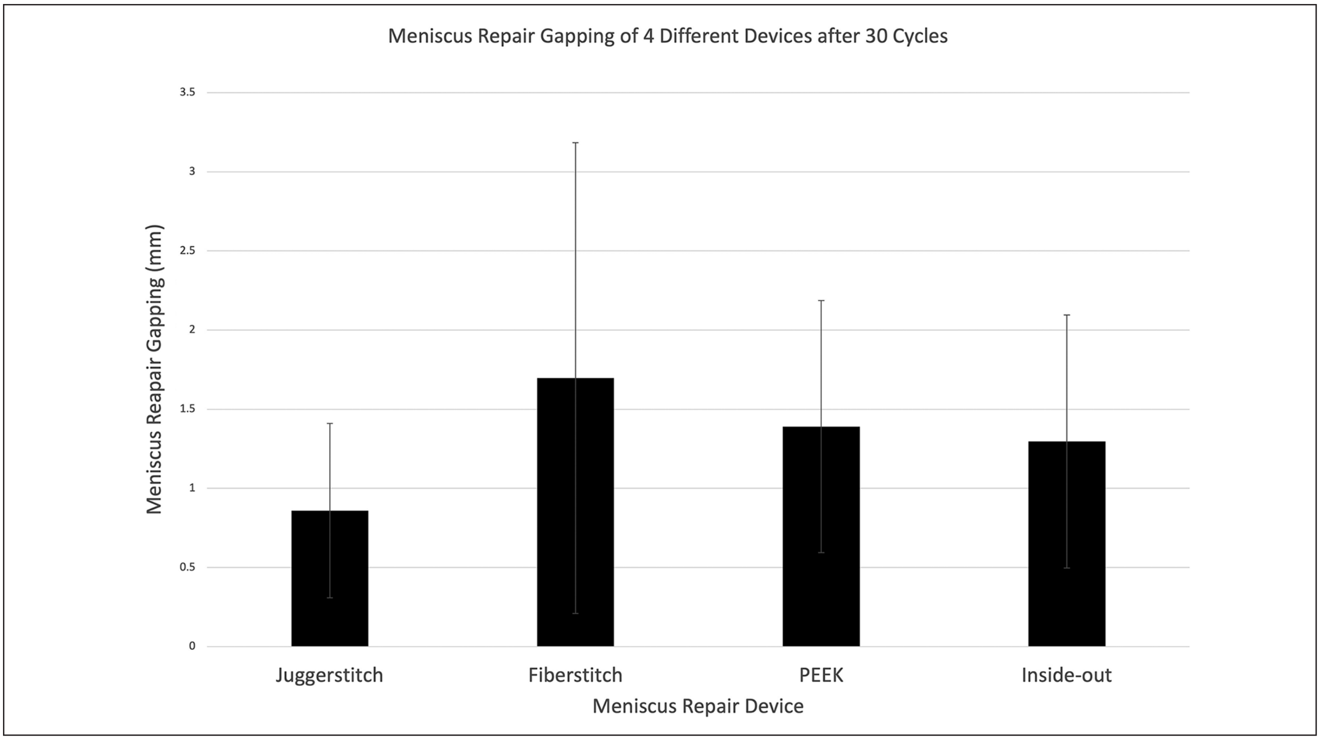

Figure 3. Meniscus gapping of 4 different devices after cycling. Error bars represent the standard error for each of the 4 different devices. No statistically significant difference was found between the groups (*P* = 0.212). PEEK = polyether ether ketone–based all-inside device.

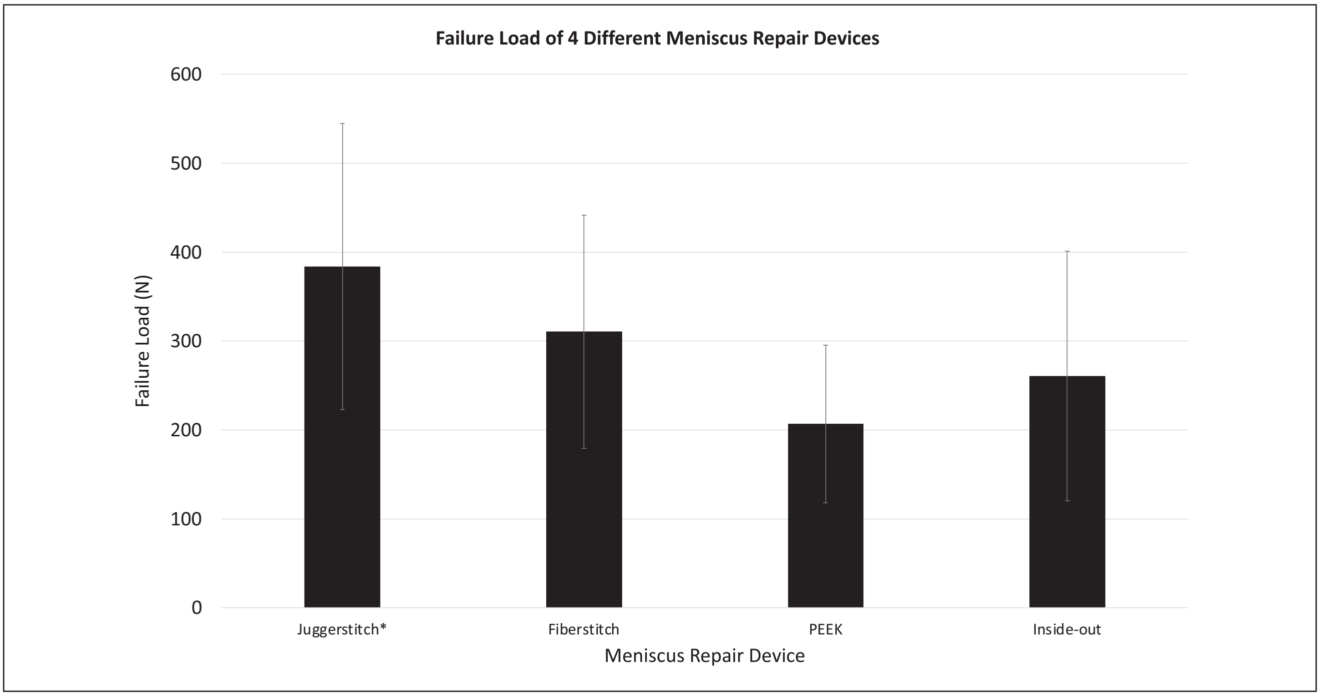

Figure 4. Failure load of 4 different repair devices. The error bars represent standard error for each of the 4 device's failure load averages. A significant difference between the groups was found (*P* = 0.034). **Post hoc* analysis showed the JuggerStitch failure load was higher than the PEEK all-inside and inside-out (*P* = 0.005 and *P* = 0.045, respectively). PEEK = polyether ether ketone–based all-inside device.

Table 5. Failure Data of 4 Devices.

Device	Failure Load (N)	SD	Stiffness (N/mm)	SD	Average Gapping at Preload (mm)	SD	Average Gapping after Cycling (mm)	SD
JuggerStitch	384.1	160.8	17.5	3.1	0.88	0.5	1.74	0.8
FiberStitch	310.7	131.2	18.3	5.3	1.59	1.2	3.22	2.6
PEEK all-inside	207	88.8	15.3	4.5	1.59	1	2.98	1.5
Inside-out	260.7	140.4	16.3	3.4	1.6	1	2.89	1.3

SD = standard deviation; PEEK = polyether ether ketone.

Table 6. Failure Modes of 4 Devices.

Device	Anchor Pullout, *n*	Suture Breakage, *n*	Suture Cutout, *n*	Suture Slippage, *n*
JuggerStitch	-	4	5	1
FiberStitch	1	1	8	-
PEEK all-inside	-	6	4	-
Inside-out	1	2	6	1

PEEK = polyether ether ketone.

Another study by Milchtiem *et al.*[1] utilized 2 repairs (parallel vertical and crossed vertical sutures) for each group similar to this present study and showed no difference between failure load of 2 all-inside PEEK anchor devices (FAST-FIX and Speed Cinch). Their study showed a failure load of 89.6 N and 71.9 N for the FAST-FIX and Speed Cinch, respectively. While comparing suture configuration is beyond the scope of this study, further research is warranted to compare these groups in the current study's design. Ramappa *et al.*[30] also performed 2 longitudinal repairs on each meniscus. They compared the FAST-FIX to inside-out and an all-inside running suture PEEK anchor device called the Sequent. Ramappa *et al.*[30] demonstrate failure loads of 140 N for the FAST-FIX and 188 for the inside-out group, with a higher failure load for the inside-out group. While some previous studies demonstrated the inside-out had a higher failure load than the FAST-FIX 360, the JuggerStitch actually had a higher failure load than both the PEEK all-inside and inside-out.[3,28,30] As many of the load failures occurred due to meniscus cutout, it may be hypothesized that the higher load to failure of the Juggerstich is, in part, due to its relatively minimally traumatic insertion within the meniscus. The soft polyester suture anchors and the tapered tip inserter needle may leave more robust surrounding meniscal tissue for the anchor to lodge in.

Previous studies have shown the FAST-FIX 360 repairs to have displacement of 1.4 to 11 mm, depending on the study.[3,29,30] Rosso *et al.*[29] demonstrated no difference in gapping after 100,000 cycles among 2 all-inside groups, the FAST-FIX 360 and Omnispan all-inside device. This is similar to the present study, where a difference in gapping was not found among all 4 groups. This study, however, utilized a low number of cycles and further studies should be done on higher cycles to determine whether there is an increase in gapping. If a larger number of cycles leads to a difference in gapping between devices, this would be an important distinction to determine as it is likely that *in vivo* failure is related to gapping and not catastrophic failure.

Barber found a mean stiffness of 12.1 N/mm for the FAST-FIX, 16.4 N/mm for the AIR meniscal repair device (Stryker, Kalamazoo, MI), and 15.7 N/mm for OrthoCord all-inside.[3] Another study found a vertical FAST-FIX had a stiffness of 14.4 N/mm.[21] An additional study by Masoudi *et al.*[28] demonstrated similar stiffness between all-inside devices with the FAST-FIX and Inside-out measuring 13.8 N/mm and 14.0 N/mm, respectively. These previous studies have demonstrated stiffness for the inside-out group and PEEK anchor all-inside devices that is similar to the stiffness values found here. The stiffness found of 15.3 N/mm for the PEEK all-inside and 16.3 N/mm for the inside-out is similar to previous studies. For baseline consideration, Markis found that circumferential directed fibers of the meniscus had a varying tensile modulus between 100 and 300 MPa.[31]

The mode of failure in this study for the PEEK all-inside was predominantly due to suture rupture, while the FiberStitch was mainly due to meniscus cutout. The JuggerStitch was almost split evenly among meniscus cutout and suture rupture. Previous studies have shown that suture breakage or rupture is the main mode of failure of the FAST-FIX.[28,29] This is similar to the present study, where the suture potentially breaks at lower loads before it is able to cut through the meniscus. The JuggerStitch appears to have a lower rate of cutting through the meniscus than the FiberStitch (50% vs 80%). Multiple reasons may account for this observation including the high tensile strength of

2-0 Fiberwire and the taper tip needle design of the JuggerStitch device which imparts less damage to the meniscal tissue than a cutting needle tip design. The Juggerstich 1.6-mm needle inserter has a circumferential tissue disruption of 2.01 mm^2 on insertion compared with the 2.54 mm^2 circumference. There was no difference in failure load between the 2 all-suture all-inside occupied by the 1.8-mm needle inserter for the FiberStich. The 0.53 mm^2 difference in needle circumference may impart additional tissue damage contributing to the increased rate of cutout in the FiberStitch group.

It should also be noted that the FiberStitch required more tension to reduce the implant. This is likely related to the internal design of the implants with more friction occurring with the FiberStitch during reduction of the tear. This extra tension was required on the suture to cause the suture to slide and reduce the tear. This is likely due to the tensioning mechanism of the FiberStitch device, which utilizes friction to tension the repair device. The increased tension needed for tightening this device is clinically significant for surgeon awareness in the operating room to provide tactile feedback and tension on the repair of the tear.

Limitations

One of the study's main focuses was on failure load, which represents one of the first limitations. This study used 20 cycles (between 5 and 30 N) for pre-conditioning and assessed gapping while other studies have used up to 100,000 cycles (between 5 and 20 N).[29] The amount of 20 cycles was chosen based on a previous biomechanical study on meniscus repair.[22] It is possible there would have been a difference in gapping between groups had more cycles been used.

Another potential limitation was related to the force required to reduce each implant. The dynamometer that was used could have limited the assessment of tension. The FiberStitch required significantly greater tensioning to secure the repairs than the other devices. This could potentially affect the strength of the repair, resulting in falsely lower gapping measurements. It was clear, however, that with lower forces, the FiberStitch would not reduce the meniscus. The authors assumed that the lateral and medial menisci would behave in a similar manner when biomechanically tested. While this may or may not be true, it represents a limitation of the study.

Finally, this testing was completed on cadaveric knees which leaves out the true biomechanics of an *in vitro* knee. No compressive forces or forces from condylar rollback were placed on the menisci after repair. This study more focused on the force to failure of the implant with distraction of the menisci after repair. This model of comparison was utilized to better compare the different fixation methods in a controlled setting.

The study was performed at room temperature in a nonaqueous environment, representing another limitation. The cadaveric specimens used were older than the appropriate population and the testing load does not exactly replicate the possible mechanisms of meniscal repair failure.

Conclusion

The JuggerStitch all-suture device, FiberStitch all-suture device, PEEK all-inside, and inside-out devices have similar biomechanical properties for gapping and stiffness. The JuggerStitch all-suture, all-inside device has superior failure load compared with the PEEK all-inside and inside-out repair for longitudinal meniscus tear repair.

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