A Biomechanical Comparison of Patellar Tendon Repair Materials in a Bovine Model

DAVID C. FLANIGAN, MD; MICHAEL BLOOMFIELD, MD; JASON KOH, MD

abstract

Full article available online at ORTHOSuperSite.com. Search: 20110627-13

We evaluated the biomechanical properties of FiberWire (Arthrex, Inc, Naples, Florida), a new suture material, for both repair and augmentation as compared to standard Ethibond suture (Ethicon, Inc, Somerville, New Jersey), hypothesizing that primary repair and cerclage augmentation with the new suture material would have similar biomechanical properties as a standard repair with wire augmentation.

Forty-five fresh bovine knees were placed in 3 groups of equal size: (1) #5 Ethibond tendon repair plus 18-gauge wire augmentation; (2) #5 FiberWire repair plus #5 FiberWire augmentation; and (3) #5 Ethibond repair plus #5 FiberWire augmentation. A straight static pullout test was performed, randomly alternating between the different groups. Gap formation was measured at the center of the repair by a metric ruler, with the examiner blinded to the developing force-tension readout. For each millimeter of gap formation (1-10 mm), the force on the repair was recorded, as well as the force at the ultimate failure of the repair, designated by breakage of any repair material. Analysis showed no significant difference between the standard Ethibond/wire repair and the FiberWire/FiberWire repair. The Ethibond/FiberWire repair was shown to be significantly weaker than the other 2 groups. Ultimate failure data indicated that the Ethibond/wire repair was significantly stronger than both other groups. No significant differences were found between the FiberWire/FiberWire repair and the Ethibond/FiberWire repair. Newer, stronger suture material for both primary repair and augmentation may provide equivalent biomechanical strength at clinically significant levels.

Dr Flanigan is from the Department of Orthopedics, Sports Medicine Center, The Ohio State University, Columbus, and Dr Bloomfield is from Cleveland Clinic, Cleveland, Ohio; and Dr Koh is from the Department of Orthopedic Surgery, Feinberg School of Medicine at Northwestern University, Chicago, Illinois.

Drs Flanigan, Bloomfield, and Koh have no relevant financial relationships to disclose.

The authors acknowledge the contributions of the late Eugene Lautenschlager, PhD, to this manuscript.

Correspondence should be addressed to: David C. Flanigan, MD, Department of Orthopedics, Sports Medicine Center, The Ohio State University, 2050 Kenny Rd, Ste 3100, Columbus, OH 43221 (david.flanigan@osumc.edu).

doi: 10.3928/01477447-20110627-13
Patellar tendon ruptures are relatively rare injuries. Preexisting patellar tendinosis and repetitive microtrauma have been associated with a predisposition to patellar tendon rupture.\(^1\) Other conditions including systemic diseases (chronic renal disease, rheumatoid arthritis, systemic lupus erythematosus),\(^2,4\) prior surgery (anterior cruciate ligament [ACL] reconstruction with central third patellar tendon),\(^7\) and prior steroid injections\(^1\) have also been associated with increased risk of patellar tendon rupture. Commonly, they are seen in athletes younger than 40 years who sustain a low velocity, indirect, minor traumatic event via a knee flexion moment with a concomitant extensor mechanism contraction. The ruptures can occur at the distal pole of the patella or intrasubstance.\(^8\) The treatment has been surgical repair in the acute setting to restore the quadriceps mechanism.

Multiple techniques have been described in the literature for acute primary repair of the patellar tendon.\(^6-17\) Siwek and Rao\(^18\) described primary repair and augmentation with Steinman pins, pullout wires, and/or wire cerclage. Classically, a primary repair of the tendon with suture has been augmented with wire cerclage to relieve tension across the repair site while the tendon is healing.\(^8,10,19,20\) This repair has had reliable results but often requires a secondary surgery for wire removal, either for mechanical irritation or wire breakage.\(^8,18-21\)

The purpose of this study was to evaluate the biomechanical properties of new suture material for both the repair and augmentation. FiberWire (Arthrex, Inc, Naples, Florida) is a braided polyethylene and polyester nonabsorbable suture, with reported #2 FiberWire equal in strength of standard #5 Ethibond suture (Ethicon, Somerville, New Jersey). Our hypothesis was that primary repair and cerclage augmentation with new suture material would have similar biomechanical properties as a standard repair with wire augmentation.

## Materials and Methods

Forty-five fresh healthy bovine knees (age ≤20 weeks), closely approximating the size of a human knee, were obtained for the study. In each specimen, the subcutaneous tissues were dissected away and the femur removed. All knees were free of visible pathologic changes and all tendons were of approximately the same dimensions. A patellar tendon rupture was created by transversely incising the tendon 3 mm distal to its insertion on the distal pole of the patella.

Each knee was randomly prepared in 1 of 3 groups: (1) #5 Ethibond tendon repair plus 18-gauge wire augmentation, (2) #5 FiberWire repair plus #5 FiberWire augmentation, and (3) #5 Ethibond repair plus #5 FiberWire augmentation. The primary repair consisted of 2 sutures in a locking Krackow technique (5 throws per limb). The 4 suture limbs were then passed through 3 longitudinal drill holes (medial, central, and lateral) in the patella and tied on the superior pole of the patella until the gap in the tendon was closed. The augmentation cerclage loop was passed through transverse holes in the midpatella and tibial tubercle and secured with consistent tension with the patella held in a position of full extension. A secondary transverse patellar hole was drilled for passage of a 14-gauge wire to connect the specimen to the top of the testing apparatus.

The tibias were secured with bone cement vertically into a PVC pipe segment, which was later secured to the testing platform via a custom-made apparatus (Figure 1). The knees were then mounted to an Instron materials testing machine (Instron, Norwood, Massachusetts) and aligned so that the patella and tibial tubercle were plum. A straight static pullout test (1 inch/minute pull speed) was performed, randomly alternating between the different groups. Gap formation was measured at the center of the repair by a metric ruler, with the examiner being blind to the developing force-tension readout. For each millimeter of gap formation (1-10 mm) the force on the repair was recorded, as well as the force at the ultimate failure of the repair, designated by breakage of any repair material. Clinical failure was defined as 5-mm gap formation.\(^22\)

A power analysis was calculated to detect a 1 standard deviation (SD) difference between groups (assumed to be 15 lbs; therefore an effect size of 1) with 80% confidence. Analysis of variance and Student Newman-Keuls post-hoc analyses were performed. A \(P\) value < .05 was used for statistical significance. The slope and \(R^2\) value for each specimen, indicating the stiffness of the repair, were determined averaged within each group.

## Results

### Ethibond/Wire Repair

For the standard repair group, the 5-mm gap was achieved at an average load of 115.6 lbs (SD = 21.6). Ultimate failure of the repair occurred at a mean load of 273.6 lbs (SD = 47.9). The average stiffness of this repair (slope) from 1 to 10 mm of gap formation was 14.7 (\(R^2 = 0.980\)). In this group, there were 3 complications in the 15 specimens. In each case, the augmentation loop pulled completely through
the inferior pole of the patella before the repair itself failed. Therefore, ultimate failure data for that group were calculated from the remaining 12 intact samples. In 1 of the above 3 knees, this occurred before the 10-mm gap measurement, so in this sample the slope was calculated based on the last intact measurement. Most repairs ultimately failed with the wire untwisting (2 cases) or breaking at the area of the twist (10 cases).

**FiberWire/FiberWire Repair**

In the all-FiberWire repair, a mean force of 110.4 lbs (SD = 27.3) was required to produce a 5-mm gap in the repair. Ultimate failure of the repair occurred at a mean of 226.5 lbs (SD = 30.0). The stiffness of this repair was found to be 14.2 (R² = 0.952). Three of the 15 repairs in this group had their ultimate failure before a 10-mm gap was achieved, so the slopes for these specimens were calculated from 1 mm until the last measurement before failure. The cerclage breaking at the knot was the mechanism of failure for all samples in this group.

**Ethibond/FiberWire Repair**

For the mixed suture repair group, the 5-mm gap formation was achieved at an average load of 91.2 lbs (SD = 20.9). Ultimate failure of the repair occurred at a mean of 238.7 lbs (SD = 31.0). The average stiffness of this repair group was 12.3 (R² = 0.952). In this group, none of the repairs failed prior to 10-mm gap formation. The mechanism of failure was the cerclage breaking near the knot, except in 1 case when the primary repair failed first by pulling through the patella.

**Analysis of the Repair Groups**

The comparative results of the 5-mm gap testing are seen in Figure 2. Analysis of variance and post-hoc analyses showed no significant difference between the standard Ethibond/wire repair and the FiberWire/FiberWire repair. This represents a difference of 4.5%, with retrospective power calculated at 83% given the observed SDs of approximately 25 lbs. The Ethibond/FiberWire repair was shown to be significantly weaker than both other groups.

The ultimate failure data are shown in Figure 3. The statistical analysis indicated that the Ethibond/wire repair was significantly stronger than both other groups. No significant differences were found between the FiberWire/FiberWire repair and the Ethibond/FiberWire repair.

The average 1- to 10-mm gap loads data are seen in Figure 4. The average stiffness (force/displacement) of all 3 repairs closely approached linear, as evidenced by the R² values close to 1.0. The slopes of the Ethibond/wire repair and the FiberWire/FiberWire repair have a difference of 3.4%, both being significantly stronger than the Ethibond/FiberWire group. The stiffness of the overall repair construct of Ethibond/wire and FiberWire/FiberWire were similar. The Ethibond/FiberWire repair was not as stiff as a construct and was found to be significantly different.

Finally, statistical analysis was also performed using the results of 3-, 4-, 6-, and 7-mm gap formation as a means of evaluating the applicability of the 5-mm arbitrary failure designation. The statistics at 3- and 4-mm gaps were identical to those of the 5-mm gap. At 6 and 7 mm, the results more closely approximated to the ultimate failure findings.

**DISCUSSION**

Throughout the literature, the methods and results of patellar tendon repair have been highlighted in case reports and retrospective case series. Although acute repair is warranted for this injury, no great consensus exists on how the repair should be done and if augmentation is needed. Classically, primary suture repair with wire augmentation has been the probable gold
Concerns with this repair have been wire irritation and necessity of secondary removal of the wire.

Over the past decade, an emerging emphasis on early mobilization and accelerated rehabilitation following the repair has predominated. This contrasts previous protocols calling for 6 weeks of immobilization and delayed mobilization. The benefits of early mobilization and the effects of immobility have been shown in numerous basic science and clinical studies. Some hesitations about early mobilization were concerns about possible patella alta due to stretching across the repair or early failure. Cerclage augmentation has been advocated to help prevent this and allow protection of the repair during the healing phase. This has been called into question by a recent retrospective review of 15 patients with primary patellar tendon repair only and an accelerated rehabilitation protocol. No reruptures or significant change in patellar height were identified during the mean follow-up of 2.6 years.

Few basic science studies have addressed the biomechanical properties of different techniques of patellar tendon repair. Ravalin et al was the first study to evaluate primary repair alone vs 2 augmentation techniques with cyclical loading. Gap formation in excess of 5 mm was seen in the isolated primary repair. Both augmentation techniques (Ethibond and Dall-Miles cable) had a protective effect on gap formation. Their findings support the reasoning and need for augmentation, especially if early mobilization is desired. Furthermore, it indicates that material of augmentation may not be as important as augmentation itself.

A recent study looked at the mechanical properties using various materials that could be applied for a tension band. Materials that were tested included 18-gauge wire, Mersilene tape (Ethicon, Inc), and Ethibond suture in varying number of loops (2-4 strands). Mersilene tape had equivalent strength to 2 Ethibond sutures. Wire was found to have a higher stiffness, although ultimate load to failure was similar with 4 strands of Ethibond suture. Their conclusion was that multiple strands of Ethibond suture could be substituted for wire if a compliant repair was needed, as in a patellar tendon repair. FiberWire has been shown to have higher loads to failure compared to Ethibond suture. In this study, the primary repair material (Ethibond vs FiberWire) was varied as with the augmentation material (wire vs FiberWire).

One limitation to the current study design was tensioning the augmentation loop at full extension. Current recommendations are to tension the augmentation loop at 30° to 90° of knee flexion. For the biomechanical setup used in this model, the straight static pullout test was also in full extension and therefore would test the integrity of the augmentation loop fully. Tensioning the loop at any flexion angle would have caused some slack in the augmentation loop at full extension and would stress at the primary repair more than the combined repair in this setup.

No specific amount of gap formation has been clearly defined for failure of large tendon repairs, as in the patellar tendon. In the Ravalin et al study, gap formation was arbitrarily defined as a failure at 5 mm. When comparing the loads at gap formations <5 mm, statistical analysis closely resembled the findings at 5 mm. Analysis of gaps >5 mm more closely resembled the findings at ultimate load to failure. The integrity of the repair construct seems change at 5 mm, and this may lead to clinical failure of the repair.

In comparing use of an all-FiberWire repair to the standard repair of Ethibond and wire cerclage, the overall stiffness of both repairs were similar. Also, there was no significant difference in 5-mm gap formation. This would suggest that use of an all-suture repair with FiberWire would provide an equivalent strength of repair compared to the accepted gold standard at clinically significant levels. Using FiberWire for both the primary and augmented loop was necessary to achieve this level of strength at <5-mm gap formation. Conversely, ultimate failure seemed to be associated to the augmentation loop alone, with the wire augmentation having significantly higher loads to failure than a FiberWire construct. The significance of this in an in vivo situation is unknown.

**CONCLUSION**

This study suggests that use of newer, stronger suture material for both primary repair and augmentation can provide equivalent biomechanical strength at clinically significant levels. While an all-suture repair with suture augmentation has the advantage of potentially eliminating the need for a secondary surgery for hardware removal, it resulted in a decreased ultimate failure load.

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