Biomechanical evaluation of a 4.75-mm and a 5.5-mm bone anchor at two insertion angles using one and two strands of suture

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OBJECTIVE
To compare biomechanical strength of 4.75- and 5.5-mm suture anchors when pulled at 45° or 90° angles using 1 versus 2 strands of suture.

SAMPLE
48 synthetic bone block samples.

PROCEDURES
Anchors were inserted into synthetic bone blocks and tested for pullout in 4 configurations (1 suture strand vs 2 strands and 45° vs 90° insertion angle) for a total of 8 groups with 6 samples each. A 3-way ANOVA was used to compare effect of anchor size, strand amount, and angle of pull.

RESULTS
All constructs failed via anchor pullout. Anchor configurations with 2 strands of suture and 4.75-mm anchor (mean, 286 ± 24 N) or 5.5-mm anchor (mean, 300 ± 15 N) had greater pullout strength than configurations with only 1 strand of suture and 4.75-mm anchor (mean, 202 ± 12 N) or 5.5-mm anchor (mean, 286 ± 13.6 N). The 5.5-mm anchors had a higher maximum load to failure under axial pull at 45° (mean, 300 ± 15 N) and 90° (mean, 295 ± 24 N), compared with 4.75-mm anchors at 45° (mean, 202 ± 12 N) and 90° (mean, 208 ± 15 N). There was a higher maximum load to failure for the double-stranded constructs, regardless of anchor size, at both angles of insertion. Anchors inserted at 45° had a higher maximum load to failure than those inserted at 90°. Constructs with 2 strands of suture had a greater pullout strength regardless of the direction of pull.

CLINICAL RELEVANCE
The strength of the anchor construct is likely increased with the use of double-loaded anchors inserted at 45°. Clinicians should consider using 2 strands in clinical cases.

The first suture anchor was developed in 1985 and designed for Bankart labral repair in shoulder joints. Since that time, the suture anchor has been revolutionized to provide stronger and more functional implants that can be used in a variety of orthopedic repairs. Common uses of suture anchors include soft tissue fixation during synthetic reconstruction of damaged tissues such as collateral ligament repair. They are used frequently in both human and veterinary surgery. In veterinary patients, suture anchors have been used successfully in joint ligamentous repair, cranial cruciate extracapsular repair, coxofemoral joint luxation repair, and common calcaneal tendon avulsion repair. Failure of the construct can occur at the bone-anchor interface, the soft tissue-suture interface, or via suture breakage. The pullout strength of a suture anchor is an important factor in the strength of the repair. Similarly, technical application, cortical bone mineral density, and overall design of the anchor have been described as factors influencing the strength of the suture anchor. Clevenger et al evaluated the pullout strength of anchors based on their insertion angle. Anchors were placed from 45° to 135° in 15° increments; the authors hypothesized that there would be increased load to failure with increasing angle of insertion relative to the pull of suture. It was determined that anchors inserted at more acute angles failed at lower loads than those placed closer to 90°. Failure at more acute angles may be the result of anchor design. In contrast, one study suggests that a 45° angle, otherwise termed...
as the “deadman’s angle,” is ideal for anchor insertion. Given the discrepancies in the literature regarding the ideal insertion angle of suture anchors, there is controversy regarding what insertion angle will provide the strongest anchor construct or if the angle of insertion is even relevant to the strength of the construct.

In addition to anchor insertion angle, the type and quantity of suture material utilized contribute to overall construct strength. There are a number of anchor designs that allow for a multitude of suture configurations including fully threaded anchors, knotless anchors, distal eyelet anchors, and more recently, all-suture anchors. Of the numerous designs available, the strongest suture configuration or ideal number of suture strands to use has not been defined.

Knotless suture anchor systems are available that are composed of a radiolucent, nonbiodegradable material called polyetheretherketone (PEEK). These systems allow for application of a knotless suture in orthopedic soft tissue reconstruction. Single or multiple sutures within the anchor construct have been reported. In a model of rotator cuff repair in sheep, the initial repair is enhanced by increasing the number of suture anchors and by using anchors that are double loaded with suture. However, a direct biomechanical comparison of a suture anchor with 1 strand of suture, compared with 2 strands of suture, has not been evaluated.

Figure 1—Experimental setups used to compare biomechanical strength of 4.75- and 5.5-mm suture anchors to pullout when pulled with 1 versus 2 strands of 2.0-mm nonabsorbable synthetic polyethylene ribbon-like suture. The anchors were applied to the synthetic bone blocks perpendicular to the bone surface in the same orientation and then placed in a vice that allowed for pullout at either 90° to the surface of the bone block (A) or in a variable-angle vice that allowed the angle to be set to 45° to the surface of the bone block (B). To allow pull of suture in the 45° direction, a vice clamp was used for those samples versus the set angle vice that affixed the sample to a base plate, which allowed for pull in a direction 90° to the bone block surface.
Currently, the biomechanical strength of the knotless PEEK anchors has not been evaluated to determine if constructs have increased pullout strength at 45° or 90°, although both 45° and 90° insertion angles are commonly used in practice. Similarly, the number of sutures within the anchor that produces the strongest construct has not been determined. Therefore, the goal of this study was to determine the pullout strength of a 4.75-mm and a 5.5-mm knotless PEEK anchor system (SwiveLock; Arthrex, Inc) when inserted at 45° or 90° angles and using 1 versus 2 strands of nonabsorbable synthetic polyethylene ribbon-like suture (FiberTape; Arthrex Inc) under both axial and cyclic loading. We hypothesized that there would be no difference in pullout strength at different angles between anchor size and that constructs with 2 strands of suture would have a higher load to failure than constructs with only 1 strand of suture.

Materials and Methods

Sample preparation

A total of 64 samples were prepared with 4.75-mm (AR-2324PSLC SwiveLock; Arthrex Inc) or 5.5-mm anchor systems (AR-2323PSLC SwiveLock; Arthrex Inc) and tested in 4 configurations, for a total of 8 groups of 8. The samples within the groups were allocated per test (axial, n = 6; cyclic, n = 2).

A band saw was used to cut 320.37 kg/m³ synthetic bone (Sawbones Corp) into 4 X 4 X 4.2 cm blocks. The blocks were clamped into a vice grip. For samples tested at 45°, they were placed in a variable-angle device that allowed the degrees to be set specifically to the desired angle. Pilot holes were drilled according to manufacturer recommendation using a 3.6-mm spade-tipped drill for the 5.5-mm suture anchors and a 3.6-mm twist drill for the 4.75-mm suture anchors in the foam blocks at a 90° angle to the surface of the synthetic bone block for all the samples. All residual debris from drilling was removed using compressed air. Pilot holes in each block were tapped with an appropriate tap for the size suture anchor assigned (5.5-mm tap for the 5.5-mm anchors, and 4.75-mm tap for the 4.75-mm anchors). The anchors were then loaded with either 1 or 2 strands of 2.0-mm nonabsorbable synthetic polyethylene ribbon-like suture (FiberTape; Arthrex Inc), based on group assignment. A rubber mallet was used to lightly tap the anchor into the pilot hole, while simultaneously applying tension to the suture to prevent bunching of the suture in the pilot hole. The driver was then used to apply light back pressure to fully insert the anchor until the top of the anchor was flush with the surface of the test block. This was performed for all the samples.

Axial test—load to failure

A mechanical testing system (Series 5544 tensile tester; Instron) with manufacturer-provided software and a 2-kN load cell was prepared with a pneumatic clamp on the crosshead and a variable-angle vice, set at the appropriate angle so that the axial pull on the suture anchor was set to either 45° or 90° from the surface of the synthetic bone block (Figure 1). A gauge length of 127 mm was measured on the nonabsorbable synthetic polyethylene ribbon-like suture beginning from the top of the foam block. The mechanical testing system was programmed, and the load cell was balanced. A sample was secured, and the crosshead was adjusted to allow for the 12.7-cm gauge length. A manual preload of 5 N was applied, and the testing program was initiated. Axial pullout was performed at a rate of 5 mm/s until failure, with data collection at 500 Hz. Maximum load and failure mode were recorded.

Fatigue test—cyclic loading with load to failure

An electric dynamic testing system (ElectroPuls E10000; Instron) with manufacturer-provided software and a 1-kN load cell was prepared (Figure 1). The was programmed, and the load cell was balanced. A manual preload of 5 N was applied to the sutures, and the program was initiated. The samples...
underwent cyclic load from 10 to 70 N for 3,000 cycles at 1 Hz to simulate quadruped walking on a single leg, followed by load to failure at 33 mm/s. Data were collected at approximately 100 Hz. Maximum load and failure mode were recorded. Statistical analysis was not performed on samples that underwent cyclic load to failure as there were only 2 samples in each group.

**Statistical analysis**

The size, strand amount, and angle were considered independent variables. All metrics for comparison (ie, stiffness, cyclic displacement, and ultimate load from the axial and fatigue test) were considered dependent variables. Data were tested for normality using a Shapiro-Wilk test. Variance between the groups was assessed using a Brown-Forsythe test. Results were compared across groups with the use of a 3-way ANOVA test. The statistical analysis was performed with available software (Sigmaplot, version 14.0; Systat Software Inc) at a significance level of \( P < 0.05 \).

**Results**

All the samples in this study failed via anchor pullout (Figure 2); however, damage to the surface of the synthetic bone was consistently noted for the 5.5-mm anchors but was not observed with the 4.75-mm anchors (Figure 3). When comparing the strength of 1- versus 2-strand configurations under axial pullout, the maximum load to failure was higher for the double-strand constructs for both 4.75- and 5.5-mm anchors (Table 1).

The maximum load to failure under axial pull was significantly greater for the 5.5-mm anchor, compared with the 4.75-mm anchor \( (P < 0.001) \) at both 45° \( (P < 0.001) \) and 90° \( (P = 0.006) \). There was a higher maximum load to failure for the double-stranded constructs, regardless of anchor size \( (P < 0.001) \). When using 3-way ANOVA to compare the angle of pullout, those constructs inserted at 45° had a significantly higher load to failure \( (P = 0.033; \text{Table 2}) \).

Cyclic loading was performed on 2 samples. The maximum load to failure was greater in constructs inserted at 45° versus 90° and those that were anchored with 2 versus 1 suture (Table 3). Statistical evaluation of the samples undergoing cyclic loading was not performed given there were only 2 samples in each group.

**Table 1**—Mean ± SD maximum load to failure for 4 configurations (1 suture strand vs 2 strands and 45° vs 90° insertion angle) for 4.75- and 5.5-mm suture anchor constructs (8 groups with 6 samples each) that underwent axial load to failure testing.

| Configuration                        | Mean ± SD maximum load to failure (N) |
|--------------------------------------|---------------------------------------|
| 4.75-mm Anchor constructs            |                                       |
| 45° Angle X single strand            | 202 ± 12                               |
| 45° Angle X double strand            | 286 ± 24*                              |
| 90° Angle X single strand            | 208 ± 15                               |
| 90° Angle X double strand            | 287 ± 17*                              |
| 5.5-mm Anchor constructs             |                                       |
| 45° Angle X single strand            | 286 ± 14                               |
| 45° Angle X double strand            | 300 ± 15*                              |
| 90° Angle X single strand            | 242 ± 15                               |
| 90° Angle X double strand            | 295 ± 24*                              |

*Biomechanical strength of the anchors was significantly \( (P < 0.05) \) greater when 2 strands (vs 1 strand) of suture were used, regardless of insertion angle or anchor size when tested under axial load.

Variance between the groups was assessed with the Brown-Forsythe test.

**Table 2**—Summary of the 3-way ANOVA results comparing the effect of anchor size, strand amount, and angle of pull for axial load to failure for the configurations described in Table 1.

| Factor         | Group          | Least square mean (N) | Comparison              | \( P \) value |
|----------------|----------------|-----------------------|-------------------------|---------------|
| Anchor size    | 4.75 mm        | 246                   | 5.5 mm vs 4.75 mm       | \(< 0.001\)   |
|                | 5.5 mm         | 281                   |                         |               |
| Strand amount  | Single strand  | 235                   | Double vs single strand | \(< 0.001\)   |
|                | Double strand  | 292                   |                         |               |
| Angle          | 45°            | 269                   | 45° vs 90°              | 0.033         |
|                | 90°            | 258                   |                         |               |
the number of implants that have to be used during surgery. Potential to increase surgical efficiency and decrease the number of holes to be drilled into the bone during repair. As discussed previously, the angle that will yield the greatest biomechanical strength is also controversial. The goal of this study was to provide early biomechanical data related to the suture anchor size and the number of sutures used. However, the clinical relevance of this data is unclear without additional in vivo studies. Although in vivo studies have been performed to evaluate the use of double-stranded suture anchors in people, the data are limited. A cadaveric study by Kamath et al compared the strength of the repair of a standard Bankart lesion using 3 single-loaded anchors for repair with 2 double-loaded suture anchors. Results indicated that the 2 double-loaded suture anchor constructs had significantly higher tensile load than 3 single-loaded anchors. The use of double-loaded sutures may allow for fewer implants to be used and fewer holes to be drilled into the bone during repair. Kamath et al primarily evaluated a repair technique rather than the biomechanics of the anchors. To the authors’ knowledge, there are no studies evaluating the basic pullout strength of 1 or 2 suture strands used in a suture anchor construct. The results of our study showed that the biomechanical strength of the 4.75- and 5.5-mm anchors was greater when 2 strands of suture, compared with anchors with only 1 strand of suture, were used, regardless of insertion angle or anchor size (4.75 mm or 5.5 mm) under axial load.

The exact mechanism for increased strength of the 2-stranded constructs has not been determined. The use of additional strands of suture does not appear to decrease purchase of the anchor in the bone, rather the increased volume within the bone tunnel appears to increase the overall strength. The use of double-stranded suture anchors has the potential to increase surgical efficiency and decrease the number of implants that have to be used during reconstruction. In people, the use of a double-loaded suture anchor has been utilized as a technique for the repair of labrum and capsule after hip arthroscopy. The presumed advantage of a double-loaded suture is that the repair can simulate in vivo natural structures more closely allowing more anatomic repair using only 1 anchor, thus improving surgical efficiency. Based on the results of our study, the double-loaded suture anchors appear to be biomechanically superior, similar to findings in human shoulder reconstruction.

Although 2-stranded anchor constructs were stronger than 1-stranded for both 4.75- and 5.5-mm constructs, the 5.5-mm anchors had a greater maximum load for both axial and cyclic pullout. This is consistent with the findings of Barber et al., who determined that larger (5.0 and 6.5 mm) anchors are biomechanically stronger and are more likely to fail by eyelet or suture breakage, compared with smaller (2.9- and 3.0-mm) anchors that failed by pullout. In our study, all anchors (both 4.75 and 5.5 mm) failed by anchor pullout, regardless of suture configuration. However, the 5.5-mm anchors demonstrated damage to the synthetic bone surface as a result of pullout, indicating an added mode of failure of bone-anchor interface failure. In our study, the larger anchor may have had overall increased biomechanical strength due to the increased outer diameter of the anchor, but also the use of 2 strands may have increased the overall biomechanical strength of the constructs. The addition of the second suture increased the volume and thus the pressure within the bone tunnel. This may have generated interference that could have been a contributing factor to the increased biomechanical strength. What is unknown is the effect that use of different types of suture material, or size of suture material would have on these constructs, and this should be considered in future biomechanical evaluations.

In this study, we also evaluated the biomechanical strength of suture anchors at different angles of pull (45° vs 90°). There is controversy in the literature regarding the ideal angle of insertion for suture anchors in terms of strength. Burkhart originally proposed the “deadman’s angle” as the optimal angle of anchor insertion. The decreased insertion angle (compared with 90°) is thought to have increased pullout strength. In our study, the 45° angle of insertion had a significantly greater axial pullout strength. The maximum load to failure was also higher in the samples that underwent cyclic loading, although with only 2 samples per group, the significance of this data could not be determined. Still, there are multiple studies that demonstrate no biomechanical advantage when comparing 45° versus 90° insertion angle. It is possible that the discrepancy in the literature may indicate that factors other than angle are determinants of construct strength. For instance, the addition of an additional suture strand may contribute more to overall strength than the angle of insertion.

Limitations of this study included low samples size for all groups, particularly the groups that underwent cyclic loading. The major limitation of

Table 3—Mean ± SD maximum load to failure for 4 configurations (1 suture strand vs 2 strands and 45° vs 90° insertion angle) for 4.75- and 5.5-mm suture anchor constructs (8 groups with 2 samples each) that underwent cyclic load to failure testing.

| Configuration                  | Mean ± SD maximum load to failure (N) |
|-------------------------------|---------------------------------------|
| 4.75-mm Anchor constructs     |                                       |
| 45° Angle X single strand     | 236 ± 6                               |
| 45° Angle X double strand     | 281 ± 19                              |
| 90° Angle X single strand     | 214 ± 22                              |
| 90° Angle X double strand     | 260 ± 30                              |
| 5.5-mm Anchor constructs      |                                       |
| 45° Angle X single strand     | 300 ± 16                              |
| 45° Angle X double strand     | 347 ± 30                              |
| 90° Angle X single strand     | 244 ± 9                               |
| 90° Angle X double strand     | 301 ± 16                              |

Discussion

To the authors’ knowledge, surgeon preference has been the primary determinant in the decision to use 1 or 2 suture strands when placing suture anchors. As discussed previously, the angle that will yield the greatest biomechanical strength is also controversial. The goal of this study was to provide early biomechanical data related to the suture anchor size and the number of sutures used. However, the clinical relevance of this data is unclear without additional in vivo studies. Although in vivo studies have been performed to evaluate the use of double-stranded suture anchors in people, the data are limited. A cadaveric study by Kamath et al compared the strength of the repair of a standard Bankart lesion using 3 single-loaded anchors for repair with 2 double-loaded suture anchors. Results indicated that the 2 double-loaded suture anchor constructs had significantly higher tensile load than 3 single-loaded anchors. The use of double-loaded sutures may allow for fewer implants to be used and fewer holes to be drilled into the bone during repair. Kamath et al primarily evaluated a repair technique rather than the biomechanics of the anchors. To the authors’ knowledge, there are no studies evaluating the basic pullout strength of 1 or 2 suture strands used in a suture anchor construct. The results of our study showed that the biomechanical strength of the 4.75- and 5.5-mm anchors was greater when 2 strands of suture, compared with anchors with only 1 strand of suture, were used, regardless of insertion angle or anchor size (4.75 mm or 5.5 mm) under axial load.

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Limitations of this study included low samples size for all groups, particularly the groups that underwent cyclic loading. The major limitation of
this study was the use of synthetic bone rather than cadaveric bone. The goal of this study was primarily to evaluate the biomechanical strength of both 4.75- and 5.5-mm anchor systems and the effect of anchoring with 1 or 2 strands of suture on the strength of the construct. Synthetic bone was utilized rather than cadaveric bone in order to provide a consistent medium by which we evaluated the biomechanical properties of the anchors. However, synthetic bone does not possess the same biomechanical properties of actual bone; thus, evaluation of the pullout strength in cadaveric models is necessary to apply this information to clinical decisions. Another limitation of this study was the use of a maillet to tap the anchors into the pilot holes. This was done by feel, and not with a set amount of torque, so small variations may have occurred. This was done to mimic a clinical setting; additionally, a single investigator inserted all the anchors, in an attempt to limit variability.

In conclusion, this study revealed that PEEK knotless suture anchor systems have increased biomechanical strength when 2 strands of suture are used, compared with 1 strand in this synthetic bone model. Based on this, we accepted our hypothesis that the biomechanical strength of 4.75- and 5.5-mm anchors is increased with the use of 2 strands of suture. Although we did find a greater strength of constructs inserted at 45°, compared with 90°, the effect of the suture number appeared to be a stronger determinant of pullout strength. We also found the 5.5-mm anchor system to be stronger, compared with the 4.75-mm anchor system. Although further in vivo studies may provide more information regarding clinical significance, these data suggested that the use of double-loaded anchors may provide a stronger construct.

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The authors declare that there were no conflicts of interest.

Drs. Salyer, Suber, and Kieves contributed to the conception of this study, study design, data acquisition, data analysis, and interpretation. Dr. Melara contributed to data analysis and interpretation and statistical analysis. All authors contributed to the writing and revision of the manuscript.

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