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Effect of anchor threads on the pullout strength: A biomechanical study

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ABSTRACT

Pullout tests to determine the effect of anchor threads on the pullout strength was conducted by using universal testing machine, synthetic cancellous bone and thread-less metallic anchor. Anchors were inserted at 45°, 90° or 135° from the surface and they were pulled at 45° from the surface. The maximum load to failure was compared among the 3 insertion angles. Pullout strength of the anchors inserted at 45° was significantly greater than those inserted at 90° or 135°. Pullout strength of the thread-less anchor was the greatest when it was inserted at 45° to the bone surface.

Level of evidence: level II.

1. Introduction

Fixing soft tissues using suture anchors are quite common in orthopaedic surgeries.[1–5] Many different kinds of suture anchors are widely distributed, and their fixation strength is said to rely on its design, bone density, insertion depth, and insertion angle.[6–10] Burkhart introduced the deadman theory in 1995, saying that "minimizing the angle insertion of the suture anchor, as well as the angle that the suture makes with the rotator cuff can increase the pullout strength of the anchor and reduce the tension in the suture".[11] This description is difficult to understand. Simply put, it could be interpreted that inserting the anchor perpendicular to the line of pull makes the pullout strength the greatest. This is intuitively understandable because this is exactly what we do when we set up a tent, inserting tent pegs perpendicular to the tent ropes. When we perform rotator cuff repair, the line of pull by the suture passed through the rotator cuff tendon is approximately 45° to the bone surface.[11] Thus, inserting the anchor perpendicular to the line of pull is equivalent to inserting the anchor at 45° to the bone surface. After the introduction of this theory, many researchers and surgeons use 45° as a standard angle of anchor insertion.[6,8–10,12,13] However, biomechanical studies using cadavers and synthetic bones revealed that the pullout strength of the anchor inserted at 90° to the bone surface was greater than that of the anchor inserted at 45°.[14–16] The greatest difference between the commonly-accepted intuitional understanding of tent peg insertion and the outcome of these biomechanical studies is the friction between the bone (ground) and the anchor (peg). Thus, if an anchor has a very small amount of friction, it seems likely to show performance similar to a tent peg in the ground. A previous biomechanical study has demonstrated that the pullout strength of the threaded anchors was greatest when it was inserted at 90° to the surface, suggesting that the deadman theory may not be applicable in clinical conditions.[16] Therefore, to further prove the effect of threads around the anchor on the pullout strength and to substantiate the results of studies using threaded anchors, the current biomechanical study using thread-less anchor was conducted. Our hypotheses were 1) a thread-less anchor inserted at 45° to the bone surface would show higher pullout strength than that inserted at 90° or 135° to the bone surface and 2) the lower the friction, the greater the advantage of 45°-insertion. The purpose of this study was to prove these hypotheses.

2. Methods

Synthetic bones (Sawbones, Pacific Research Laboratories, Vashon, WA) of 0.24 g/cm^3 (solid rigid polyurethane foam) were chosen based on the past reports of its use as a biomechanical testing model with the bone mineral density of the greater tuberosity of normal human humerus.[16,17] The bone was cut into the size of 60 mm in width, 40 mm in depth and 40 mm in height. Thread-less metallic anchor, 2.9 mm in width and 14 mm in length, was created for this biomechanical testing: threads of the metallic anchor (TwinFix™ 5.0 Ti, Smith & Nephew, Andover, MA) was grounded off (Fig. 1). Sutures (#2 Ultrabraid™, Smith & Nephew, Andover, MA) loaded originally to the anchors were replaced to braided polyethylene lines and they were tied to custom-made pulling jig. The sutures were replaced to prevent from the suture cut out and to resemble the threaded-anchor testing condition.[16] After creating a fisherman's knot with quadruple loop, for preventing the

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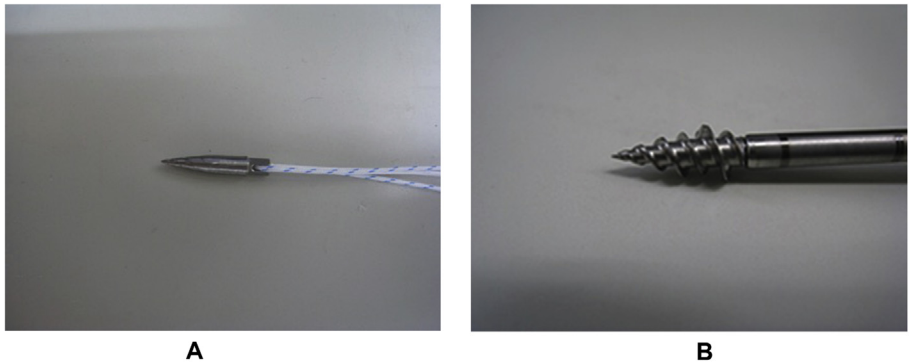

Fig. 1. (**A**). A custom-made thread-less anchor. (**B**). A standard threaded anchor.

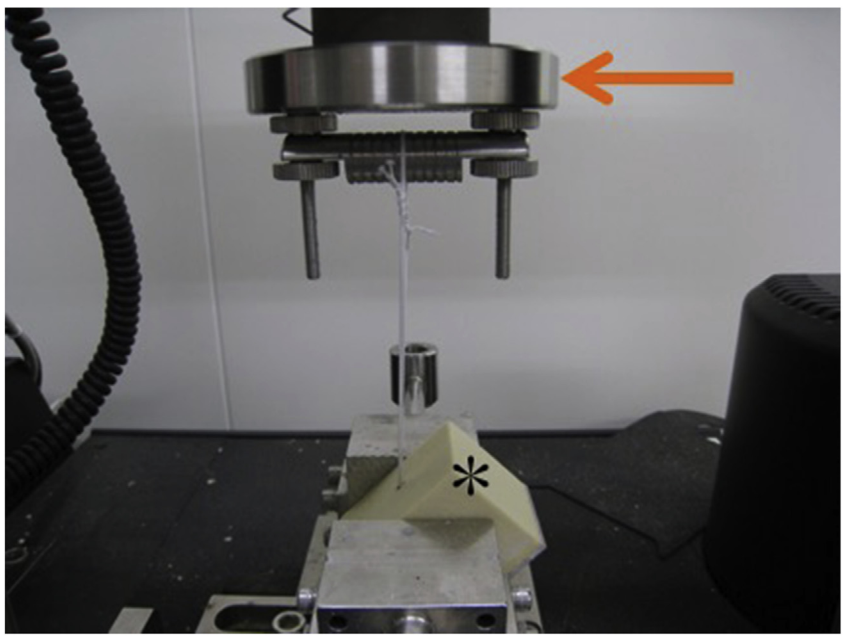

Fig. 2. Experimental setup. * indicate synthetic cancellous bone, and arrow indicates crosshead.

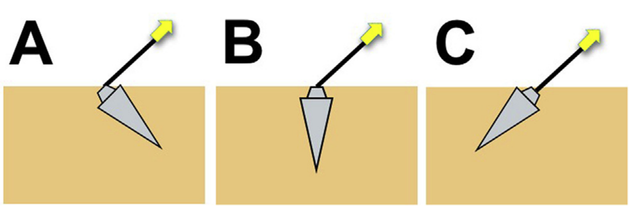

Fig. 3. All the anchors were pulled in the same direction (45° from the bone surface). (A) Thread-less anchor inserted at 45° from the bone surface. (B) Thread-less anchor inserted at 90° from the bone surface. (C) Thread-less anchor inserted at 135° from the bone surface.

knot from loosening and to resist the pulling load, 8 half-hitches were added to each end of the suture, also resembling the previous testing condition.[16] Universal testing machine (Instron® 566, Instron, Norwood, MA) was used to perform the pullout tests (Fig. 2). Synthetic bones were predrilled to create the pilot hole using 2.0- and 2.5-mm diameter drill and they were set up in a custom testing device for holding. The test was done in 2 different diameter holes to analyze the effect of friction between the thread-less anchor and bone, with lesser friction using the larger diameter hole. The anchors were inserted at 45°, 90° or 135° from the surface and they were pulled at 45° from the surface (Fig. 3). The pulling angle was determined using a goniometer. To ensure the full engagement of the anchor to the bone, the anchor was preloaded to 10 N with the extension rate of 1 mm/s followed by suture pull at a crosshead speed of 1 mm/s.[16,18] The maximum load to failure was defined by the load prior to sudden cessation of the testing or gradual load decrease caused by the complete pullout of the anchor. Maximum load was digitally recorded for 10 pullout tests performed for each condition.

3. Statistical analysis

For all the statistical analyses, JMP® Pro 12 software (SAS Institute, Cary, NC) was used. Differences in pullout strength between insertion angles and diameters of the pilot hole were analyzed using ANOVA. For the comparison between the insertion angles, the groups were compared individually by using the post hoc Tukey-Kramer HSD test. Results were considered statistically significant if the p value was less than 0.05. Upon all the testing and statistical analysis, power analysis was performed. Referring from our previous testing results, required sample size was 6 for each condition.

4. Results

Pullout strength of the anchors inserted at 45° (2.0 mm: 56.5 ± 2.6 N (95% CI, 54.7–58.3 N), 2.5 mm: 45.8 ± 3.0 N (95% CI, 43.6–47.9 N)) was significantly greater than those inserted at 90°

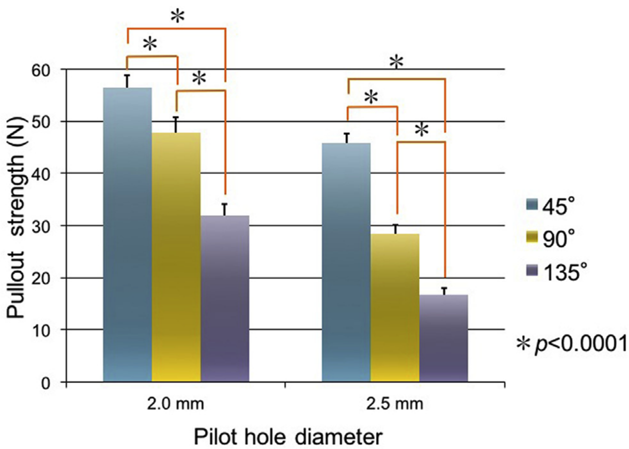

Fig. 4. Comparison of the pullout strength among the 3 suture insertion angles for each pilot hole diameter.

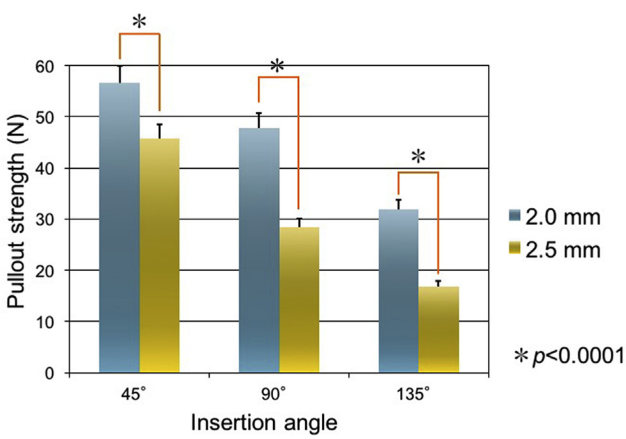

Fig. 5. Comparison of the pullout strength between the suture pilot hole diameters for each suture insertion angle.

(2.0 mm: 47.8 ± 3.5 N (95% CI, 45.3–50.2 N), 2.5 mm: 28.4 ± 3.9 N (95% CI, 25.6–31.2 N)) and 135° (2.0 mm: 31.9 ± 2.8 N (95% CI, 29.9–33.9 N), 2.5 mm: 16.8 ± 2.8 N (95% CI, 14.8–18.7 N)) and that of the anchor inserted at 90° was significantly greater than that of the anchor inserted at 135°, for both pre-drilling diameter ($p < 0.0001$, respectively) (Fig. 4). When the pullout strength was compared between the 2.0-mm and the 2.5-mm pilot holes, those inserted at 2.0-mm pilot hole were significantly greater than those inserted at 2.5-mm pilot hole for all the insertion angles ($p < 0.0001$, respectively) (Fig. 5). The pullout strength of the 45° anchor showed 118% and 177% increase compared to that of the 90° and 135° anchors, respectively. For 2.5-mm pilot hole, those increases were 161% and 272%, respectively. The pullout strength of the 45° anchor relative to the 90° and 135° anchors were significantly greater when the pilot hole was 2.5 mm than 2.0 mm ($p = .001$, $p = 0.0001$, respectively).

5. Discussion

This biomechanical study showed that the anchor inserted at 45° from the bone surface showed greater pullout strength compared to those inserted at 90° or 135° for all the thread-less anchors pulled at 45° from the surface. All the previous biomechanical studies in the literature showed the pullout strength data which did not match the deadman theory.[14–16,18,19] With the use of a thread-less anchor, this study was the first one to demonstrate the data which perfectly matched the deadman theory. As the pullout strength was the greatest when inserted at 45°, and this effect was greater with less friction at bone-anchor interface, the deadman theory is likely to be more applicable in a situation with less friction, such as a thumbtack or a tent peg. As we have hypothesized in the past report, multiple threads around the anchor provides a frictional force around them, whereas a thread-less device retains load by the creation of the angle away from the loading direction.[16] This study has proved this hypothesis by conducting a pullout test of anchors without threads.

In the field of earth structures, it has already been known that the use of transverse member along the longitudinal member reinforces the pullout bearing force.[20–22] They all report that friction is one of the parameters affecting the pullout strength. In our study, the transverse member equals to the threads around the anchor. One interesting study demonstrated the relationship between nail and soil during pullout.[23] The results showed that the peak pullout force increased as the shear strength of the soil increased. This indicated that the friction between the nail and the soil played an important role in pullout strength. They also compared the pullout strength between the rough-surfaced and smooth-surfaced nail. The latter nail showed significantly smaller peak pullout forces. These data strongly support our studies that the pullout strength of the suture anchor relies on the friction between the anchor and the bone.

There are several limitations in this study. First, synthetic bones were used rather than cadaveric humeri. The use of synthetic bones for biomechanical testing has been reported in the literature and to test in a uniform condition was necessary to clarify precise relationship between pullout strength and bone density since bone density affects the anchor pullout strength.[16,19] Also, to resemble the condition used in previous study to that of the current study was necessary to compare the effects of the anchor threads. Second, used anchor was metallic instead of bioabsorbable material. Non-metallic anchors are becoming more popular and are widely used.[1,6] However, thread-less non-metallic anchors are technically demanding to create and could be very vulnerable as there is a possibility of anchor breakage. In addition, this study was not meant to resemble clinical situation, but to demonstrate the effect of the anchor threads on the pullout strength. Creating a thread-less anchor using non-metallic anchor is unrealistic because it is usually made of bio-absorbable materials. In our study, it is crucial to match the conditions used in the previous study to make the comparison between the threaded anchor and thread-less anchor possible. Third, the test was given an ultimate load rather than cyclic load. Cyclic load is known to represent the repetitive loading during activities of daily living.[1,8,10,12,14] However, to compare the results of the study of threaded anchors, the testing condition had to be identical.[16]

6. Conclusion

When pulled at 45°, the pullout strength of the thread-less anchor inserted at 45° to the bone surface was the strongest followed by 90° and the weakest at 135°. This benefit of inserting the anchor at 45° was greater when the friction was less.

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