A Biomechanical Comparison of High-Tensile Strength Tape Versus High-Tensile Strength Suture for Tendon Fixation Under Cyclic Loading

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Purpose: To compare the biomechanical properties of high-tensile strength tape and high-tensile strength suture across 2 selected stitch techniques, the Krackow and whip stitch, in securing tendinous tissue during 5,000 cycles of nondestructive loading followed by a load to failure. **Methods:** Fourteen matched pairs each of cadaveric Achilles, quadriceps, and patellar tendons ($n = 84$) were randomly assigned to either Krackow or whip stitch and sutured with either 2-mm high-tensile strength tape or No. 2 high-tensile strength suture. Specimens were preloaded to 20 N, cyclically loaded from 20 to 200 N for 5,000 cycles at 2 Hz, and then loaded to failure at 200 mm/min. Linear mixed models evaluated the effects of suture material and stitch technique on cyclic normalized tendon−suture elongation, total normalized tendon-suture elongation at 5,000 cycles, and maximum load at failure. **Results:** Across all suture constructs, normalized elongation was greater during the initial 10 cycles, compared with all subsequent cycling intervals (all $P < .001$). There was less total normalized elongation ($\beta = -0.239$; $P = .007$) and greater maximum load at failure in tape ($\beta = 163.71$; $P = .014$) when used in the Krackow stitch compared with the whip stitch. **Conclusions:** Our findings indicate that tape used in the Krackow stitch maintains the most favorable fixation strength after enduring cyclic loading, with greater maximum load at failure. In addition, overall normalized elongation during long-term cyclic loading was predominately affected by the stitch technique used, regardless of the suture material; however, tape allowed less normalized elongation during the initial loading cycles, especially when placed in the whip stitch. **Clinical Relevance:** Understanding the potential short- and long-term outcomes of suture material and stitch technique on securing tendinous tissue under repetitive stresses can help inform clinicians on optimal tendon fixation techniques for early postoperative activities.

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Acute tendon ruptures are common injuries among physically active individuals, with increasing incidence in recent decades due to the growing participation in sports-related activities in the adult population.[1-5] Surgical management often is required to restore functionality, initiate early mobility, and reduce the time between injury and return to activity/duty.[6-8] However, the optimal surgical management of an acute major tendon rupture continues to be a subject of debate. Variation in the anatomy and mechanism of rupture, as well as the numerous available treatment options, creates difficulty in establishing the optimal surgical management method.[9,10] Furthermore, postoperative complications, such as rerupture, usually cannot be associated back to any specific suture fixation method. Therefore, there is a need to identify the most effective suture fixation method for repairing acute tendon rupture.

Several factors affect the biomechanical properties of the suture construct, including the quality of the tissue, the type and shape of the material, and the type of stitch technique used.[11] Currently, there are a variety of suture materials and stitch techniques used to surgically manage acute tendon ruptures, including traditional suture and high-tensile strength tape.[12-16] High-tensile strength tape includes wider suture material that increases contact area with tendinous tissue, which theoretically facilitates greater force distribution and decreases suture pull-through, thereby improving fixation integrity.[17,18] In a single load-to-failure biomechanical study, high-tensile strength tape demonstrated greater maximum load at failure strength in both the Krackow and whip stitch techniques.[18] However, this study was limited to the application of a progressive load to failure at a constant rate of distraction, which is sufficient for evaluating the overall strength of the fixation at the time the fixation is performed, but this approach is not necessarily representative of in vivo repetitive loading characteristics. Thus, cyclic loading or a combination of cyclic loading followed by a single load to failure has been suggested to better represent the onset of changes in the fixation potentially caused by repetitive stresses.[19]

The objective of this study was to compare the biomechanical properties of high-tensile strength tape and high-tensile strength suture across 2 selected stitch techniques, the Krackow and whip stitch, in securing tendinous tissue during 5,000 cycles of nondestructive loading followed by a load to failure. Our hypothesis was 3-fold: (1) tape will have less normalized elongation and greater maximum load at failure compared with suture across all stitch techniques; (2) the Krackow stitch technique will have less normalized elongation and greater maximum load at failure compared with the whip stitch across all suture materials; and (3) a fixation construct using tape in the Krackow stitch will have the best overall performance resulting in the least normalized elongation and greatest maximum load at failure compared with all other constructs.

Methods

Specimens

Tendon specimens were obtained from the lower extremities of 8 fresh-frozen cadavers (5 male, 3 female, age = 78.5 ± 7.7 years old) and stored at −20°C. The calcaneus−Achilles tendon unit was dissected from the ankle plantar flexion mechanism. The quadriceps tendon−patella−patellar tendon unit was dissected from the knee extensor mechanism. The patella was transected transversely to create the superior hemipatella−quadriceps tendon and inferior hemipatella−patellar tendon specimens. Fourteen matched pairs of each bone−tendon specimen type were produced by splitting bone−tendon specimens longitudinally down the midline. The width of each tendon specimen was measured with a digital caliper and marked exactly at the midline to ensure equal size when divided. One cadaver had a patellar tendon with an insufficient length for the testing setup, and as such, the quadriceps and Achilles tendons from this cadaver were combined with the patellar tendon of another cadaver. Altogether, 7 complete sets of patellar, quadriceps, and Achilles tendons, 84 bone−tendon specimens in total were produced from the 8 cadavers. Specimens were thawed overnight before testing. Tendon length was measured before testing using a digital caliper. Testing was conducted at room temperature and specimens were periodically moistened with normal saline solution. All study procedures were reviewed and approved by the Walter Reed National Military Medical Center institutional review board.

Experimental Design

Matched pairs were randomly assigned to 1 of 2 stitch techniques, a uniform Krackow stitch with 4 locking loops placed at a depth of 5 mm and spaced at 5-mm intervals or a uniform whip stitch with 4 nonlocking loops configured at the same depth and spacing (Fig 1).[18] These stitch techniques were selected based on the Gnandt et al.'s[18] results from single load-to-failure testing, which demonstrated tendon fixations using the Krackow and whip stitch resulted in greater maximum load at failure compared with other stitch techniques. Krackow and whip stitch were among the most common techniques used in tendon fixation scenarios reported in the literature.[20-23] One specimen of each matched pair

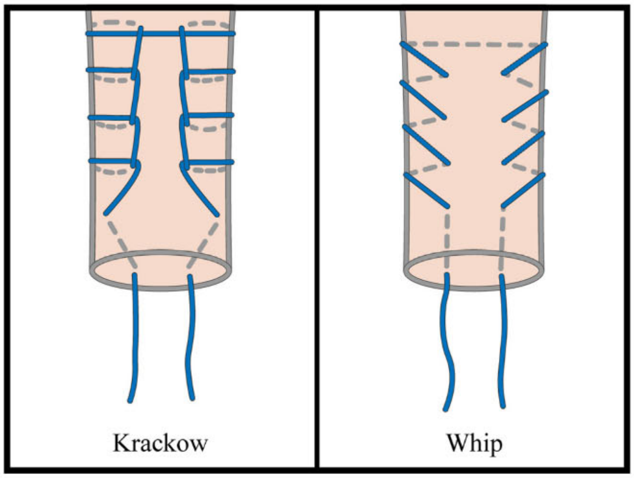

Fig 1. Illustrations of the selected stitch techniques used for suturing the loose end of the bone–tendon specimens (adapted from Gnandt et al.[18]).

was sutured with high-tensile strength 2-mm tape material (FiberTape; Arthrex, Naples, FL), and the other specimen was sutured with high-tensile strength No. 2 suture material (FiberWire; Arthrex). Sutures were placed distal-to-proximal in the Achilles and quadriceps tendons and proximal-to-distal in the patellar tendons. All suture constructs were completed by a single senior orthopaedic surgery resident (W.B.R).

Biomechanical Testing

Specimens were mounted on a servohydraulic material testing system (MTS 858 Mini Bionix II; MTS Systems Corp., Eden Prairie, MN). The bony segment of each specimen served as a mechanical stop in the gripper mounted to the actuator, whereas the sutured tendon end was affixed at a standardized 2-cm distance from K-wire rigidly mounted to the load cell below with 7 uniform squared knot throws (Fig 2). The bone–tendon specimens were preloaded at a constant 20 N in tension for 15 seconds and then cyclically loaded from 20 to 200 N for 5,000 cycles at 2 Hz.[18,24-28] The testing procedure automatically stopped in any specimen that failed to maintain forces between 20 and 200 N. Following cyclic loading and a subsequent 30-second constant 20-N preload, specimens were loaded to failure at a constant longitudinal distraction rate of 200 mm/min. Failure occurred when the load across the specimen failed to maintain 25% of the maximum load detected throughout distraction. Displacement and force were continuously measured (102 Hz) by the MTS actuator and in-line load cell throughout the cyclic loading and load to failure testing.

Data Reduction

Force and displacement data were processed with custom MATLAB scripts (vR2020a; MathWorks Inc., Natick, MA). Normalized tendon–suture elongation was determined as the change in displacement relative to the initial tendon-suture length under constant 20-N preload. Normalized tendon–suture elongation was analyzed at the trough of the final cycle within the following discrete cycling intervals (0-10, 11-250, 251-500, 501-1,000, 1,001-2,000, 2,001-3,000, 3,001-4,000, and 4,001-5,000) with total normalized tendon–suture elongation analyzed at 5,000 cycles. Maximum load at failure and mode of failure were recorded. Modes of failure included (1) tendon avulsion, (2) suture rupture, (3) tendon rupture, and (4) suture pull-through. Specimens that failed before 5,000 cycles along with any corresponding matched pair were excluded from analyses. Normalized tendon–suture elongation and maximum load at failure values less than the 25th percentile value minus 1.5 times the interquartile range [Q1 − 1.5 * IQR] or greater than the 75th percentile value plus 1.5 times the interquartile range [Q3 + 1.5 * IQR] were identified as outliers and excluded from analyses.

Statistical Analysis

An a priori power analysis determined the minimum required sample size based on data from a previous study with a similar experimental design.[18] With the assumption of a standard deviation of 50 N, a sample size of 6 matched pairs per stitch technique was

Fig 2. Patellar tendon specimen sutured with tape, affixed to the servohydraulic material testing system, and preloaded at a constant 20 N in tension.

determined to provide 90% power to detect a 90-N difference in maximum load at failure between the 2 materials (tape vs suture) at an $\alpha = 0.05$.

Three separate linear mixed models evaluated the fixed effects of age, tendon type, material, stitch technique, and the interaction of material and stitch technique on normalized tendon-suture elongation at discrete cycling intervals as repeated measures, total normalized tendon-suture elongation at 5,000 cycles, and maximum load at failure. The random effect of matched pairs was included in all models, and specimen age and tendon type were incorporated into the models to control for their potential confounding effects. Linear mixed models were selected to handle excluded specimens that failed before 5,000 cycles, resulting in unbalanced groups and to control for the matched pair experimental design. A mixed binomial logistic model assessed the probability of specimens failing before 5,000 cycles based on sex, age, tendon type, material, stitch technique, and the interaction of material and stitch technique, with the random effect for matched pairs.

For all models, age, normalized elongation, and maximum load at failure were classified as continuous variables, while sex, tendon type, material, and stitch technique were classified as categorical variables. Age was scaled to have the associated estimated coefficient conveniently interpreted as the change in the dependent variable per standard deviation increase of age. The estimated coefficients (β) from each association in the models were reported. Post-hoc pairwise comparisons of the main fixed effects, material at each level of stitch technique and vice versa, were conducted. Significance level was set a priori at $\alpha = 0.05$.

A χ^2 test was used to examine the relationships between suture constructs (i.e., suture material and stitch technique) and modes of failure. Since expected frequency in one of the contingency table cells was less than 5, a Fisher exact test was performed. Post-hoc analyses using the adjusted standard residual method were performed following a significant Fisher exact test.[29] All statistical analyses were performed using R (v4.0.2, Vienna, Austria) in RStudio (v1.3, RStudio, Inc., Boston, MA) using the rstatix and lme4 packages.[30]

Results

Cyclic Normalized Tendon-Suture Elongation during 5,000 Cycles

Thirty specimens were excluded because they failed before 5,000 cycles (n = 22) or were paired with a specimen that failed before 5,000 cycles (n = 8). No outliers were identified based on normalized tendon-suture elongation. Normalized elongation was greater during the initial 10 cycles of loading compared with all subsequent cycling intervals across all suture constructs (all $P < .001$). When accounting for the 3-way interaction between cycles, material, and stitch technique, normalized elongation during the initial 10 cycles was similar to normalized elongation during cycles 11-250 ($P = .080$) but was greater than normalized elongation during all subsequent cycling intervals after 250 cycles (all $P < .05$; Fig 3). During the initial 10 cycles, normalized elongation was greater in suture compared with tape when used in the whip stitch (0.74 ± 0.02 vs 0.57 ± 0.02; $P < .001$; Fig 3). There was less normalized elongation in the Krackow stitch during the initial 10 cycles compared with whip stitch when used with suture (0.42 ± 0.02 vs 0.74 ± 0.02; $P < .001$) and when used with tape (0.37 ± 0.02 vs 0.57 ± 0.02; $P < .001$; Fig 3).

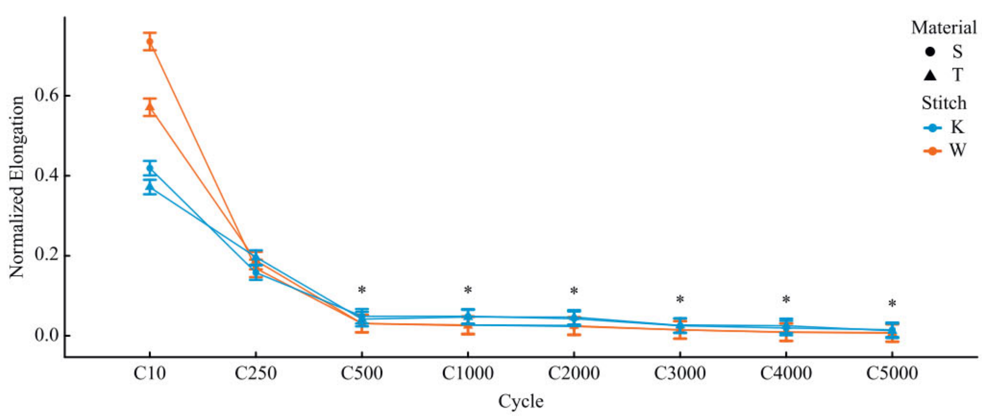

Fig 3. The effect of material and stitch technique on normalized tendon−suture elongation in tendon fixation during the following cycling intervals: cycles 0-10 (C10), 11-250 (C250), 251-500 (C500), 501-1,000 (C1000), 1,001-2,000 (C2000), 2,001-3,000 (C3000), 3,001-4,000 (C4000), and 4,001-5,000 (C5000). Estimated marginal means and standard errors were calculated from the linear mixed-effects model for normalized tendon−suture elongation at the specified discrete cycles. *$P < .05$ compared with C10 across all suture constructs. (K, Krackow stitch; S, suture; T, tape; W, whip stitch.)

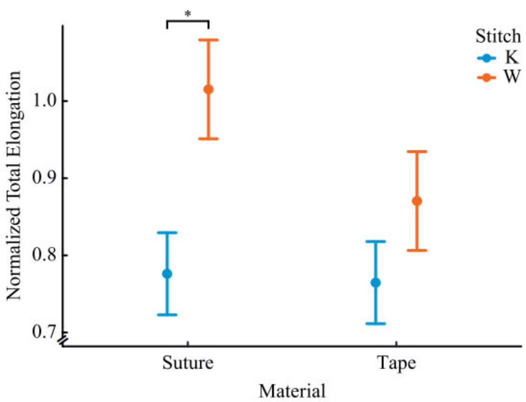

Fig 4. The effect of material and stitch technique on total normalized tendon–suture elongation in tendon fixation at 5,000 cycles of loading. Estimated marginal means and SEs were calculated from the linear mixed model for total normalized tendon-suture elongation. *$P < .05$; K = Krackow stitch (n = 16 matched pairs); W = whip stitch (n = 11 matched pairs).

Total Normalized Tendon–Suture Elongation at 5,000 Cycles

Age did not affect total normalized elongation ($P = .089$). Suture constructs in the patellar tendon experienced greater total normalized elongation at 5,000 cycles compared with quadriceps or Achilles tendons ($\beta = 0.56$; $P < .001$). There was no difference in total normalized elongation when using suture compared with tape ($P = .116$). The Krackow stitch allowed less total normalized elongation at 5,000 cycles compared with using the whip stitch ($\beta = -0.24$; $P = .007$). The estimated marginal means revealed a difference in total normalized elongation between the Krackow and whip stitch when used with suture (0.78 ± 0.05 vs 1.02 ± 0.06; $P = .006$; Fig 4). However, the estimated marginal means revealed no difference in total normalized elongation between the Krackow and whip stitch when used with tape (0.77 ± 0.36 vs 0.88 ± 0.26; $P = .211$). The interaction of material and stitch technique did not influence total elongation ($P = .260$).

Maximum Load at Failure

One outlier and its matched pair were excluded based on maximum load at failure. There was no effect of age on maximum load at failure ($P = .412$). In addition, tendon type did not affect maximum load at failure as there were no differences in maximum load at failure for suture constructs used in the Achilles tendon compared with the patellar or quadriceps tendons ($P = .715$ and $P = .296$, respectively). There was no difference in maximum load at failure when suture constructs used suture compared with tape ($P = .069$). The Krackow stitch demonstrated greater maximum load at failure of suture constructs compared with the whip stitch ($\beta = -100.70$; $P = .029$). Despite the model results for the separate main effects of material and stitch technique, maximum load at failure was greater when tape was used in the Krackow stitch ($\beta = 163.71$; $P = .014$). Hence, the main effects of material and stitch technique were uninterpretable by themselves and their effects should only be interpreted in the context of their interaction. Comparison of estimated marginal means showed greater maximum load at failure when using tape compared with suture in the Krackow stitch (640.21 ± 27.67 N vs 384.89 ± 27.67 N; $P < .001$; Fig 5). However, maximum load at failure was found to be greater in the whip stitch than in the Krackow stitch only when the material used was the suture (485.59 ± 34.84 N vs 384.89 ± 27.67 N; $P = .029$; Fig 5).

Mode of Failure

Suture rupture was the most common mode of failure in suture for both the Krackow and whip stitch (61.9% and 47.6%, respectively; Fig 6). Tendon avulsion was the most common mode of failure in tape overall (40.5%). When tape was used in the Krackow stitch, tendon avulsion remained the most common mode of failure (47.6%); however, when tape was used in the whip stitch, suture pull-through became the most common mode of failure (61.9%; Fig 6). The Krackow stitch predominately failed by suture rupture (52.4%), especially with the use of suture (61.9%; Fig 6), while the whip stitch commonly failed by suture pull-through failures (47.6%), which was more evident when tape was used (61.9%; $P < .001$; Fig 6).

Cyclic Failure

The most common mode of failure for specimens failing before 5,000 cycles was tendon avulsion (n = 12). Otherwise, 9 specimens failed via suture pull-

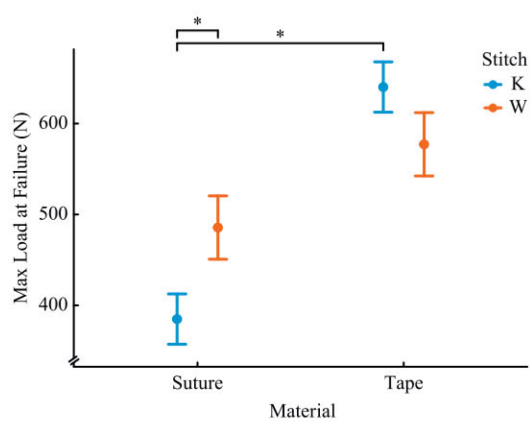

Fig 5. The effect of material and stitch technique on maximum load at failure after cyclic loading in tendon fixation. Estimated marginal means and standard errors were calculated from the linear mixed model for maximum load at failure. *$P < .05$; K = Krackow stitch (n = 16 matched pairs); W = whip stitch (n = 10 matched pairs).

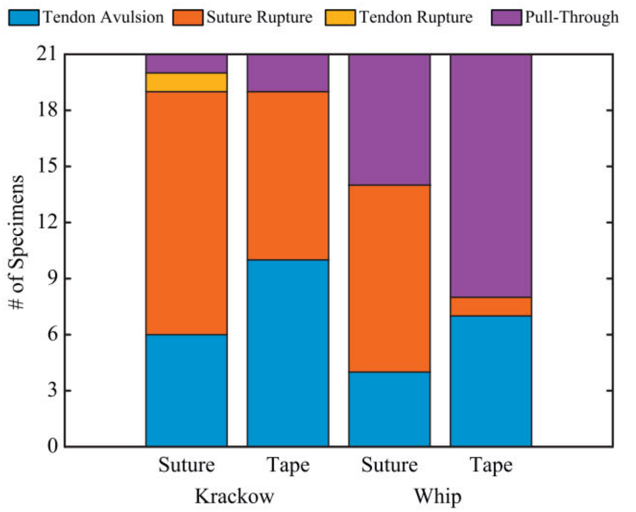

Fig 6. Modes of failure for each suture construct, including specimens that failed before 5,000 cycles.

through, and one specimen failed via tendon rupture before 5,000 cycles of loading. Sex ($P = .249$) and age ($P = .063$) did not contribute to specimen failure before 5,000 cycles. Patellar ($P = .371$) and quadriceps ($P = .078$) tendons did not influence the likelihood of specimen failure before 5,000 cycles, as compared with Achilles tendon ($P = .371$ and $P = .078$, respectively). Likewise, material ($P = .527$), stitch technique ($P = .601$), and their interaction ($P = .936$) did not affect the likelihood of specimen failure before 5,000 cycles.

Discussion

In partial support of our first hypothesis, normalized elongation was less in tape compared with suture when used in the whip stitch during the initial 10 cycles of loading, while total normalized elongation at 5,000 cycles and maximum load at failure were comparable between tape and suture across stitch techniques. In support of our second hypothesis, the Krackow stitch allowed less normalized elongation compared with the whip stitch during the initial 10 cycles. Total normalized elongation at 5,000 cycles was also less in the Krackow stitch compared with the whip stitch but only when used with suture. Furthermore, the Krackow stitch demonstrated greater maximum load at failure compared with the whip stitch. Overall, our study found that tape used in the Krackow stitch demonstrated the most favorable performance in tendon fixation, with less normalized elongation after initial and prolonged cyclic loading, and greater maximum load at failure, supporting our third hypothesis. Our study expands upon previous work[18] by evaluating the combination of longitudinal changes and overall strength of the 2 materials in the most clinically relevant stitch techniques for tendon fixations. Our findings help elucidate the biomechanical properties of suture compared with tape when used in different stitch techniques and subjected to extended repetitive stresses. This information can help guide clinical practice when surgeons are determining the most appropriate treatment approach, which is essential for improving outcomes, decreasing risk of re-rupture, and enabling early postoperative movement and better quality of life long-term.

The initial 10 cycles of loading simulate movement during the early postoperative period. Normalized elongation was greatest during the initial 10 cycles of loading as compared with the subsequent elongation during all other cycling intervals for all suture constructs. This indicates that a pretensioning of the material, stitch, and tendon is critical, intraoperatively. This early peak in elongation has been reported in other studies investigating the biomechanical properties of tendon fixation techniques and tendon graft.[24,31-33] Markolf et al.[24] described how the largest amount of elongation in the patellar tendon graft, used for posterior cruciate ligament reconstruction, occurred during the initial cycle. There was then a significant reduction (up to 46%) in elongation between cycle 1 and cycle 6 in both tunnel and inlay graft constructs tested.[24] Similarly, Black et al.[31] observed this phenomenon in their study evaluating a novel augmentation technique for patellar tendon fixation. They found that the majority of the gap formation, a biomechanical metric similar to elongation, occurred during the initial 50 cycles of loading.[31] Likewise, Becker et al.[32] identified the largest elongation in both quadruple hamstring tendon and patellar tendon in femoral fixation for anterior cruciate ligament reconstruction during the initial 100 cycles of loading. Although cyclic loading parameters vary across studies, this trend in the large accumulation of elongation during the initial cycles of loading appears to be consistent with fixations in tendinous tissue. Much of the observed elongation or gap formation could result from the intrinsic creep behavior of tendinous tissue as a viscoelastic material and suture cut-through caused by initial loading.[34] Altogether, our current study reiterates how pretensioning the tendon−suture construct in situ before fixation may minimize laxity in early postoperative movement and reduce the likelihood of clinical failure.[32,33]

When comparing normalized elongations of the suture constructs during the initial 10 cycles, tape resulted in less normalized elongation compared with suture when used in the whip stitch. In addition, the Krackow stitch minimized normalized elongation during the initial 10 cycles of loading compared with the whip stitch when used with tape and suture materials. Given these findings and considering how early functional protocols have become the recommended approach for rehabilitation,[35] using tape in the Krackow stitch may be the favorable method for facilitating proper healing and beneficial outcomes.

Total normalized elongation in tendon fixations was primarily influenced by the stitch technique used. At 5,000 cycles of loading, total normalized elongation did not differ between using tape and suture in the Krackow or whip stitch. However, the Krackow stitch allowed less normalized elongation compared with whip stitch when used in high-tensile strength suture. Our results suggest that the material choice does not longitudinally affect normalized elongation following fixation; however, the stitch technique in which the material is placed in may result in differences in outcomes. Such that the Krackow stitch may have an advantage over whip stitch independent of the material used, even though total normalized elongation was comparable between stitch techniques when used with tape. Thus, the Krackow stitch is recommended to minimize overall elongation in tendon fixation as a result of long-term repetitive stresses.

Tape in the Krackow stitch technique demonstrated greater maximum load at failure after enduring cyclic loading. This result was similar to the Gnandt et al.[18] study that compared tape and suture across 4 selected stitch techniques, Krackow, whip, Mason−Allen, and simple, and found that tape had greater maximum load at failure than suture when used in both the Krackow (427.58 ± 125.29 N) and whip stitch (709.34 ± 91.10 N). In contrast, our study found that there was no difference in maximum load at failure between tape and suture when used in the whip stitch after being subjected to cyclic loading. Theoretically, the Krackow stitch should require greater loads before pull-through occurs compared with the whip stitch, independent of the material used, due to the interlocking configuration.[36-38] However, our results showed that maximum load at failure was greater in the whip stitch compared with the Krackow stitch only when the material used was suture rather than tape. We hypothesize this contradiction, as well as the lack of difference in maximum load at failure between tape and suture in the whip stitch, may be due to how the whip stitch orients the thin edges of the tape more parallel to the axis of tension, enabling the material to pull-through the tendinous tissue. This notion was supported by the higher proportion of suture pull-through failure in tape used in the whip stitch (61.9%; Fig 5). Regarding the overall differences in maximum loads at failure between our study and the Gnandt et al.[18] study, it is reasonable to hypothesize that differences in experimental designs and testing protocols may have cause differences in the results. Gnandt et al.[18] assigned each stitch technique exclusively to a different tendon type (e.g., whip stitch was only implemented in matched pairs of quadriceps tendon specimens for tape vs suture comparison) and their specimens did not experience nondestructive cyclic loading before load to failure testing. In contrast, we implemented each stitch technique in an even distribution of tendon types and our specimens endured 5,000 cycles of nondestructive cyclic loading before load to failure testing.

Fixation devices and tendon augmentations techniques were not used, which may clinically affect tendon fixation strength, to focus on the tendon−suture interface and minimize any potential confounding variables. In contrast to previous studies, we evaluated fixation across 3 different tendon types, Achilles, patellar, and quadriceps, allowing us to examine suture constructs in the context of a boarder application.[24,25,28,31,33,39] We mitigated bias in tendon elongation that could arise from differences in material properties and lengths (Achilles: 89.58 ± 16.72 mm, quadriceps: 80.30 ± 14.80 mm, and patella: 39.58 ± 3.86 mm) by normalizing the displacement measurement, translated to tendon-suture elongation, to tendon length. Moreover, such normalization provides a generalizable scale of elongation since displacement in tendon fixation can differ clinically based on method of measurement, tendon type, and patient-specific characteristics. Although the significance level was not met, fixations in the quadriceps tendon appeared to less likely fail before 5,000 cycles compared with Achilles and patellar tendons ($\beta = 2.85$; $P = .078$). This result further emphasizes why there were differences in maximum loads at failure between our study and the study of Gnandt et al.,[18] where the whip stitch was exclusively used in quadriceps tendons and the Krackow stitch was exclusively used in Achilles tendons. Moreover, this finding may be valuable in leveraging quadriceps tendon, as the surgical graft choice for reconstruction surgery, such as anterior cruciate ligament reconstruction, and therefore, warrants further investigation.[40]

Limitations

This study is not without limitations. As with any biomechanical study, it can be difficult to translate the properties of cadaveric tissue and controlled biomechanical testing to the complexities inherent to in vivo conditions. In addition, the specimens used in our study were derived from the lower extremity of an older population, and thus, findings from our study may not represent outcomes in other anatomical areas, such as fixations in rotator cuff tears or pectoralis tendon rupture, as well as outcomes in different age groups. Sutures placed in the quadriceps tendon were also not in an anatomic region, where the tendon typically ruptures (i.e., from its insertion into the patella). Sutures were placed from distal to proximal rather than proximal to distal—opposite of the clinical scenario.

Conclusions

Our findings indicate that tape used in the Krackow stitch maintains the most favorable fixation strength after enduring cyclic loading, with greater maximum load at failure. In addition, overall normalized elongation during long-term cyclic loading was predominately affected by the stitch technique used, regardless of the suture material; however, tape allowed less normalized elongation during the initial loading cycles, especially when placed in the whip stitch.

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