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Research Article

Biomechanical effect of increased number of suture strands on rotator cuff repair in a bovine model

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ABSTRACT

Objective: This study aimed to investigate if there was a link between the biomechanical properties and the number of suture strands in repairing a rotator cuff (RC) tear in a bovine model using the transosseous technique.

Methods: Fifty-four fresh tendons from bovine (mean age: 7.1 ± 0.5 months; range 6.5-7.5 months) and 1 humeral head from porcine (8.5 months) were used in this study. All the specimens had no apparent abnormalities. Using the transosseous structure, the RC tendon was detached from the greater tuberosity and randomly assigned to 3-strand, 4-strand, 5-strand, and 6-strand groups, with the glenohumeral abducted at 0° and 90°. Biomechanical tests were conducted to compare the groups' differences in the failure mode, pull-to-extension load in the 1-, 2-, and 3-mm formations, and the maximum load. The analysis of variance test was performed to compare the results. Statistical significance was set at $P < .05$.

Results: No significant difference was observed among the groups concerning the tendon characteristics (all $P \geq .05$). At 90° shoulder abduction, a significant difference was detected in the load between 3- and 5-strand groups for 1-mm gap formation ($P = .049$). No statistical differences were noted in the load at the gap displacements in the 1-, 2-, and 3-mm formations at 0° and 90° shoulder abduction (all $P > .05$). The maximum failure load and extension in maximal tension increased with the number of sutures.

Conclusion: The maximum load and ultimate extension increase with the number of sutures at both positions. The number of sutures was not an influencing factor of gap formation. Regarding the tear size and tension of the RC, choosing the appropriate number of strands individually instead of excessively increasing the number of sutures is advocated for RC repair.

Introduction

Rotator cuff (RC) tears are a common cause of shoulder pain and lead to the loss of function. Surgeries aim to repair RC tendons by reattaching the torn leads to the footprint area.[1] The primary goal of RC repair is to achieve secure fixation of the tendon to the bone until substantial healing occurs. The healing rate is reported to be only 43% for patients older than 65 years after single-row repair.[2] Up to 20% to 82% of failure occurs within the early postoperative period (<3 months).[3] Furthermore, the increase in primary stability after repair could reduce the retear rate of double-row reconstruction compared to that of single-row reconstruction. Thus, primary stability and strong fixation is crucial for RC healing.

Considering the increased surgical time and expense of double-row repair,[4] transosseous repair was proposed to minimize these disadvantages. Several studies have shown that repair using more sutures could provide better strength and reduce failure rates.[5-7] However, Strick et al[8] found that multiple strands may cause ischemia during the intrinsic healing process by decreasing the total cross-sectional area of the injured site in flexion tendon repair. Further, Su et al[9] proved that the nonabsorbable suture caused more inflammation, a condition which influenced the healing in a rabbit model. Nevertheless, knowledge about the number of sutures to achieve sufficient fixation for the transosseous technique after RC repair is still limited.

To understand the balance between the stable fixation and appropriate number of suture strands, this study compared the biomechanical properties of the transosseous technique using the 3-, 4-, 5-, and 6-strand suture rows at arm abduction angles of 0° and 90°. We hypothesize that the maximum failure load would increase by using more sutures until a plateau is reached.

Materials and methods

Experimental design and specimen preparation

This biomechanical study was approved by the Institutional Animal Care and Use Committee of Nantong University (No. S20210302-809). Fifty-four fresh tendons from bovine (mean age: 7.1 ± 0.5 months; range 6.5-7.5 months) and 1 humeral head from porcine (8.5 months) were obtained from a local abattoir. The specimens had no apparent abnormalities. The RC tendon was detached from the greater tuberosity. To ensure the uniformity of the

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experimental samples, we trimmed the samples into a regular and uniform shape. Given the larger size of the bovine humerus, we used a porcine humerus, which is similar in size to the human humerus, as a substitute.[10,11]

We used 1 humerus for both positions (0° and 90°) to standardize the variables because the conditions of samples vary with respect to nutritional status and activity levels. A digital vernier caliper (Mitutoyo, Tokyo, Japan) was employed to standardize the specimen sizes prior to testing the following features: tendon thickness at insertion, tendon width at insertion, tendon length, and the cross-section area of tendon. Specimens were stored at −20°C following dissection and were thawed 6 hours prior to testing at room temperature. During testing, specimens were kept moist by irrigation with 0.9% saline solution.

Surgical repair

The humerus was cut transversely at the shaft 10 cm distal to the surgical neck. The humerus was secured by a clamp fixed to the base of an Instron 3365 system controlled by the Instron Bluehill software.

The base which secures the humerus had 2 locked positions of abduction: 0° (humerus vertical and at right angles to the direction of pull of the supraspinatus), 90°, and 180° (Figure 1). Specimens were randomly assigned to 4 groups for RC repair, including the 3-, 4-, 5-, and 6-row groups. The position was set with the glenohumeral joint at 0° and 90° abduction.

Sutures were passed through the tendon 10 mm medial to the torn edge of the tendon in a simple fashion.[12,13] The suture insertion points on both sides are 5 mm from the edge of the tendon,[14,15] a position which is used as the boundary, and the remaining sutures are evenly distributed consisting of 1 medial-lateral osseous tunnels through the greater tuberosity (Figure 2). Then, standard arthroscopic sliding knots were followed by 3 half-hitches to lock the knot. The suture was tensioned until the tendon was reduced to cover the bony footprint.

Mechanical testing

The tendons were secured with tendon-grasping clamps tightened with 4 screws that were parallel to the transverse plane of the tendon. The repairs were tested with the direction of pull at 90° to simulate the position of the supraspinatus tendon when the patients' arms perform adduction. The repairs were tested at arm 0° abduction to simulate the position of the supraspinatus tendon when the patients lift their upper limbs horizontally. These angles in the range seemed within the limits of anticipated motion during early postoperative rehabilitation. Then, the repaired RCs were biomechanically tested.

The specimens were preloaded with 10 N for 30 seconds.[7] The repaired tendon was then pulled at 1 mm/s to 1, 2, and 3 mm with the data captured on a computer. The specimens were subsequently loaded at a rate of 1 mm/s until construct failure occurred.[16] The ultimate load, absorbed energy, and displacement at ultimate load were measured and calculated. Modes of failure were recorded for each specimen.

HIGHLIGHTS

- This work can provide valuable information for choosing the number of sutures during rotator cuff (RC) repair.
- This study can provide some information regarding the adequacy of a transosseous for repairing a torn RC.

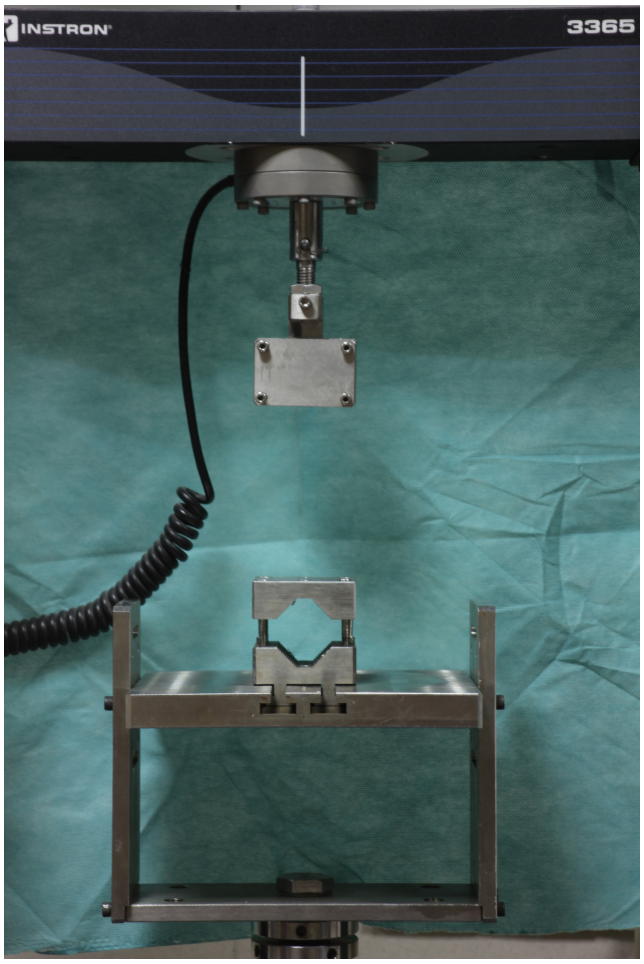

Figure 1. Instron 3365 controlled by Bluehill software.

This study tested the hypothesis that humeral head positions potentially encountered during rehabilitation after cuff repair can dramatically increase the relative tension in certain positions of the RC repair sutures.

Data analysis

Data analysis was performed using Prism 8 (GraphPad, San Diego, California, USA). The continuous data are presented as mean ± SD. The distribution of the data in each group was evaluated by the Shapiro–Wilk test. The Kruskal–Wallis test was applied to compare the continuous data among the groups. The analysis of variance and normality tests were performed to compare the specimen geometry parameters for the testing groups, namely (1) tendon thickness and width at the site of the suture passing through and (2) tendon length and the cross-section area of tendon. Statistical significance was set at $P < .05$.

Results

Specimen characteristics

As previous studies have described, the thickness, width, and cross-section area of the supraspinatus tendon were 4.9 ± 2.1 mm, 26.9 ± 2.1 mm, and 114.4 ± 33.8 mm, respectively.[2,17-19] Given the physical properties of tendons, we measured the standardized tendons again with vernier calipers and selected samples that met the experimental requirements for testing. The detailed values of these tendons in different groups are presented in Table 1. No significant difference

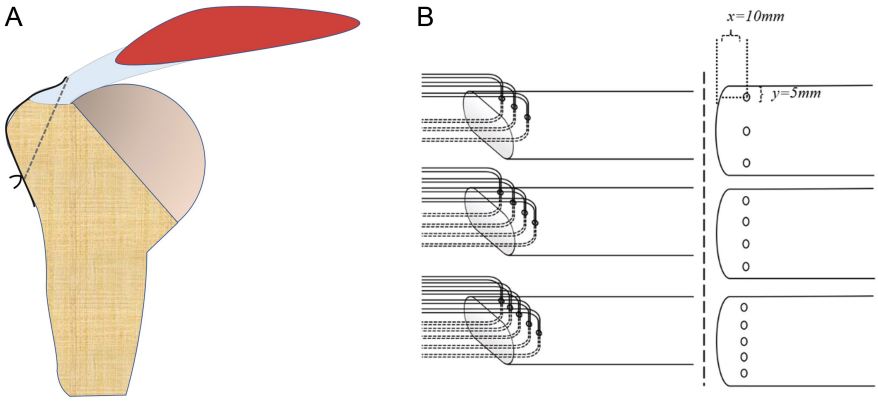

Figure 2. (A) Illustration of the method for repair of the tendons to the humerus. (B) Detailed suture method when passing the tendon. Sutures were passed through the tendon 10 mm medial to the torn edge of the tendon, and the suture insertion points on both sides are 5 mm from the edge of the tendon.

Table 1. Comparison of sizes of supraspinatus tendon in 0° and 90° abduction as per numbers of sutures

Variable		3 rows	4 rows	5 rows	6 rows	*P*-value
Tendon thickness at insertion (mm)	90°	3.44 ± 0.06	3.43 ± 0.06	3.43 ± 0.06	3.57 ± 0.04	0.32
	0°	3.41 ± 0.07	3.48 ± 0.05	3.56 ± 0.05	3.56 ± 0.04	0.05
Tendon width at insertion (mm)	90°	36.68 ± 0.37	36.63 ± 0.80	38.80 ± 0.42	35.62 ± 0.19	0.44
	0°	38.36 ± 1.27	35.33 ± 0.59	37.34 ± 0.39	35.43 ± 0.27	0.20
Tendon length (mm)	90°	121.70 ± 6.36	118.90 ± 1.36	119.30 ± 2.73	119.60 ± 1.21	0.31
	0°	118.5 ± 1.90	119.30 ± 2.03	119.6 ± 1.80	116.90 ± 2.13	0.27
Cross-section area of tendon (mm^2)	90°	126.90 ± 3.29	125.80 ± 2.80	133.20 ± 2.8	129.60 ± 1.46	0.38
	0°	131.00 ± 4.15	122.90 ± 3.02	132.70 ± 2.63	130.10 ±1.30	0.27

Note: data are presented as the mean ± SD.

was observed between these groups with respect to the tendon thickness and width at the site of the suture passing through, the tendon length, and the cross-section area of the tendon (all $P \geq .05$). Finally, all 54 tendons were included in the study.

Biomechanical test

Failure mode

All specimens were found to fail because the suture cut through the tendon substance, with 3 sutures in the 0°, 4 sutures in the 0°, and 6 sutures in both the 0° and 90° abduction groups. Further, 3 and 4 sutures in 7 specimens of the 90° abduction groups exhibited failure because the sutures cut through the tendon substance. A specimen with 3 sutures in the 90° abduction group failed because of suture anchor disconnection. One of 4 sutures in the 90° abduction group also failed because of anchor pullout. Six specimens with 5 sutures in both the 0° and 90° abduction groups failed because the suture cut through the tendon substance. In the 90° abduction group, failure occurred because of anchor pullout for 1 specimen and suture breakage for another specimen. In addition, 2 specimens with sutures in the 0° abduction group failed because of suture breakage. No loosening of the knots, slipping of the tendon ends from the tensile machine jaws, and anchors pulling out were observed. At the end of the study, 54 tendons had been evaluated. The detailed information about the failure modes are summarized in Table 2.

Pull-to-extension testing

At 90° shoulder abduction, significant difference was detected in the load between rows 3 and 5 for a 1-mm gap formation ($P=.049$). No statistically significant differences were noted in the load at the displacement in the 1-, 2-, and 3-mm formations among other groups at both 0° and 90° ($P > .05$) (Figure 3).

Pull-to-failure testing

At 0° shoulder abduction, the maximum load increases with the number of rows. The 6-row group showed significantly higher failure load than the 5-row counterpart ($P < .001$), and the 4-row group had higher failure load than the 3-row group ($P=.002$) (Figure 4A). At 90°

Table 2. Failure modes of all the tested sample

Groups	Suture cutting through tendon	Tendon rupture	Anchor pullout	Suture anchor disconnection	Suture breakage	Total number
90° abduction						
3 rows	7	0	0	1	0	8
4 rows	7	0	1	0	0	8
5 rows	6	0	1	0	1	8
6 rows	8	0	0	0	0	8
0° abduction						
3 rows	8	0	0	0	0	8
4 rows	8	0	0	0	0	8
5 rows	6	0	0	0	2	8
6 rows	8	0	0	0	0	8

Note: data was presented as number.

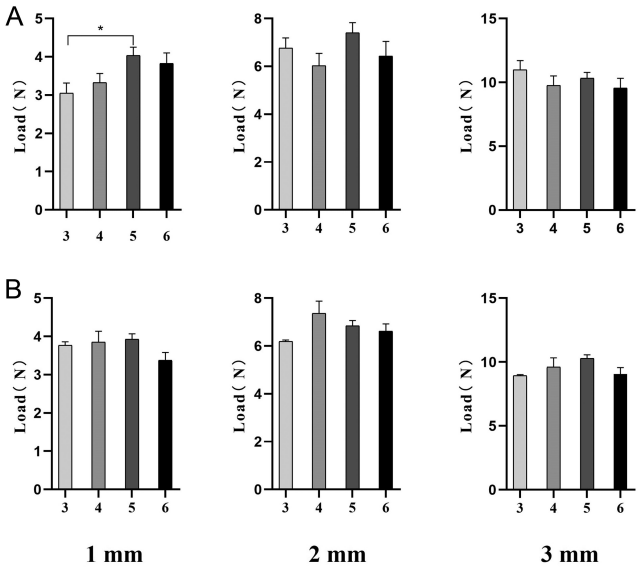

Figure 3. Comparison of the load for 1mm, 2mm, and 3mm gap formation among the groups in 0° (A) and 90° (B); not significant, $P > .05$, *, $P < .05$.

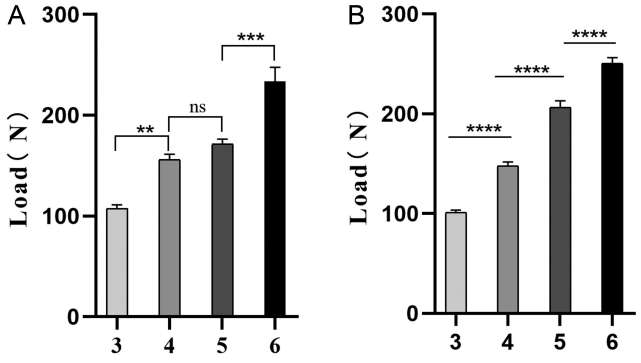

Figure 4. Comparison of the maximum failure load in 0° abduction (A), and in 90° abduction (B); not significant, $P > .05$; *, $P < .05$; **, $P < .01$, ***, $P < .001$.

shoulder abduction, significant increases were found when the number of sutures was increased (all $P > .001$) (Figure 4B).

At 0° shoulder abduction, the maximum extension of the 6-row group was increased significantly compared with that of the 5-row group ($P < .001$) (Figure 5A). No significant difference was observed between the other groups. At 90° shoulder abduction, the maximum extensions of the 4- and 6-row groups were significantly higher than that of the 3-row group ($P = .001$ and $P = .004$, respectively) (Figure 5B).

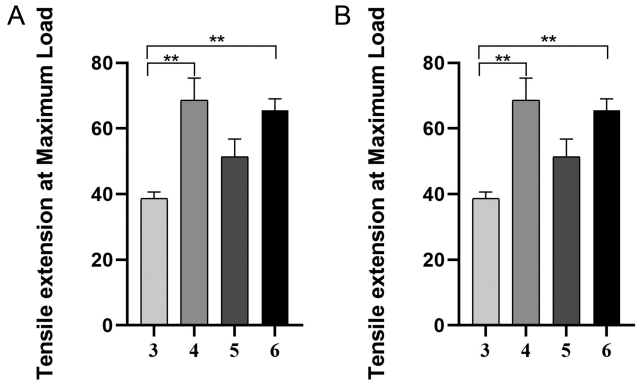

Figure 5. Comparison of tensile extension at maximum load in 0° abduction (A), and in 90° abduction (B); not significant, $P > .05$; *, $P < .05$; **, $P < .01$, ***, $P < .001$.

Discussion

The most important findings of this study are as follows: (1) the load to failure and ultimate extension at maximal load increase significantly if the number of sutures increases using the transosseous technique at both shoulder positions and (2) no significant difference was found for the load of displacement at 1-, 2-, and 3-mm formations among the groups at both the 0° and 90° abduction positions.

In pull-to-failure testing, the failure load increases significantly as the number of sutures increases from 3 to 6 rows using the transosseous technique. The plateau we hypothesized seemed not to exist according to the results and may lie outside the range of this study. This result also corresponds to a previous study which indicated that the failure load of repaired infraspinatus tendon increases by increasing the number of sutures using 2 suture anchors that were 10 mm apart from each other.[12] Although some differences arise in the present and prior studies because the infraspinatus tendon and 2 anchors were used in the latter, similar results were achieved. In the current study, we used the protocol that reduces the tendon to the original footprint of the supraspinatus tendon to investigate the biomechanical characteristics in 2 different degrees. This setting is believed to be more similar to the conditions in clinical practice as the supraspinatus tendon is repaired in most RC repairs and the 2 degrees studied were more closely related to postoperative rehabilitation.

At 0° abduction, significantly higher ultimate extension occurred at the maximum load of the 6-row group compared with the other 3 groups, with no significant difference among the 3-, 4-, and 5-row groups. At 90° abduction, the ultimate extension at the maximum load of the 4- and 6-row groups was significantly higher than that of the 3-row groups. The appropriate technique for RC repair should ideally provide high pullout strength and compression at the footprint.[20] Demirhan et al[21] found that the primary fixation strength of hybrid repair techniques was stronger than that of transosseous suture or suture anchor methods. Rawson et al[22] reported on several suture repair techniques with a 4-strand double-modified Kessler and a modified locking Kessler that were similar with the 4- and 2-row repairs utilized in this study except for the buried knot; however, their work did not report on the distance from the edge or suture depth.

Under the premise that sufficient tension can be provided at different angles of upper limb sagging and horizontal raising and given the attempt to avoid tendon ischemia and tissue adhesion caused by excessive rows of sutures, the number of strands and the ratio of total suture volume to tendon volume are important for ideal repair. To simplify the analysis, we considered only the displacement of the integral structure of the repair. At 0° abduction, under the testing of the 1-, 2-, and 3-mm extensions, the load increased with the number of strands, although no significant difference was found. At 90° abduction, no statistical difference was found among the groups. Gap formation has been proven to be related to the retear rate after RC repair.[23] The current study revealed that 4 groups showed similar load at the same gap formation. The results suggest that the number of sutures does not appear to be a risk factor for gap formation when using a transosseous technique at time 0.

Cummins et al[24] confirmed that increasing the number of sutures per anchor significantly increases the load to failure. Al-Qattan et al[25] established that the failure force from using the 2-, 4-, and 4-strands repair technique was positively correlated with an increased number of strands crossing the repair site in an experimental ovine model. Similar conclusions appear in the distal extremity tendon repair of the human hand, indicating that increasing the number of strands passing through the repair can improve the strength of the overall repair site.[26,27] This result was also verified in some experimental studies using suture tapes.[28-30] The present work also demonstrated higher ultimate failure load by employing a 6-row repair using the transosseous technique compared with the other 3 groups. It has been postulated that the ultimate strength of a repair may be more dependent on the number of suture penetrations through the tendon and the tendon angle than on the number of sutures used.[31,32]

Excessive suture tension may have no benefit for the stability of the repair construct and poses a potential risk of compromising the vascularity of the repaired RC tendon.[33,34] Cho et al[35] found that undue tension at the medial row can be a risk factor for medial RC failure with the repair. Kummer et al[36] concluded that large amount of suture tension is not necessary for the mechanical stability of the transosseous-equivalent construct. Consequently, transosseous repair using more sutures may be an alternative for RC repair. Given the increase in the number of suture materials on the tendon surface, the interaction between the suture and the surrounding soft tissue may increase, a condition that may lead to peritendon adhesion.[37] The appropriate number of sutures when using the transosseous technique must therefore be ascertained.

Limitation

This study reported some inherent limitations. First, the properties of the samples used differed from those of the human shoulder. However, the size of the tendon samples was trimmed to be comparable with that of human RC tendon. Second, the experiment does not accurately represent clinical scenarios because of the ex vivo nature. However, this is a time 0 research aiming to investigate the relationship between the number of sutures and RC repair. Third, a cyclical loading protocol was not applied because this work focused on studying the acute load placed on the RC repair at time 0. Lastly, a single brand of suture was selected because they are commonly used in surgery, and the current results cannot be extrapolated to other commercial sutures.

The number of sutures was not an influencing factor of gap formation. Under maximum load, a greater ultimate extension was observed when the number of sutures increased at both positions. Regarding the tear size and tension of the RC, choosing the appropriate number of strands individually is advocated for RC repair instead of excessively increasing the number of sutures.

Ethics Committee Approval: This study was approved by Ethics Committee of Nantong University (Approval No: P20210302, Date: 2021.03.02).

Informed Consent: N/A

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Declaration of Interests: The authors have no conflict of interest to declare.

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