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Original article

Comparison of the strength of two multi-strand tendon repair configurations in a chicken model

Comparaison des résistances à la rupture des tendons fléchisseurs réparés selon deux configurations de suture multibrins sur un modèle de poulet

Q.Q. Yang, Y.L. Zhou *

The Hand Surgery Research Center, Department of Hand Surgery, Affiliated Hospital of Nantong University, Nantong 226001, PR China

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ABSTRACT

We sought to investigate the strength of two multi-strand tendon repair configurations in a chicken model. Fifty-six chicken flexor tendons were repaired with one to two different four-strand configurations: 1) a four-strand repair consisting of a two-strand core modified Kessler suture with a circle loop repair and 2) a four-strand core Kessler suture repair with three separate peripheral suture points. The strength of the repaired tendons were measured 2, 3 and 4 weeks after the surgical repair and were analyzed statistically. The strength of the two repair methods was not statistically different 2 weeks after surgery. The tendons repaired with the four-strand core Kessler suture repair and three separate peripheral suture points were significantly stronger than those repaired with a two-strand core modified Kessler suture and a circle loop repair at 3 weeks ($P = 0.033$) and 4 weeks ($P = 0.039$). The four-strand repair with three separate peripheral suture points had greater strength than a two-strand repair with one circle loop suture based on an in vivo chicken flexor tendon model.

RÉSUMÉ

Nous souhaitions étudier la résistance à la rupture des tendons fléchisseurs comparant deux configurations multibrins sur un modèle de poulet. Cinquante-six tendons fléchisseurs de poulet ont été réparés à l'aide de deux configurations à quatre brins : 1) une réparation à quatre brins associant un point central de Kessler à deux brins et une boucle circulaire et 2) un point central de Kessler à quatre brins avec trois points séparés de suture périphérique. La résistance à la rupture des tendons fléchisseurs a été mesurée aux semaines 2, 3 et 4 après la réparation et a été analysée statistiquement. La résistance à la rupture des deux méthodes de réparation n'était pas statistiquement différente à la semaine 2. Les tendons réparés avec le point central de Kessler à quatre brins et trois points séparés de suture périphérique avaient une résistance à la rupture statistiquement supérieure aux tendons réparés avec le point central de Kessler à deux brins et la boucle circulaire aux semaines 3 ($p = 0,033$) et 4 ($p = 0,039$). La réparation à quatre brins avec trois points de suture périphérique offre une résistance à la rupture plus élevée des tendons réparés que la réparation à deux brins avec une boucle circulaire.

* Corresponding author.
E-mail address: youlangzhou@163.com (Y.L. Zhou).

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1. Introduction

Postoperative active motion of the repaired flexor tendon in zone 2 is important to prevent or limit the development of adhesions [1–6]. However, the risk of gap formation and rupture increases with early active motion. Strong sutures are needed for surgical tendon repair [7–12]. Multi-strand repairs have been proven to better resist gap formation and to increase the ultimate strength of injured tendons [10–13]. Clinically, multi-strand configurations are the mainstay of zone 2 flexor tendon repairs [11–13].

To evaluate the efficacy of multi-strand repairs, most researchers and surgeons compare different multi-strand tendon repairs using in vitro biomechanics studies and focus on initial gap formation force, 2-mm gap formation force, ultimate strength, and elongation of tendon segment after a single loading cycle or cyclical loading [13–19]. The biological healing response of the repaired tendons is not considered. It is unclear how tendon healing strength differs based on the type of repair used in animal models. To our knowledge, few investigators have reported how the strength of repaired tendons differs according to different suture configurations.

In our study, we sought to compare the strength of repaired flexor tendons between two different multi-strand configurations in a chicken model:

- a two-strand core modified Kessler suture with a circle loop repair and;
- a four-strand core Kessler suture repair with three peripheral suture points.

We hypothesized that the two different suture configurations have significantly different impact on the strength of repaired tendons in the early healing period.

2. Material and methods

2.1. Study groups

Given their similar structure to human flexor tendons, flexor tendons from Sanhuang chickens were used in this investigation [20–22]. The average age of the chickens was 1 year and their weight was about 1.5 kg. Fifty-six long toes from 28 chickens were divided into two groups with two different four-strand repair configurations:

- a four-strand repair consisting of a two-strand core modified Kessler suture with a circle loop repair; and;
- a four-strand core Kessler suture repair with addition of three separate peripheral suture points. The tendon repair strength was tested at 2, 3, and 4 weeks.

2.2. Surgical technique

Firstly, we set up a chicken tendon laceration and repair model. A 10% chloral hydrate solution was injected into a muscle (400 mg/kg of body weight) for anesthesia. Elastic bands were added to the chicken's legs for hemostasis and immobilization. Between the proximal interphalangeal (PIP) joint and distal interphalangeal (DIP) joint, a zig-zag incision was made in the plantar skin and the sheath was opened longitudinally about 1.5 cm to completely expose the flexor tendon mechanism. The exposed flexor digitorum superficialis (FDS) tendon was resected over about 1.5 cm and the flexor digitorum profundus (FDP) tendon was transected completely with a sharp scalpel blade.

Two different multi-strand configurations were used to repair the transected FDP tendons:

- group 1: a two-strand core modified Kessler suture was made first with 5–0 suture. Then a circle loop made with 5–0 suture was added in the middle; the distance from the needle entry point to the lacerated tendon end was about 1.5 mm (Fig. 1A–C);
- group 2: a four-strand core suture repair a double Kessler repair was made with 5–0 suture with three addition of separate peripheral suture points made with 6–0 sutures; the three peripheral suture points were placed in the middle and two sides of the tendon laceration sites (Fig. 1D–F).

Fig. 1B and E show cross-sectional views of the two different multi-strand repair configurations.

The FDS tendon was not repaired. After the suture repair of the FDP tendon was completed, the plantar skin was closed surgically. The toes were immobilized with sterile gauze and adhesive tape in semi-flexed position for 3 weeks at which point the toes were released from the immobilization and free toe motion was allowed.

2.3. Biomechanical testing

We harvested the flexor tendons at 2, 3, 4 weeks postoperative and tested the ultimate strength of the repaired tendons in both groups. The plantar skin was incised longitudinally over the entire length of long toe to expose the repaired tendon. Then the FDP tendon was separated carefully from the surrounding tissues. After dissection, the top of the FDP tendon was fixed on pneumatic upper clamps and the proximal end of the FDP tendon was fixed on pneumatic lower clamps in a tensile testing machine (Instron 3365; Instron, Norwood, MA, USA).The upper clamps were pulled upward at a speed of 25 mm/min until the FDP tendon ruptured. The point at which the load-displacement curve showed a sharp decline represented the ultimate strength of the repaired tendon. (Fig. 2)

2.4. Statistical analysis

Data are expressed as means and standard deviations. The data were analyzed with a two-way analysis of variance. The Tukey test was used to compare the means between the two repair groups at

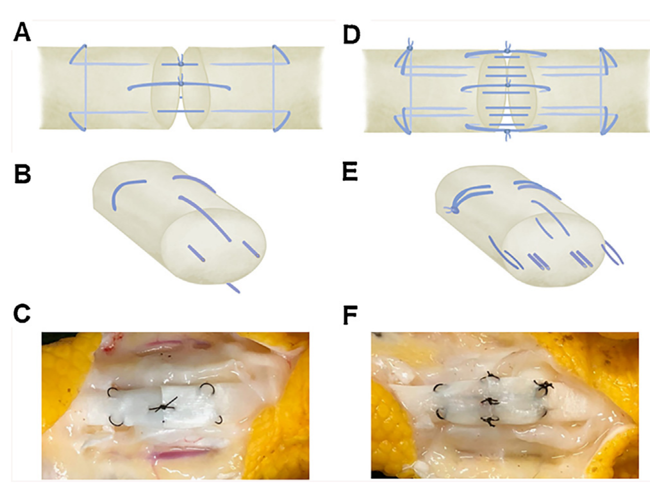

Fig. 1. Illustration of the two different multi-strand configurations used in this study: a two-strand core modified Kessler suture with an additional circle loop repair (A–C), and a four-strand core Kessler suture repair with three separate peripheral suture points (D–F).

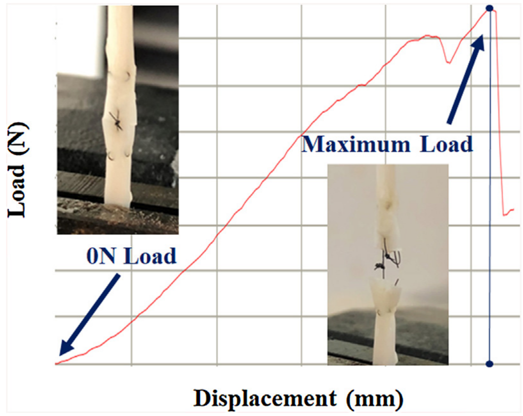

Fig. 2. Biomechanical testing. Load-displacement curve generated during testing.

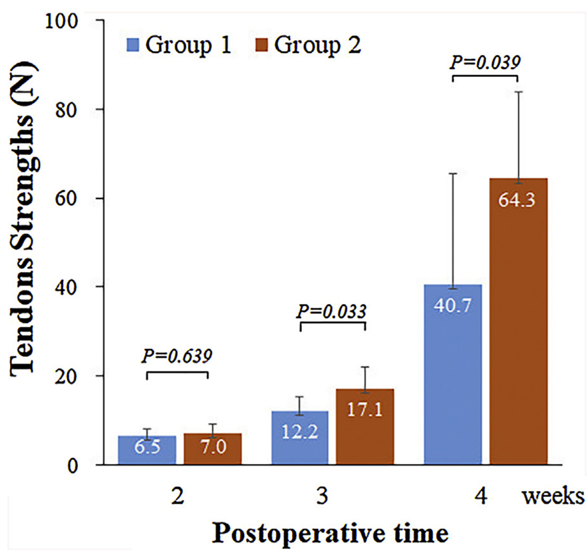

Fig. 3. Tendon strength in the two groups at the three time points tested in vivo. Group 1 represents the group of two-strand core modified Kessler suture with an additional circle loop repair and group 2 represents the group of four-strand core suture repair with three separate peripheral suture points.

the same time points and between two points. We set the level of significance at $P < 0.05$.

3. Results

3.1. Strength of repaired tendon at 2, 3 and 4 weeks

At 2 weeks, tendons in the two groups had a similar mean ultimate strength (Fig. 3). No statistical difference was found between the two repair configuration. At 3 and 4 weeks, the ultimate strength of tendons in group 2 was statistically greater from that of group 1 (P = 0.033, P = 0.039, respectively) (Fig. 3).

3.2. Change in strength of repaired tendons over time

The strength of the tendons in the two groups significantly increased between weeks 2 and 4 (Fig. 4). In group 1, the mean repair strength increased from 6.5N at 2 weeks to 12.2N at 3 weeks and to 40.7N at 4 weeks; 186% increase at weeks 3 and 334% increase at weeks 4 when compared with weeks 2 data. In group 2, the increase in the repair strength was even greater (244% increase at weeks 3 and 376 % increase at weeks 4) (Fig. 4).

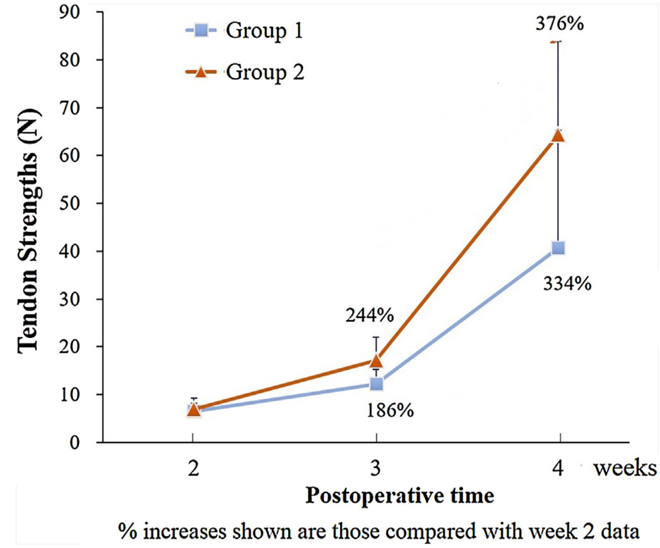

Fig. 4. Change in tendon strength in the two groups at the three time points tested in vivo. Group 1 represents the group of two-strand core modified Kessler suture with an additional circle loop repair and group 2 represents the group of four-strand core suture repair with three separate peripheral suture points.

4. Discussion

In our study, lacerated tendons treated with a four-strand core suture repair with three separate peripheral suture points had a significant increase in strength, especially at weeks 3 and 4. At week 2, the strength of the repaired tendons in group 2 was only slightly higher than in group 1 and not statistically different. The tendons were in the inflammatory phase and the collagen produced at this point is not mature and does not contribute to tendon strength and the tendon ends may be softened [20,21].

At weeks 3 and 4, we found that the strength of the flexor tendons repaired with the four-strand core suture repair with three separate peripheral suture points was significantly higher than that of the tendons repaired with the two-strand core modified Kessler suture with a circle loop repair. The difference was more dramatic at weeks 4. The two-strand sutures with a circle loop cannot provide a stable junction at the tendon repair site and the tendon ends were easily deformed or staggered. For the four-strand core suture repair with three separate peripheral suture points, the four-strand sutures were all in tendon tissue and provided stable approximation between the tendon ends. Although both configurations studied were multi-strand repairs, the stability created at the junction of the cut tendon ends might be different. This resulted in different tendon healing process and variable increase in strength 2 weeks after surgery. The 4-strand core suture method with three separate peripheral suture points might place greater tension on the tendon junction and ensure a more stable environment for tendon healing, thereby increasing the repair strength dramatically. The additional three peripheral suture points further promoted tendon stability and augmented the repair strength.

Multi-strand patterns are now used widely in the clinical repair of flexor tendons [23–33]. We used the 4-strand Kessler repair rather than the modified Kessler repair as the core suture in group 2 of this study and the different locations of knots in two groups might have affected healing as well, because the Kessler repairs have no knots between two tendon cuts and were found to have better gap resistance [33,34]. Although the in vitro strength of many multi-strand configurations has been investigated [9,10,35,36], they are different from the strength of healing tendons in vivo. Investigating the repair strength of different multi-strand configurations in vivo is a new topic. Strick et al. studied adhesion formation and gliding of the tendons repaired with two-strand and four-strand techniques in a chicken model, but the strength of the multi-strand configurations was not evaluated [37].

The current study is a preliminary attempt to examine the different healing strength of two suture configurations initially. This study was limited in that we did not investigate the biological mechanism of the different healing responses in the two groups and only compared two multi-strand configurations. We did not include histology in this study and the two multi-strand repairs studied are very different in their configuration. We may need to use histology to investigate differences in tendon healing biology and our future studies need to include other suture configurations.

Ethical approval

This experimental protocol was approved by the Research Ethics Committee of Nantong University. All groups were handled according to Council on Animal Care guidelines, Nantong University, Nantong, China.

Disclosure of interest

The authors declare that they have no competing interest.

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