Original Article

Comparative Study of Biomechanical Properties between Needled Suture and Needleless Suture in Multi-Strand Tendon Graft Model

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Objective: To compare the biomechanical properties of the Chinese finger (CF) suture, a needleless suture technique, with the baseball stitch (BS) suture, a needled suture technique, in a multi-strand model by using a 4-strand tendon model. Additionally, the BS was compared with the serial rolling hitch (RH), a locking needleless suture technique.

Materials and Methods: 4-strand grafts, made from two 20-cm fresh porcine toe extensors, were used in all three groups. After the grafts were sutured, pretension was applied with a load of 100-N distraction force for five minutes. After the tendon elongation was measured before and after the pretension, the distraction force was continued until the constructed graft failed. Stress-strain relationship graphs were recorded by universal testing machine (UTM), distributing to the calculation of percentage on tendon elongation, stiffness, and load-to-failure.

Results: The BS had significantly higher load of failure than the CF (p=0.001) but no significant difference when compared with the RH. Comparing between BS, CF, and RH, there were no significant difference in stiffness and percentage of tendon elongation. In modes of failure, there was evidence of knot slipping in CF in six of six cases and graft strangulation in RH in four of six cases.

Conclusion: Multi-strand model BS, a needled suture, had a higher load to failure than CF, a needleless suture. Moreover, needleless sutures had serious modes of failure, which were knot slipping and strangulation of graft by the suture material. Therefore, needleless suture technique for multi-strand tendon graft preparation was not recommended.

Keywords: Tendon preparation; Multi-Strand; Needled suture; Needleless suture; Chinese finger; Baseball stitch; Rolling Hitch; Biomechanical study; Graft elongation; Load to failure

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There are generally two suturing techniques for tendon graft preparation, the needled and needleless suture techniques. Needled suture techniques require a suture material passing through a graft by several choices of configuration, while needleless suture techniques use a suture material grasping onto a graft.

Chinese finger trap configuration (CF) is one of the needleless suture techniques. Su et al[(1)] reported CF had equal load of failure when compared with needled suture techniques, which were Krackow stitch, locking-whipstitch, and non-locking-whipstitch. However, CF had less tendon elongation after pretension and cyclic loading than the others.

Many studies[(2-5)] reported the disadvantage of too many throws in needled suture techniques. As the number of throws increases, the injury to the graft is increased and this leads to further tendon elongation.

To decrease the chance of a graft failure, the needleless suture technique may be a good choice for preparing the single-strand graft as reported in recent literature[(1,6)]. However, using a multi-strand graft can possibly decrease the contact surface area between each individual tendon and the suture material. Slipping one strand of the multi-strand graft can affect the whole construct and thus lead to graft failure. The purpose of the present study was to compare the biomechanical properties of the CF, which is a needleless suture technique, with that of the baseball stitch (BS) suture, which is a needle suture technique, in a multi-strand model by using a 4-fold tendon model. Additionally, comparing the BS with the

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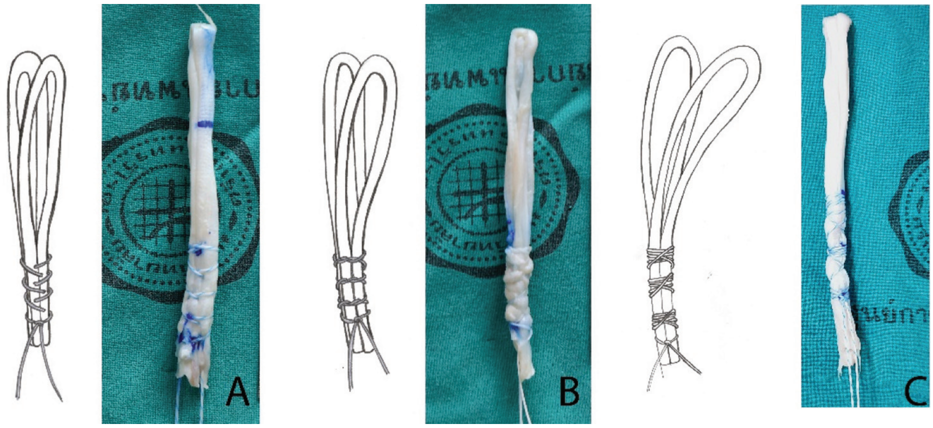

Figure 1. (A) Baseball stitch (BS), (B) Chinese finger (CF) and (C) Serial rolling hitch (RH).

serial rolling hitch (RH), a locking needleless suture technique, was conducted. The authors hypothesized that the needleless suture had less biomechanical properties than the needled suture technique.

Materials and Methods

The present study was approved by the Institutional Animal Care and Use Committee (Approved No. COA/AE-008-2563). To create the multi-strand graft model, two 20-cm fresh porcine toe extensors were folded to become the 4-strand graft for the present study. Four ends of the strands were held together with the CF and the BS suture techniques (Figure 1A, B). In the CF group, a series of four square-knots were made at 2 to 4 cm away from the tendon end with 0.5 cm pitch. Similarly, in the BS group, four pairs of sutures were performed at the same level of the tendon (Figure 1C). The sliding knot was used at the final loop for allowing more tension during distraction. The RH group was prepared in the same manner as the CF by using rolling hitch configuration.

Tendon length and diameter were measured. The specimens were applied to a universal testing machine (UTM) that was calibrated and set to zero position and force. All the specimens were loaded with 100-N distraction force for five minutes for pretension. To exclude the length of the suture from using the machine measurement, the tendon length was measured before and after the pretension by using a digital measurement with 6,000×4,000 pixels photographs taken by Canon EOS 80D. The distraction force was applied until the construct failed. The tendon slipping, suture breaking, and tendon rupture were considered as the construct failure. Stress-strain relationship graphs were recorded by UTM. Stiffness and load-to-failure were calculated from these graphs.

The outcomes of the present study were the percentage of tendon elongation (PTE) after pretension, stiffness, load-to-failure, and mode of failure.

Statistical analysis

The sample size was calculated by using type I error as 0.05, type II error as 0.20, and the significant tendon elongation of 5 mm as the difference of anterior drawer grading in the pilot study. The sample size was six specimens for each group.

One-way ANOVA was used to compare the length and diameter between the three groups. A Bonferroni method, a post hoc test, was used to evaluate the outcomes between each group, which were the percentage of tendon elongation after pretension, stiffness, and load-to-failure.

Results

There was no significant difference in diameter and length between the three groups ($F (2, 15)=0.78$, $p=0.47$ and $F (2, 15)=1.76$, $p=0.2$, respectively) (Table 1). Using Bonferroni post hoc test (Table 2), the BS had significantly higher load to failure than CF with a mean of 344.84 versus 211.88 ($p=0.001$) but no significant difference when compared with RH. In PTE and stiffness, there was no significant difference (Table 3).

The six specimens in the BS group failed due to suture material rupture (Figure 2A). In the CF group, the six specimens failed due to knot slipping (Figure 2B). Furthermore, two from those specimens failed during the 100-N pretension. Four of six specimens in the RH group failed by suture material

Table 1. Diameter and length

	Diameter* (mm)		Length* (mm)	
	Mean	SD	Mean	SD
BS	7.02	0.48	90.88	5.21
CF	6.90	0.81	87.95	5.49
RH	6.62	0.25	93.80	5.48

BS=baseball stitch; CF=Chinese finger; RH=rolling hitch; SD=standard deviation

* Diameter: F (2, 15)=0.78, p=0.47; Length: F (2, 15)=1.76, p=0.2

Table 2. Percentage of tendon elongation, load of failure, and stiffness

	PTE		Load to failure (N)		Stiffness (N/mm)	
	Mean	SD	Mean	SD	Mean	SD
BS	1.58	1.20	344.84*	58.88	1.65	0.31
CF	3.34	1.68	211.88*	56.22	2.99	0.49
RH	4.37	2.47	269.44	52.89	2.63	0.84

PTE=percentage of tendon elongation; BS=baseball stitch; CF=Chinese finger; RH=rolling hitch; SD=standard deviation

* Significant difference p=0.001 (post hoc test, Bonferroni method)

Figure 2. (A) Suture material rupture, (B) Knot slipping, and (C) Suture strangulation.

rupture. Surprisingly, the other two graft specimens were torn by suture strangulation (Figure 2C).

Discussion

The number of throws that penetrates the tendon graft may weaken the tendon strength in needled suture technique such as Krackow, BS, and Whipstitch[2-5,7]. Hong et al[4] reported that the 7-throw of the Krackow suture had a significant increase in tendon elongation after a pretension of 200-N distraction force comparing with a 3- or 5-throw (p=0.03 and 0.01). In Jassem et al study[2], the increase in tendon elongation correlated with the increased number of throws and decreased pitch distance. The gap formation was increased with the number of loops or throws in Hahn et al study[5]. Many of the studies reported the same and concluded that too many throws of the suture penetrating through the tendon damaged the tendon and diminished the tendon strength.

Needleless suture techniques could be an option. Hong et al[4] compared the Krackow stitch with needleless suture techniques such as rolling hitch and modified rolling hitch. They reported a similar ultimate failure load but an increase in elongation after cyclic loading. Su et al[1] tested the biomechanical properties among the modified CF trap, Krackow, locking whipstitch, and non-locking whipstitch. They had similar load to failure, but modified CF trap had the lowest tendon elongation after 100-N pretension and cycling loading. All the mentioned studies were done using a single-strand model and the needleless techniques seemed to have a better result.

In previous single-strand model studies, most of them reported needled techniques had a higher tendon

Table 3. Compare between groups (post hoc test using Bonfferoni method)

	PTE		Load to failure (N)		Stiffness (N/mm)	
	p-value	95% CI	p-value	95% CI	p-value	95% CI
BS vs. CF	1.000	−3.78 to 2.5	0.001	73.96 to 266.54	1.000	−1.99 to 1.29
BS vs. RH	0.092	−5.93 to 0.35	0.156	−20.89 to 171.69	0.387	−2.62 to 0.66
CF vs. RH	0.258	−5.28 to 1.00	0.054	−191.14 to 1.43	0.948	−1.01 to 2.27

PTE=percentage of tendon elongation; BS=baseball stitch; CF=Chinese finger; RH=rolling hitch; CI=confidence interval elongation than needleless techniques. However, the result in the present study was different. BS, a needled technique, had no significant difference in percentage of tendon elongation when compared with the CF and the RH, needleless techniques. However, BS had a significant higher load to failure than CF. The possible reason that BS in multi-strand model has less tendon elongation than in single-strand model when compared to needleless technique is that in multi-strand model, all knots of BS did not pass through the same strand of tendon and so there was less injury in multi-strand than in the single-strand model.

In regard to the mode of failure, all the BS grafts failed with suture material rupture. Meanwhile, the needleless groups had serious modes of failure, which were tendon slipping in the CF and graft torn by strangulation in the RH.

In the CF, a grasping force was created by a friction between a suture material making with the tendon surface. In single-strand graft, the suture material completely contacted the surface of the tendon, while it contacted each tendon less in multi-strand graft. Thus, the percentage of the grasping force would be higher in the single-strand graft than in the multi-strand graft. This is an important factor if the authors used the CF for preparing the multi-strand graft. Slipping one of the tendons could lead to a rapid loosening of the whole construct and failure. The result from the present study may support this theory. All the CF slipped during the test with a mean force of 174.58 N, and a range of 141.71 to 262.76 N.

Ideally, the needleless suture allows more grasping force while the distraction force was applied through the construct. The serial RH is locking needleless technique. In the present study, the RH was over tight while applying the distraction force and so strangulated the graft.

The authors' biomechanical study simulated the multi-strand tendon graft model with a 4-strand tendon to compare the BS as needled with the CF and the RH as needleless technique. This might be the first study in multi-strand model. Weakness of the present study was using the porcine tendon rather than human tendon, thus it is not a clinical study. Nevertheless, it was easier and safer as a preliminary biomechanical study. The results of the present study did not support to use of needleless technique in multi-strand tendon graft as the previous study using single-strand tendon did. The reason it does not support to use of needleless technique is due to the serious mode of failure and lower biomechanical properties.

Conclusion

Unlike the single strand model, the present study of multi-strand models reported that the BS, needled suture, had higher biomechanical properties, in some parameter, when compared to the CF and the RH needleless techniques. In regard to mode of failure, the needleless suture had serious modes of failure such as knot slipping, or suture material cut the graft by strangulation. From the results, the authors did not support the use of the needleless suture techniques to prepare a multi-strand tendon graft.

What is already known on this topic?

There are many techniques to prepare tendon graft. In the single-strand graft, the needleless suture such as Chinese finger technique had better biomechanical property than needled suture.

What this study adds?

In the multi-strand model, needleless suture did not have better biomechanical property as in single-strand model. The baseball stitch, the needled suture, had higher load-to-failure than the Chinese finger and the modified rolling hitch, the needleless sutures. Moreover, the needleless sutures had serious modes of failure such as knot slipping and graft strangulation.

Clinical relevance

The needleless suture techniques are not recommended for multi-strand tendon graft preparation due to lesser biomechanical properties than the needled and have more serious modes of failure.

Conflicts of interest

The authors declare no conflict of interest.

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