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Biomechanical Analysis of Resorbable Barbed Suture Tenorrhaphy

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Purpose: To evaluate the tensile strength and repair-site profile of a technique of resorbable barbed suture tenorrhaphy.

Methods: Forty-eight flexor digitorum profundus tendons were collected from the 8 adult cadavers. In the test group, the tendons were sutured using absorbent 2-0 barb knotless sutures in a 2-strand or 4-strand zig-zag pattern. In the control group, 2-0 Prolene and 3-0 polydioxanone (PDS) were used to suture the tendons using the 2-stand Modified Kessler method and the 4-strand cruciate suture method. Using a tensile force measurement machine, the breaking load (N) and the stiffness (N/mm) were measured. The types of rupture were categorized into suture breaking, knot rupture, and pullout.

Results: In the comparative analysis between the absorbent 2-0 Quill (Angiotech Pharmaceuticals, Canada) suture that used the 2-strand core suture and the 3-0 PDS and 2-0 Prolene sutures, the average breaking load for the 2-0 Quill suture was 26.83±7.47 N, and 21.96±6.78 N and 17.20±4.93 N for the 2-0 Prolene and 3-0 PDS sutures. In the comparison using the 4-strand core suture, the average breaking load for the 2-0 Quill suture was 62.50±13.34 N, and 22.35±5.72 N and 18.67±4.27 N for the 2-0 prolene and 3-0 PDS sutures. The most common type of rupture were knot rupture.

Conclusion: For flexor tendon sutures using the absorbent barb sutures, compared to the conventional 2-0 Prolene or 3-0 PDS sutures, absorbent barbed sutures have a higher tensile strength.

Keywords: Barbed suture, Tenorrhaphy, Tensile strength

INTRODUCTION

When repairing damaged flexor tendons, it is very important to acquire an adequate tensile strength to enable early passive and active exercise[1-5]. To obtain such adequate tensile strength, it is critical to select an appropriate suturing technique and suture materials[6]. Therefore, many suturing methods have been developed. Use of barbed suture was first reported in the 1950's, when Bunnell[7] and Jennings et al.[8] used this suture for flexor digitorum tendon repairs. In 2009, Parikh et al.[9] compared the tensile strength of 3-strand and 6-strand sutures using

non-absorbent barbed sutures with the 4-strand cruciate suturing technique that used monofilament polypropylene sutures in *ex vivo* research. They confirmed that the technique using the barbed sutures was able to maintain adequate tensile strength without suture knots and also that the barbed sutures had a similar healing effect progression as the previous sutures.

Using the Quill resorbable barbed suture (Angiotech Pharmaceuticals Inc., Vancouver, BC, Canada), it is assumed that tendon suturing would be possible without the knots by attaching the suture and the tendon. If knots and loops are eliminated, not only can the tensile strength be increased, but it was considered that any bunching in the suture area could be decreased. Therefore a comparative analysis was conducted on the tensile strength and characteristics of the suture areas when using a barbed suture compared to when using the conventional suture in the flexor tendon repairs.

MATERIALS AND METHODS

Forty-eight flexor digitorum profundus (FDP) tendons from the index finger, middle finger, and ring fingers of 8 Korean adults cadavers that were not fixed were obtained. The FDP tendons were collected right before suturing. The ages of the 8 cadavers ranged from 54 to 84 years for an average of 69.5 years. Mean height was 169.00±12.08 cm and mean weight was a 61.5±20.56 kg. Each of the specimens was collected from the flexor tendon zone II–III. Using a #15 scalpel the flexor tendon was harvested at a pre-indicated point. To protect the specimens from desiccation during the collection, preparation, and suturing, they were stored in normal saline solution. The collected tendons were randomly allocated into three groups to form one test group and two control groups. Within each of the groups, the tendons were subdivided into a 2-strand core suture group and a 4-strand core suture group. Sutures were completed only using the core suture to remove the effect of the epitendinous suture.

1. Suture materials

For the test group, reabsorbing 2-0 Quill (bidirectional barbed polydioxanone) was used. It had a 1 cm interval space in the center without barbs and were made up of 7 mm barbs that stuck out in both directions. Percutaneous needles (18 mm, 3/8 circle) were used. Using a model 5567 tensile force measurement device (Instron Corp., Canton, MA, USA), the break load (N) of the control group was measured to select a suture product with a similar strength to that of the 2-0 Quill (Fig. 1). The fracture loads for 2-0 Quill (52.16±2.54 N) and 3-0 PDS (56.73±8.35 N) were the closest (p=0.24) with 2-0 Prolene (58.72±2.96 N) being the second closest (Fig. 2). For the control group, 3-0 PDS (monofilament polydioxanone, Johnson & Johnson Medical GmbH, Norderstedt, Germany) and 2-0 Prolene (monofilament polypropylene, Ethicon Inc., Somerville, NJ, USA) were selected.

2. Suturing method

The test group used the 2-0 Quill suture using the 2-strand or 4-strand zig-zag suturing pattern. One side of the barbed suture needle penetrated towards the distal direction of the tendon from the distal tendon that was cut, and the other needle penetrated in the proximal direction from the proximal tendon that was cut. Each

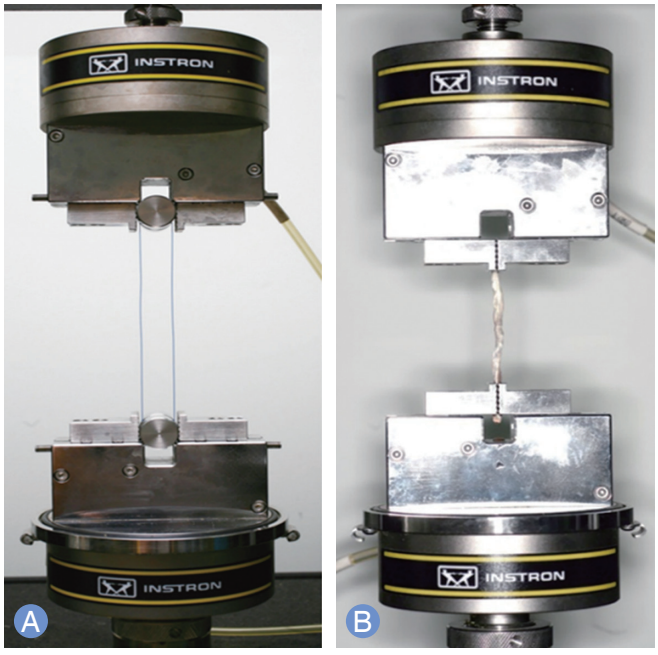

Fig. 1. Test machine for the **(A)** wire strength test and **(B)** suture strength test.

of the needles penetrated in a parallel direction to the fibers and proceeded 0.5 cm until they reached the tendon sheath. This was repeated three times using the zigzag pattern so that the middle part of the barbed suture without barbs would be located at the sutured area. The barbed suture that came out of the surface of the tendon was cut off. By repeating this step two or four times, 2-strand and 4-strand suture technique tendon sutures without knots, respectively, were completed (Fig. 3). The control group used 3-0 PDS and 2-0 Prolene to complete sutures with the 2-strand modified Kessler's method and 4-strand cruciate suturing method.

3. Break load measurement

After suturing the flexor tendon, the break load (N) and the types of tendon rupture for the test group and the control group were examined. The break load of the sutures was measured with the aforementioned tensile strength measuring device with a starting load of 2 N and subsequent increases of 50 mm per minute until the suture broke, at which point the strength of the suture was measured. Mechanical rupture was defined as a sudden widening at the suture area or a newly occurring 3 mm space at the suture area. The break load was measured by recording when the first mechanical rupture occurred at the suture area. To check the rupture type, the four magnification glass was used. The types of rupture were categorized into suture breaking, knot rupture, and pullout that remained knots (Fig. 4).

The results from the research were statistically analyzed using the Mann-Whitney U-test, which confirmed that the results had a $p<0.05$ statistical significance.

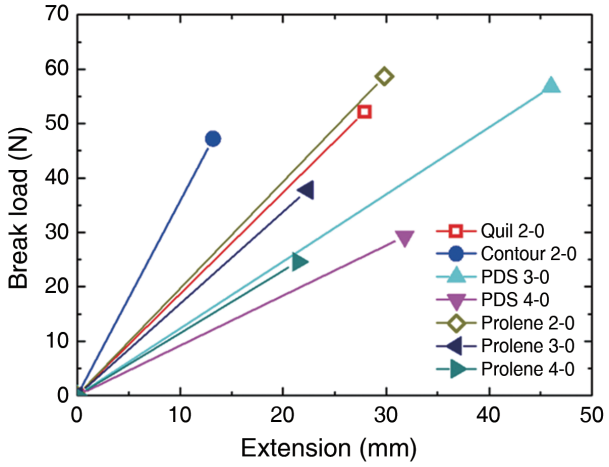

Fig. 2. Graph of break load and extension. PDS, polydioxanone.

RESULTS

A total of 48 FDP tendons divided into 24 tendons in the

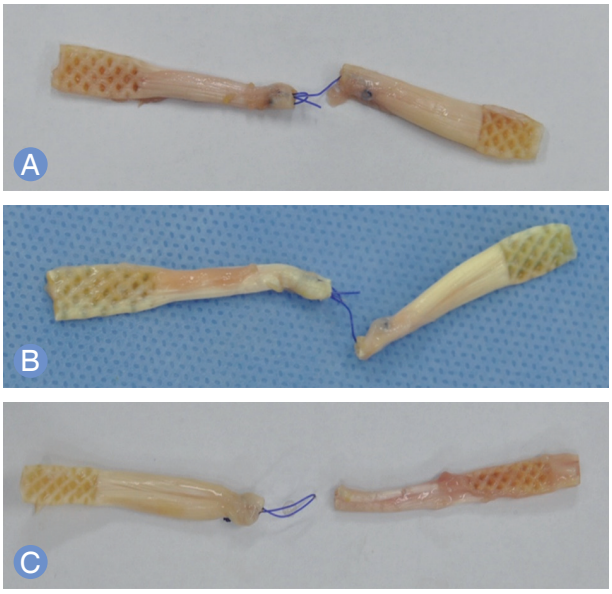

Fig. 4. Analysis of results. The panel shows **(A)** suture break, **(B)** knot rupture, and **(C)** pullout, respectively.

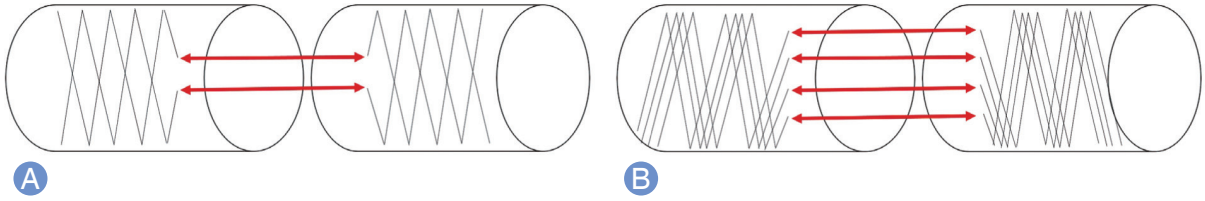

Fig. 3. (A) 2-strand and **(B)** 4-strand barbed suture technique.

Table 1. Load of failure in 2-strand tenorrhaphy

Wire	Suture	Sample no.	1st Failure load (N)
Quill 2-0	2S	12	26.83±7.47
PDS 3-0	2S	6	17.20±4.93
Prolene 2-0	2S	6	21.96±6.78

PDS, polydioxanone.

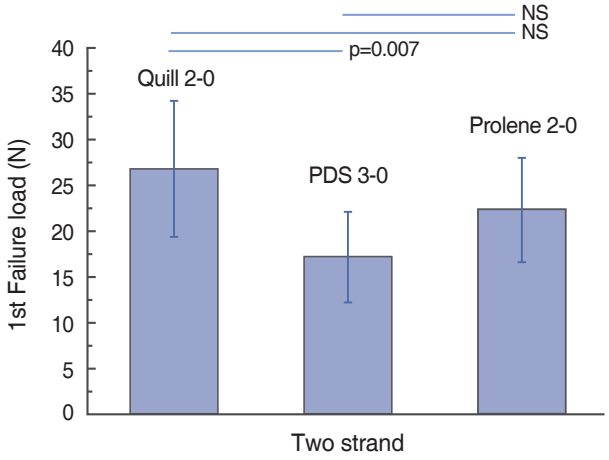

Fig. 5. Load of failure in 2-strand tenorrhaphy. NS, not significant; PDS, polydioxanone. A p<0.05 was considered significant.

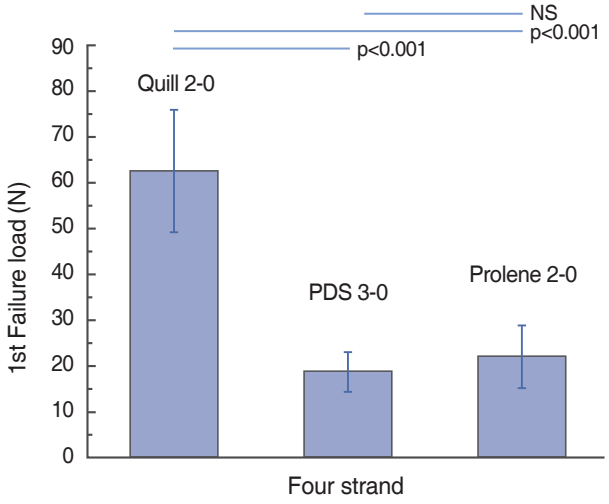

Fig. 6. Load of failure in 4-strand tenorrhaphy. S, not significant; PDS, polydioxanone. A p<0.05 was considered significant.

test group and 24 tendons in the control group were analyzed. 2-strand and 4-strand zig-zag sutures were completed on the 24 flexor tendons in the control group. For the sutures on the 24 flexor tendons in the control group, the 2-strand modified Kessler method and the 4-strand cruciate suturing method was used.

For the 2-strand suture, the break load for the 2-0 Quill averaged 26.83±7.47 N and averaged 17.20±4.93 N for 3-0 PDS, showing that the 2-0 Quill was significantly stronger (p=0.007). The average for the 2-0 prolene was 21.96±6.78 N, which was slightly weaker than the 2-0 Quill, but not statistically significant (p=0.25). In the 2-strand suture of the 3-0 PDS and 2-0 Prolene, the break load was not statistically significant (p=0.18) (Table 1, Fig. 5). The break load for the 4-strand suture of the 2-0 Quill averaged 62.50±13.34 N and averaged 18.67±4.27 N and 22.35±5.72 N for 3-0 PDS and 2-0 prolene, respectively (p<0.001), demonstrating that the 2-0 Quill was the strongest. The break load for the 4-strand suture of 3-0 PDS and 2-0 prolene was not statistically significant (p=0.485) (Table 2, Fig. 6).

Concerning the rupture type of the test group, 22 out of 24 were the suture break type and 2 were the pullout type. In the control group, knot rupture was the most frequent type (n=11), followed by pullout type (n=10) and suture break type (n=3) (Table 3). Concerning the swelling of the suture area, it was apparent to the naked eye that the test group had significantly decreased swelling compared to

Table 2. Load of failure in 4-strand tenorrhaphy

Wire	Suture	Sample no.	1st Failure load (N)
Quill 2-0	4S	12	62.50±13.34
PDS 3-0	4S	6	18.67±4.27
Prolene 2-0	4S	6	22.35±5.72

PDS, polydioxanone.

Table 3. Mode of failure

Rupture type	Barbed	Unbarbed
Suture break	23/24	3/24
Knot rupture	None	11/24
Pullout	1/24	10/24

the control group.

DISCUSSION

For tendon sutures, the ideal suture is strong in the suture area and inelastic, with a low reactivity to stimulation that is also easy to handle while also having a safe knot[10]. There also must be minimal swelling in the suture area, and it must be strong enough to permit active movement in the early stages after suturing[11].

In contrast to this ideal, the most widely used tendon suture has a knot and also has limitations in acquiring a high tensile strength due to swelling. The barbed suture introduced in 1967 by McKenzie[12] has no resistance in the direction of the barbs, while there is resistance when the suture is pulled in the direction opposite to the barbs. These barb characteristics obviate the need for knots and because there is interaction between the barbs of the suture and the tendon in the suture areas, stronger binding can be maintained. Through the research, it was confirmed that suturing using the barbed sutures had a similar or greater strength when compared to that of previously used conventional sutures. Also, a strength of above 40–50 N, which enables early movement, was possible to be obtained[13]. Clemente et al.[14] also reported that Quill suture guarantees a breaking force of above 40–50 N in their animal model.

According to the analysis of rupture types, for the control group there were mainly knot rupture or pullout types, and for the test group suture break was the most frequent type of rupture. For the control group, the suture knot and the inadequate interaction between the suture and the tendon was a limitation in obtaining a high tensile strength. On the other hand, for the test group it was possible to confirm that the strength of the suture itself was a factor that limited obtaining a high tensile strength. If a barbed suture with a greater diameter or if a barbed suture made of a stronger material is to be used, it will be possible to obtain an even higher tensile strength.

High tensile strength and flexibility when the sutured tendon glides through the tendon sheath and pulley is necessary. Excessive sutures or excessive bunching in the suture area can impede this gliding. Comparing with the control group, the barbed suture group could pass through more easily because of the minimal bunching. For the zig-zag suture method of the test group, because the suture passes through the tendon fiber in a perpendicular direction more than two times in both directions, the suture area can be sutured together with stability. Also, because the middle part is where there are no barbs, even in the case where re-suturing is required due to technique mistakes during surgery, this area without the barb can be cut to remove the suture.

Because this research has some limitations, more research must be conducted before clinical applications. By conducting ex vivo tests, there is a need to take into consideration the changes within the body that can occur when a tendon is actually harmed. After suturing, ischemia, edema and swelling can occur on the tendon within the body and mechanical changes due to long-term exposure can occur. Also, when completing tendon suturing for actually damaged tendons, the limitations of the surgical view must also be taken into consideration. These are the main points that must be confirmed before suturing techniques using barbed sutures can be clinically applied. But, if the limitations can be overcome through continued research, and so suturing using barbed sutures can be presented as one method for tendon suturing.

CONCLUSION

The present study introduces the idea of using resorbable barbed suture tenorrhaphy. For flexor tendon sutures using the absorbent barb sutures, compared to the conventional 2-0 Prolene or 3-0 PDS sutures, absorbent barbed sutures have a higher tensile strength. And knots and loops was eliminated, bunching in the suture area could

be decreased. Our data suggest that knotless barbed suture repair may offer several advantages in flexor tenorrhaphy, and it can be presented as one method for tendon suturing.

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흡수성 가시 봉합사를 이용한 굴곡건 재건술의 생체역학적 분석

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목적: 흡수성 가시 봉합사를 이용하여 굴곡건을 재건했을 때 인장 강도와 봉합부위 특성을 분석 하였다.
방법: 성인 시신 8구에서 얻어진 48개의 심부 수지 굴건을 대상으로 실험하였다. 실험군은 흡수성 2-0 가시 봉합사를 이용하여 2중, 혹은 4중 지그재그 봉합법으로 매듭 없이 봉합하였다. 대조군은 2-0 prolene과 3-0 polydioxanone (PDS)를 이용하여 2중 변형 케슬러법과 4중 십자형 봉합법으로 봉합을 시행하였다. 인장력 측정기를 이용하여 파괴 하중과 강도를 측정하였다. 건파열의 유형은 봉합사 파열, 봉합 매듭 파열, 봉합 견인 파열로 나누었다.
결과: 2중 봉합법을 이용한 경우 흡수성 가시 봉합사와 2-0 prolene, 3-0 PDS의 파괴 하중의 평균은 26.83±7.47 N, 21.96±6.78 N, 17.20±4.93 N이었다. 4중 봉합법을 이용한 경우 흡수성 가시 봉합사와 2-0 prolene, 3-0 PDS의 파괴 하중의 평균은 62.50±13.34 N, 22.35±5.72 N, 18.67±4.27 N이었다. 건파열 유형은 봉합 매듭부위 파열이 가장 많았다.
결론: 흡수성 가시 봉합사를 이용한 굴곡건 봉합법은 3-0 PDS 나 2-0 Prolene을 이용한 봉합법 보다 더 높은 신장 강도를 보여 주었다.

색인단어: 가시봉합사, 건봉합술, 생체역학

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