Biomechanical and Dimensional Measurements of the Pulvertaft Weave Versus the Cow-Hitch Technique

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Abstract

Background: In this study, biomechanical strength and bulkiness of the cow-hitch technique and Pulvertaft weave were compared. Our goal was to investigate whether the cow hitch can withstand equal strength in comparison with the Pulvertaft and to see if there is a difference in bulk, which could enhance gliding function and reduce friction and adhesion formation. **Methods:** Sheep tendons were used to perform 10 cow-hitch and 10 Pulvertaft repairs. Tensile strength was obtained with a cyclic loading tensile testing machine and tendon width and height measurements were obtained through digital analysis by photographs of the repairs. **Results:** The cow hitch showed significantly better ultimate strength and had less bulk. There was no statistical difference in displacement, defined as gain in total length of the tendon. **Conclusions:** The results in this study show that the cow hitch outperforms the Pulvertaft weave in both ultimate strength and bulk.

Keywords: Pulvertaft, cow hitch, flexor tendon reconstruction, mechanical testing, tendon transfer, tendon grafts, tenorrhaphy

Introduction

The most preferred weave for tendon grafts and tendon transfer surgery is the Pulvertaft (PW).¹⁴ It has been the standard technique since Pulvertaft described it in 1956.¹² In clinical practice, surgeons usually use 3 to 4 weaves, and in the past it has been shown to be a strong and reliable technique.^{3,5}

More recently, there have been several studies done comparing the PW with other suture techniques to see whether they are stronger. This is because there are some limitations to the PW. A commonly described failure is instability of the sutures leading to elongation of the junction.² Also, the weave is bulky, which creates a greater amount of friction on the surrounding tissue.⁸ It is thought that reducing this bulkiness improves the ability of the repaired tendons to glide through the surrounding tissue, resulting in less friction and thus fewer adhesions.¹⁶

The goals of a successful tendon transfer or graft surgery are to create a strong weave, have the suture be small in volume, and to have stable suture sites. Thus, less friction and a stronger and more stable suture allow patients to start rehabilitation earlier, which ultimately leads to less adhesion formation and better mobilization.

The concept of the cow hitch (CW) arose while fixating a tent canvas, one of its current applications. This noose has first been described by Heraklas in his essay, which dates

back to the first century AD. Heraklas used it not only for traction but also for holding limbs and placing patients in position for surgical operations.⁷ In clinical practice, it is common that while performing a tendon transfer with, for example, the palmaris longus tendon, a part of its length is wasted. With the CW technique, the whole length of the donor tendon can be used to its advantage. The aim of this study is to compare the biomechanical properties of the PW versus the CW technique and to see whether the dimensions of the CW are smaller than those of the PW.

Materials and Methods

Material

The profundus flexor tendons and 1 of the 3 extensor tendons from limbs of adult sheep were used for the purpose of this study. As there was little or no measurable difference between the 3 extensor tendons, 1 was chosen at random. The sheep

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never underwent surgery and were free of any abnormalities. They were slaughtered for commercial industry, and the limbs were collected immediately after slaughter. Sheep tendons were used because they were found to best mimic the biomechanical behavior of human tendons.⁹ The first batch of legs was dissected under supervision of a veterinary surgeon in order to become acquainted with the anatomy. All further dissections and preparations were done in a standardized procedure. After dissection, the tendons were wrapped in sterile gauze and immersed in a saline solution to keep them moist. They were kept in a fridge at 1°C inside a plastic storage bag with ice covering them from the outside. Tensile tests were performed within 48 hours after slaughter and tested on the same day as dissection to assure freshness of the tendons.

There were differences in sizes between the flexor tendons, but as these differences were minimal and all the limbs were randomized at the slaughterhouse, it is unlikely that they will have an impact on the results.

Description of Techniques

Sample sizes of 10 PW and 10 CW were chosen.³ All repairs were sutured with 4-0 Prolene® Polypropylene Suture (Ethicon Endo-Surgery Europe GmbH, Germany). All junctions were standardized at an overlap of 25 mm.

For the PW, the first incision was made at a distance of 5 mm from the end of the flexor tendon. The distances between the following 2 incisions were also 5 mm. The extensor tendon was woven through the flexor tendon 3 times. Each weave was fixated with 2 interrupted mattress sutures. And at both ends, the tendons were also fixated with interrupted mattress sutures. This provided the repair with a total of 8 sutures (Figure 1).

For the CW, 1 incision is made at a distance of 5 mm measured from the end of the flexor tendon. A fixating mattress suture is inserted at 1 mm measured from the end of the flexor tendon and pulled through at 4 mm, so that the whole suture has a total width of 3 mm. The donor tendon is then folded and the folded side has to be pulled halfway through the incision, which will create a loop. After this, pass the 2 free ends of the donor tendon through this loop. Then, wrap the loop to the opposite side of the flexor tendon and pull the free ends to tighten the knot. Four further interrupted mattress sutures were used to fixate both tendons. A total of 5 sutures were used (Figure 2).

Once the repairs were made, a photograph was taken in 2 perpendicular directions alongside a ruler to ensure that digital scaling was possible later on. All tendons had a standardized traction of 150 mg for the photograph.

Testing

Mechanical tests were conducted on a tensile testing machine (Zwick/Roell Zmart.Pro, Zwick GmbH & Co. KG,

Figure 1. Line drawing of a Pulvertaft repair with 3 weaves.

Figure 2. Step-by-step line drawing explaining how to perform a cow-hitch repair.

Ulm, Germany). The machine was calibrated according to the manufacturer's instructions. Two custom-made clamps were used, on which P60 sand paper was glued to prevent slippage of the tendons. On both the distal and the proximal end of the tendon, the custom-made clamps were fixated to ensure that all tendons were tested under the same

Figure 3. Graph explaining the definition of initial and ultimate failure.

Note. "Initial failure" shows the first negative inflection on the repair, and "ultimate failure" is the moment in which the tendon is unable to build up ultimate strength.

conditions. The clamps were mounted vertically. Throughout the cyclic loading, the tendons were kept moist by spraying saline solution from a spray bottle onto them.

All tests were conducted at a speed of 20 mm/min. Preload was fixed at 0.2 N. Tendons were preconditioned at a force of 5 N for 2 cycles. The specimens were loaded cyclically 5 times. After every 5 cycles, we increased the strength progressively with 15 N until ultimate failure occurred. Maximum strength was held for 1 second at each cycle. After each loading, the specimens were stress relaxed for 30 seconds at the base value of 0.2 N. Photographs were taken before testing and right after failure occurred.

Data

Data were collected and analyzed using TestXpert® II V3.1 software. Load of first failure and ultimate failure were recorded in graphs (Figure 3). First failure was defined as the first negative inflection on the repair but it is still able to regain maximum strength. Ultimate failure is the moment in which the repair is unable to regain maximum strength.

Width and height of the tendons and sutures were analyzed and measured on the digital photographs with ImageJ V1.48 (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland).

Statistical analysis was performed using an unpaired *t* test to determine statistical significance between the 2 techniques. This analysis was used for initial and ultimate failure, width and height differences of the tendons and sutures, and the displacement. All calculations had a significance level of $\alpha = 0.05$. The 95% confidence interval indicates the difference in means between both groups.

Results

Both initial failure and ultimate failure were statistically significant, favoring the CW. The average ultimate strength of the PW was 72 N and for the CW 132 N (Figure 4). The statistical significance between the 2 repairs was $P < .001$ (95% CI, 41.5 to 94.4) (Table 1).

Another point of interest was the average gain in width and height of the tendon and the juncture (Table 2). After the operation, the average gain in width for the PW is 43.33%, and for the CW is 53.33%. For the height, this was 118.75% for the PW and 86.36% for the CW. The average total gaining in width and height of a PW repair was 8.3 mm and for CW it was 7.0 mm. This showed a significance of $P = .009$ (95% CI, 0.4 to 2.2) and means that the PW repair is bigger than that of the CW (Table 3).

Figure 4. Box plot of ultimate failure (N) comparing the Pulvertaft repair (technique 1) with the cow-hitch repair (technique 2).

Table 1. Mechanical Testing Results.

Parameter	PW, mean (SD)	CW, mean (SD)	95% CI ^a	P value ^b
Initial failure (N)	68 (19)	118 (34)	-76.8 to -23.6	<.001
Ultimate failure (N)	72 (21)	132 (28)	41.5 to 94.4	<.001
Displacement (mm)	14 (5)	12 (2)	-2.26 to 5.03	.428

Note. Significance level $\alpha = 0.05$. PW = Pulvertaft; CW = cow hitch; CI = confidence interval.

^a95% CI represents the 95% confidence interval for the difference in means between the groups (PW vs CW).

^bBold P values indicate a statistical significance and are obtained by unpaired t tests.

The displacement, defined as gain in total length of the tendon just before ultimate failure occurs, showed no significant difference ($P = .428$).

From the PW group, all repairs had the same mechanism of failure. The extensor tendons were pulled through the suture at the distal end of the junction. This was followed by the extensor tendon vertically translating through the flexor tendon (Figure 5). The CW, however, showed a failure mechanism of suture breakage. This occurred distal of the junction, which then led to longitudinal fiber shearing of the flexor tendon because the extensor tendon was being pulled proximally (Figure 6).

Discussion

This study supports the hypothesis that the CW repair can withstand more load than the PW and has smaller

dimensions. Although there was no significant difference in displacement at subcritical loading, the PW showed rapid displacement after initial failure as the whole length of the extensor tendon translated longitudinally through the incisions. This did not happen for the CW, as the mechanism of failure was suture breakage.

A limitation of this study is that it is an in vitro study and the moment of measurement is at time zero. This means that the effects of the healing process are not included, and the influences of friction and adhesion are unknown. For future research, it is necessary to do an in vivo study to make sure that the effects of the healing process and friction can be included in the results.

It is known that after tendon surgery, long-term immobilization may result in adhesion formation, which will have a negative effect on the rehabilitation and functional outcome

Table 2. Dimensional Measuring Results Obtained by Digital Analysis.

Specimen type and No.	Tendon width (mm)	Suture width (mm)	Tendon height (mm)	Suture height (mm)	Total gain ^a
PW 1	5.5	7.5	4.3	10	7.7
PW 2	5.8	7.8	3.7	9.2	7.5
PW 3	6.2	8.6	4.6	8.8	6.6
PW 4	6.0	8.5	5.1	11	8.4
PW 5	6.2	8.6	5.3	11	8.1
PW 6	6.2	9.7	4.8	11	9.7
PW 7	4.3	7.4	3.5	8.7	8.3
PW 8	7.1	9.5	5.4	12	9.0
PW 9	6.8	9.5	6.5	13	8.7
PW 10	6.3	8.7	4.4	11	9.0
CW 1	5.5	8.6	3.3	6.1	5.9
CW 2	5.0	7.8	3.4	7.3	6.7
CW 3	7.6	11	4.6	9.3	8.1
CW 4	6.0	9.0	4.3	8.3	7.0
CW 5	5.5	7.6	4.1	7.3	5.3
CW 6	6.8	9.6	5.6	8.7	5.9
CW 7	5.4	8.7	4.1	8.4	7.6
CW 8	5.4	9.3	4.1	7.8	7.6
CW 9	7.1	10	4.8	10	8.1
CW 10	6.2	10	5.3	8.6	7.1

Note. PW = Pulvertaft; CW = cow hitch.

^aTotal gain = (suture width – tendon width) + (suture height – tendon height).

Table 3. Average Dimensional Measuring Results.

Parameter (mm)	PW mean	CW mean	95% CI ^a	P value ^b
Tendon width	6.0	6.0	–0.8 to 0.9	.981
Suture width	8.6	9.2	–1.5 to 0.3	.181
Tendon height	4.8	4.4	–0.4 to 1.2	.273
Suture height	10.5	8.2	1.2 to 3.5	<.001
Total gain ^c	8.3	7.0	0.4 to 2.2	.009

Note. Significance level $\alpha = 0.05$. PW = Pulvertaft; CW = cow hitch; CI = confidence interval.

^a95% CI represents the 95% confidence interval for the difference in means between the groups (PW vs CW).

^bBold P values indicate a statistical significance and are obtained by unpaired t tests.

^cTotal gain = (suture width – tendon width) + (suture height – tendon height).

of the patient.¹⁵ Therefore, it is necessary to use a repair method, which has good postoperative strength. To safely commence an early active mobilization protocol, it is necessary for the suture to withstand enough strength. This threshold is somewhere around 74 N,¹³ which means that both the CW (132 N) and PW (72 N) meet this criterion. Forces that approach the limit of suture strength may lead to gapping and ultimately lead to a weaker repair and adhesion formation.⁶ Regarding the fact that rupture is the single major complication following active protocols, several hand surgeons have a “better safe than sorry” attitude. This is understandable, as the postoperative suture strength decreases in

Figure 5. Mechanism of failure of the Pulvertaft.

Note. The extensor tendon pulls through the most distal suture, which then leads to longitudinal translation of the extensor through the incisions.

the first days and the resistance of the surrounding tissue increases, thus increasing the chance for suture failure.¹⁷ For this reason, it is advisable to have a higher safety margin which, in this study, is bigger for the CW.

The CW weave was easier and more convenient to perform than the PW. Instead of making 3 incisions and pulling

Figure 6. Mechanism of failure of the cow hitch.

Note. Suture breakage occurs distal of the junction, which then leads to fiber shearing of the flexor tendon.

the extensor through them, only 1 incision was needed for the CW. Furthermore, the PW required 8 sutures, whereas the CW needed only 5. Furthermore, it was observed that it took the author about 10 minutes less to perform a CW. Unfortunately, the operation time was not exactly quantified, as this matter was not our primary research goal.

Within the last 2 decades, the PW has been subjected to several comparisons with other techniques, showing that many other weaves have the same, or even better, biomechanical properties than the PW. However, despite showing improvements to the limitations of the PW, these techniques do have their own disadvantages.

For example, there is the spiral linking technique. Results show that by using 2 spirals with 6 sutures, the repair is at least as strong and stiff as a 4-weave PW technique. Furthermore, it was easier to perform, and it was less bulky.^{10,11} The spiral linking technique does however solely rely on the sutures made to hold both twisted tendons together instead of on the strength of the tendon itself.¹

There is also the lasso weave, which is more convenient to perform and needs less tendon length to perform a repair than the PW. Concerning force measurements, both weaves are similar. Nevertheless, the lasso weave is at a disadvantage, because it is a thick weave, which means it is not usable in space-restricted areas such as zone II injuries.¹ In the same article, they also tested the side-by-side repair, but it had a significantly lower maximum load, showing it to be inferior to the PW.

Another technique, the wraparound tendon repair, was developed in an attempt to offset the bulkiness of the PW. Tests were conducted with different formations of PW, namely 2, 3, or 4 weaves. It showed that only the formation of the PW with 4 weaves could match the wraparound's strength. There was, however, no significant difference between thickness of the repairs.⁵

Another version of the side-to-side repair was developed, where 1 incision was made and a tendon was woven

through and fixated with 8 cross-stitches. A significant difference was found between the PW and side-to-side repairs regarding ultimate strength, favoring the side-to-side repair. There was no difference, however, in cross-sectional area between both techniques.²

The double-loop technique also had a significant difference when compared with the PW regarding ultimate strength. Regrettably, it too is at a disadvantage in that the repair looks like a knot making it bulky, and thus creating greater friction with surrounding tissues.⁴

Unfortunately it is difficult to properly compare the weaves described above, because different tendon material has been used (human cadaver, porcine, sheep), storage methods are different (tendons are frozen prior to testing or tendons are stored in a fridge and tested soon after dissection), and different suture material has been used (3-0 Ethilon [Ethicon, Johnson & Johnson, Amersfoort, Netherlands], 4-0 Ticron [Covidien, Mansfield, Massachusetts], 4-0 Prolene [Ethicon Endo-Surgery Europe GmbH, Germany]). Regardless, they all come to the same conclusion, namely, that there are limitations to the PW and that there are different techniques available, which can improve these limitations and provide a better weave than the PW.

For the implementation of the CW into clinical practice, it is necessary to think how to attach the 2 free ends that remain, after the suture has been made. At our center, a follow-up study is now being conducted in which we try 2 different methods for attaching the 2 free ends; this will be either a double wraparound or a double side-to-side technique. Thus our next study will further explore this issue.

The CW shows potential and proves in this in vitro study to possess all of the necessary characteristics to be a strong, slim, and stable repair. In conclusion, the PW has proven to be a reliable weave for tendon repair, but as research has, and is progressing, a new focus should be given towards researching stronger and sleeker weaves, such as the CW. Our next step is testing the CW in an in vivo setting.

Acknowledgments

Thank you, Zuzka Augusta Gazdik, for the voluntarily grammatical corrections and writing assistance. Thank you, Todor Krastev, for the drawings of our techniques.

Ethical Approval

Tests were conducted on animal waste material; thus, the Animal Ethical Commission Maastricht declared no ethical conflict in conducting this experiment.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

Informed consent was obtained when necessary.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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