

## DOUBLE WHIP STITCH FOR FREE GRAFT FEMORAL FIXATION IN ACL RECONSTRUCTION: EXPERIMENTAL STUDY ON PORCINE MODEL

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### Abstract

**Background and aims.** Using free quadriceps tendon graft for anterior cruciate ligament (ACL) reconstruction has become more popular in the last years due to the low morbidity at the harvest site and biomechanical and structural properties similar to other types of graft (hamstring and patellar tendons). As long as the tibial tunnel fixation with interference screws is considered the standard fixation, femoral fixation is still an open subject. Even though the most common type of femoral tunnel fixation are the cortical suspension devices, the type of suture used for tying the graft to the loop is still evaluated and discussed. We aimed to evaluate the resistance and elongation of a double whip stitch used for tying a tendon to the loop of a cortical suspension device.

**Method.** We used 10 porcine flexor digitorum profundus as free graft for a graft-suture-cortical suspension device construct using the double whip stitch. The total length of the construct and tendon length were recorded before and after the test was performed. Tensioning curves, total construct elongation and maximum tension at breaking point were electronically recorded on the testing device's software. The mean values and coefficient of variance were assessed.

**Results.** We noted the breaking of the suture wire where the wires passed through the loop of the cortical suspension device as final point for all tests. The mean of maximum load was 505.68N (Max=639.38 N; min=358.93 N; SD=82.88078 N) and the mean of total construct elongation was 39.54784mm (Max= 48.60466 mm; min=31.74853 mm; SD=4.85371 mm).

**Conclusion.** With some minor improvement in technique and graft preconditioning and pretensioning, the double whip stitch can be used in connecting a free tendon to a cortical suspension device.

**Keywords:** anterior cruciate ligament reconstruction, free quadriceps graft, porcine model, double whip stitch

### Background

Using quadriceps tendon graft for ACL reconstruction has become more popular in the last years due to the low morbidity at the harvest site and

biomechanical and structural properties similar to other types of graft (hamstring and patellar tendons) [1,2]. However, harvesting a quadriceps tendon with a patellar bone plug can be associated with chronic anterior knee pain resulting in less satisfactory clinical outcome [3]. The use of a free quadriceps tendon harvested from the median portion with a clean cut at the superior patellar pole has

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even less donor site morbidity, with a satisfactory length and width for an ACL reconstruction graft [4,5]. However, as long as the tibial tunnel fixation with interference screws is considered the standard fixation, femoral fixation is still an open subject. Even though the most common type of femoral tunnel fixation are the cortical suspension devices, the type of suture used for tying the graft to the loop is still evaluated and discussed.

### Aim

To evaluate the resistance and elongation of a double whip stitch used for tying a tendon to the loop of a cortical suspension device.

### Material and method

We used 10 fresh-frozen porcine hind legs from 2 year old Great White specimens provided by a local abattoir. The flexor digitorum profundus was harvested, keeping the proximal sesamoid bone for better fixation (Figure 1). During the experiment the tendons were kept in 0.9% saline to avoid excessive drying and all the tendons were used on the same day they were harvested.

At the free end of the tendon we applied the double whip stitch with No 2 Hi-Fi® suture (CONMED, Utica, NY, SUA). We used one suture for a tendon by cutting the suture into two equal length parts. To avoid shearing, entry point was at 5 mm from the tendon end on one longitudinal half

of the tendon, then 4 loops were done over 30 mm and then another 4 loops back (Figure 2). Same construct was done on the other longitudinal half, with care for not using the same entry points to avoid tendon weakening or shearing. With the 4 free sutures obtained manual pretensioning was done, then sutures were passed and crossed through the loop of the XO Button® (CONMED, Utica, NY, SUA). Sutures were then double-crossed around the loop and tied again with 3 alternative simple knots.

This construct was then fixed in the testing device INSTRON 2716-015 (Illinois Tool Works Inc., 825 University Ave, Norwood, MA, US) with the use of the inbuilt wedge clamps. The tendon end with the sesamoid bone was fixed in the inferior clamp and the metallic button of the XO Button® was fixed in the superior clamp. The test protocol was established to 10 mm/minute constant traction, humidity was 50% and environment temperature was 18°C. The total length of the construct and tendon length were recorded before and after the test was performed, using a liner and digital photo camera (Figure 3). Video recordings of all 10 tests were made. We considered the end of the test the breaking of any of the suture wires, the tendon or the suspensory loop device or the slipping of any of the ends of the construct from the clamps of the testing device. Tensioning curves, total construct elongation and maximum tension at breaking point were electronically recorded on the testing device's software.



**Figure 1.** Porcine flexor digitorum profundus with sesamoid bone preserved.



**Figure 2.** Prepared tendon graft with Hi-Fi® suture.



**Figure 3.** Construct fixed in testing device and measurements taken.

## Results

We noted the breaking of the suture wire as final point for all tests. In 8 cases the breaking occurred in 2 wires at once and in the other 2 cases 3 wires broke (Figure 4). The breaking point was where the wires passed through the loop of the cortical suspension device. We recorded the tensioning curves of all samples (Figure 5).

We recorded a mean of 505.68 N for maximum load (Max=639.38 N; min=358.93 N; SD=82.88078 N) with a coefficient of variation of 16.38981. We also recorded a mean of 39.54784mm for extension at maximum load (Max= 48.60466 mm; min=31.74853 mm; SD=4.85371

mm) with a coefficient of variation of 12.273 (Table I).

Pure tendon elongation during tests was 5 mm for all specimens (Table II). The cortical suspension device however showed no signs of slipping or extension of the loop. Also no slipping was noted at the inferior clamp fixing the tendon.

In two specimens we noted a slipping of the first suture loop due to tendon shearing, recorded as an abrupt fall on the tension/extension curve (for specimens No.4 and No.6), which resulted in the lowest maximum load recorded (358.93 N) and longest extension recorded (48.6 mm), respectively.

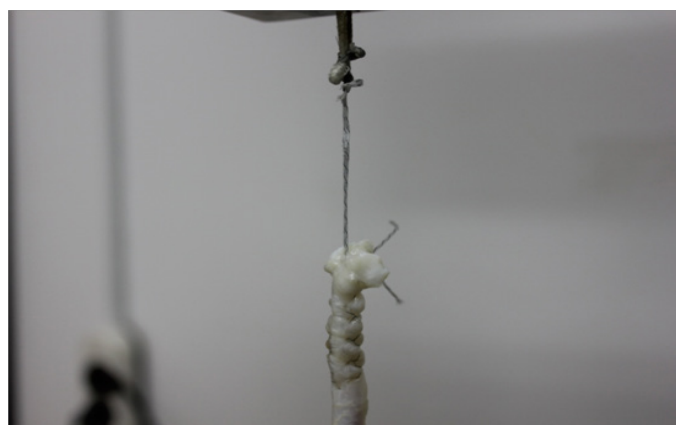


Figure 4. Maximum load breaking of the suture wires.

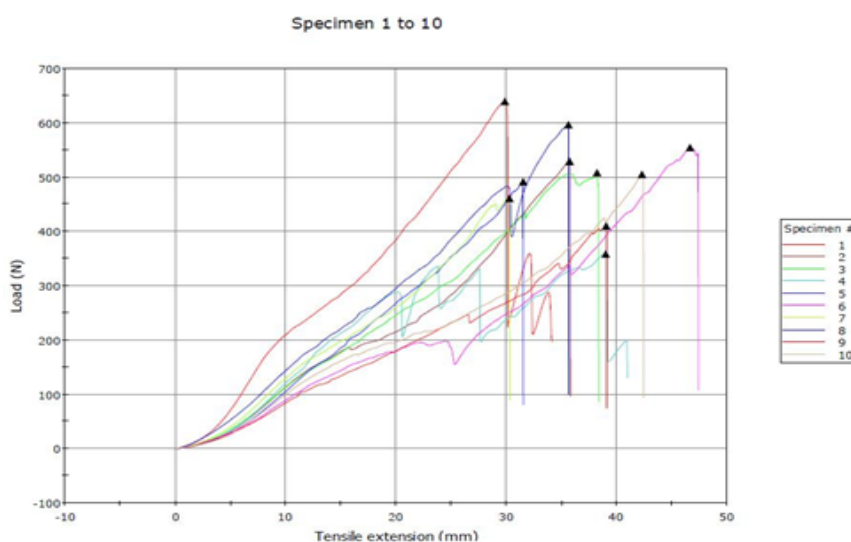


Figure 5. Elongation curves of samples according to tensile load and maximum load failure.

**Table I.** Maximum load, extension at maximum load and statistical analysis.

	Specimen Label	Maximum Load (N)	Extension at Maximum Load (mm)
	T_1	639.38	31.74853
	T_2	529.34	38.33060
	T_3	508.54	40.39202
	T_4	358.93	41.18263
	T_5	491.83	37.29122
	T_6	554.70	48.60466
	T_7	461.51	34.01135
	T_8	596.61	38.30867
	T_9	410.66	41.09939
	T_10	505.37	44.50931
Coefficient of Variation		16.38981	12.27300
Maximum		639.38	48.60466
Mean		505.68	39.54784
Median		506.95	39.36131
Minimum		358.93	31.74853
Range		280.45	16.85613
Standard Deviation		82.88078	4.85371
Mean + 1SD		588.57	44.40154
Mean – 1SD		422.80	34.69413

**Table II.** Initial and final lengths of tendon and total construct and elongation at maximum load.

No.	Initial tend length (mm)	Final tend length (mm)	Initial total construct length (mm)	Final total construct length (mm)	Tendon elongation (mm)	Total construct elongation (mm)
1	125	130	160	191	5	31
2	135	140	170	208	5	38
3	145	150	180	220	5	40
4	110	115	145	186	5	41
5	125	130	160	197	5	37
6	125	130	160	208	5	48
7	135	140	170	204	5	34
8	145	150	180	218	5	38
9	140	145	175	216	5	41
10	135	140	170	214	5	44

## Discussion

The goal of this experimental study was to evaluate the resistance and elongation of a construct made of free tendon tied with a double whip stitch to a cortical suspension device. This construct is mainly used in ACL reconstruction surgery. In order to obtain a good biomechanical and clinical result, the graft fixation inside the femoral tunnel must be strong enough to permit early rehabilitation, when the graft is not yet integrated in the bone tunnel. Improvement of the femoral tunnel fixation method is hence necessary to prevent early mechanical complication: graft slippage or fixation device failure.

The XO Button® is in the group of fixed loop cortical

suspension devices, which are the most used currently, with high resistance and effectiveness proven in experimental laboratory studies and clinical trials [6]. The Hi-Fi® suture is used in tendon related surgeries and ACL reconstruction as one of the strongest suture wire on the market (141.89N with USP Knot Pull Test).

We have chosen the porcine model for better availability than human cadaveric model and also for the structural and biomechanical properties very close to human tendons [7,8]. There were no significant differences between length and size of the tendons, thus being suitable for experimental reproducibility.

The double whip stitch, simple or modified, is used

in tenorrhaphy or tendon to bone reinsertion. Other sutures for the same purpose are the Krakow suture, the Speed Whip or the Chinese finger-trap suture. Studies have shown that there is no significant difference between modified Krakow and modified Speed Whip concerning cyclic load and maximum load [9]. We found no studies comparing the double whip stitch with any of the other type of tendon suture mentioned.

In our study, the failure of the construct occurred at more than 400N (except for one case, specimen No. 4) (Figure 1). Most recommended rehabilitation protocols after ACL reconstruction submit the neo-ligament to forces between 150 and 400N in the first 3 months, under the breaking limit of the construct tested in this study [10]. The breaking occurred at the suture wires as expected because this was the weakest material in our construct. Flexor digitorum profundus tendon in porcine model is comparable in terms of elongation with human tendons, but it has lower tension breaking point [7]. However in our study the maximum loads did not get near the porcine tendon breaking point (around 1100N). The XO Button® has one of the highest tension breaking point among cortical suspension devices (over 1700N) [6]. Also by fixing the button in the superior wedged clamp we noted no displacement at this level.

The elongation of the construct was over 30 mm, which is not considered acceptable for ACL reconstruction. However, we mentioned that the constructs were pretensioned only by hand for a few seconds, without any specific device for that purpose. During ACL reconstruction surgery it is common for the prepared graft to withstand pretensioning and preconditioning to 80 to 90 N for 5 to 10 minutes, which creates more residual tension in the graft construct, resulting in lesser elongation. There is still no consensus in the literature over the protocol for preparing the graft before fixation in the bone tunnels [11]. In our study, all samples sustained between 5 and 12 mm of elongation during the pull to 100N. Thorough preparation of the graft construct could reduce the total elongation at breaking point.

Shearing of tendon at the suture end occurred in 2 cases, which can be explained by different biomechanical properties and resistance among samples and also by the distance between the end of the tendon and first loop execution (5 mm). Other studies used similar suture type with first loop executed at 10mm from tendon end [9]. It is possible to obtain better loop security at free tendon end by observing the 10 mm distance when the construct is submitted at high loads.

We also noted no slippage of the graft in the inferior wedge clamp; this probably happened due to the sesamoid bone which allowed more compression when locking the clamp without tendon shearing.

## Conclusion

With some minor improvement in technique and graft preconditioning and pretensioning, the double whip stitch can be used in connecting a free tendon to a cortical suspension device.

## Limitations

We admit the limitations of the study concerning the manual pretensioning and the high elongation rates obtained. The limits have been analyzed in the discussion section. Further studies with a more strict protocol should be conducted in order to establish the clinical importance of this method.

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