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# Effect of suturing the femoral portion of a four-strand graft during an ACL reconstruction

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**Abstract**

*Purpose* A suture passed along the part of the graft that will be inserted into the femoral tunnel is widely used by surgeons, because it could prevent the graft sliding on the femoral fixation device during pulling from the tibial side. The aim of this study was to evaluate the biomechanical effects of suturing the intratunnel femoral part of the graft during an anterior cruciate ligament (ACL) reconstruction.

*Methods* Bovine digital extensor tendons and tibias were harvested from 20 fresh-frozen mature bovine knees ranging in age from 18 to 24 months. Quadruple-strand bovine tendons were passed through the tibial tunnel and secured distally with a bioabsorbable interference screw. In one half of all grafts ($N = 10$), the looped-over part of the graft was sutured in a whipstitch technique over a distance of 30 mm (Group 1). In one half of all grafts ($N = 10$), the looped-over part was left free from any suture (Group 2). The grafts were preconditioned at 50 N for 10 min, followed by cyclic loading at 1 Hz between 50 N and 250 N for 1,000 cycles. Load-to-failure test was then carried out at a rate of 1 mm/s.

*Results* There was no statistically significant difference between mean stiffness at pullout and yield load between the two groups. In all specimens on Group 1, failure occurred following to partial breaking and then slipping of the tendons between the screw and the tunnel. Concerning Group 2, in six cases failure occurred as described for Group 1 specimens. In the remaining four cases, failure occurred entirely through the ligament mid-substance.

*Conclusions* Suturing in a whipstitch fashion the femoral portion of the graft doesn't affect the mechanical proprieties of the ACL graft. When suspension fixation device is used, suturing the looped-over part of the graft could be helpful in order to provide equal tension in all of the strands of the graft at time of tibial fixation.

**Keywords** Anterior cruciate ligament · ACL reconstruction · Graft properties · Biomechanics · ACL graft

## Introduction

Anterior cruciate ligament (ACL) reconstruction has become one of the most common surgeries performed by orthopedic surgeons. During the last 10 years, ACL reconstruction with the looped four-strand hamstring tendon graft has gained popularity because of the adequate strength of a multi-strand graft, low donor-site morbidity avoiding extensor mechanism problems associated with patellar tendon harvest [16, 31].

During ACL reconstructive surgery the free ends of the tendon are usually sutured in a whipstitch fashion [7]. This procedure helps the surgeon to handle the graft during the tibial fixation and to assure graft tension while driving the screw avoiding its loosening and obtaining an equal tension among all graft strands [2, 7]. Furthermore, it has been observed that whipstitch sutures on a multistrand ACL graft within the bone tunnel can significantly increase graft fixation strength, probably due to engagement of the threads of the interference screw with the suture [5, 7, 27].

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On the other hand, suturing the hamstring tendon graft in a whipstitch fashion could lead to a permanent viscoplastic elongation of the graft due to slippage of the suture within the tendon tissue [18, 22].

Whipstitching tendon ends is often accompanied by a suture of the femoral side of the graft when suspensory femoral fixation is used [23, 26]. This procedure could prevent the graft sliding on the femoral fixation device during pulling from the tibial side [1, 26]. In fact, during the tibial fixation if a strand loses tension, the corresponding contralateral strand could lose tension too because of femoral graft sliding. This could affect the distribution of tension in all strands of the graft and consequently the final surgical outcome [4, 14, 15, 27]. Furthermore, it is also possible that a whipstitched portion of the quadrupled graft might exhibit a different intrinsic stiffness rather than a free quadruple bundle [21]. In adding tension, under cyclic loads, a shredding of the tendon at the interface of the first suture could be observed, compromising the success of surgery during the ACL reconstruction [21]. To our knowledge, no study has addressed the potentials of whipstitching the femoral part of the graft to distribute more evenly the load and to stiffen or weaken the overall graft response.

The aim of this study was to evaluate the biomechanical effects of a suture passed along the proximal third of the graft during an ACL reconstruction with semitendinosus and gracilis. The authors hypothesized that suturing the four strands of the femoral side of the graft could influence the mechanical graft behavior, increasing the initial stiffness of the construct but weakening the graft during cyclic load.

## Materials and methods

For the study, bovine digital extensor tendons and tibias were harvested from 20 fresh-frozen mature bovine knees ranging in age from 18 to 24 months. Bovine graft choice was based on their immediate availability and low-cost. Furthermore, bovine tibias have been used in previous work on ACL fixation with results that are not significantly different from those found with young human bone [6, 11, 34]. Similarly, bovine common digital extensor tendon present viscoelastic and structural properties comparable to a graft composed of a double loop of semitendinosus and gracilis tendons from humans [11]. Each bovine tibia was scanned by dual energy X-ray absorptiometry (General Electric Lunar Prodigy, Madison, Wisconsin). In order to eliminate the influence of bone mineral density (BMD) [g/cm$^2$] on graft fixation strength, tibias with similar BMD were selected for the study.

### Graft preparation and fixation

Bovine digital extensor tendons were harvested from each tibia and all of the soft tissue attached to the proximal tibia was removed.

As per standard intra-operative technique, tendon grafts were prepared and sized to have a cylinder multistrand diameter of 8 mm and a length of almost 24 cm. Each end of the tendon was separately whipstitched with no. 2 Ticron sutures (Tyco, Waltham, MA) for a length of 40 mm which corresponded to the length of tibial bone tunnel used for testing. All tendon grafts were immediately wrapped in a normal saline soaked cloth, stored at −20 °C and then thawed at room temperature 12 h before use. Continuous saline graft irrigation was performed throughout the preparation and mechanical testing to prevent drying.

The tibial diaphysis was cut 15 cm distal to the tibial plateau and then placed inside a cylindrical plastic potting subsequently filled with epoxy resin. Two screws were previously fixed into the distal tibia to enhance static fixation between epoxy resin and bone. On each specimen a 9 mm ACL tibial tunnel was reamed, creating a tunnel with a length of 40 mm.

The tibial specimens were fixed into a custom-designed rig fixture bolted to an electro-mechanic universal testing machine (Instron 3367), equipped with a 30 kN load cell (Instron Systems, Norwood, Massachusetts). The rig arms had several allowable degrees of freedom helping to direct the tibia so that the tibial tunnel was vertical and on the loading axis of the test machine, providing the least favorable path of resistance during testing. This allowed for testing in the worst-case scenario with direct, in-line force on the graft.

The quadruple-strand bovine tendon graft was looped around a 5 mm cylindrical metal rod connected directly to the load cell through a clevis like an adapter [35]. The method of pulling on the graft loops with a cylindrical rod was used in order to eliminate any fixation slippage that may have occurred in a femoral bone attachment [8].

The four limbs of the graft were then passed through the tibial tunnel and secured distally with a 9 × 28 Delta bioabsorbable interference screw (Arthrex, Inc) inserted concentrically between individual graft strands, applying an equal tension on each limb of the graft (Fig. 1) [17, 30]. Graft fixation was performed so that the distance from the entrance of the bone tunnel to the rod was 70 mm, in order to simulate the intra-articular space of the ACL (30 mm) and femoral tunnel length (40 mm) that could be obtained with more recent femoral fixation device, such as ACL TightRope and ToogleLoc with ZipLoop.

In one half of all grafts ($N = 10$), the looped-over part of the graft was sutured in a whipstitch technique over a distance of 30 mm (Ticron, No. 2, Tyco) leaving 30 mm

**Fig. 1** Illustration showing the experimental setup. The tibial tunnel was aligned with line of force application

which corresponded to the length of the intra-articular graft (Group 1). In this step, care was taken to pass each stitch through each graft strand. In one half of all grafts ($N = 10$), the looped-over part was left free from any suture (Group 2) (Fig. 2). The suture was passed when the graft was under a slight tensile load, immediately after graft tibial fixation. This was performed in order to avoid permanent graft elongation that may affect the graft during cyclic loading, due to the slippage of the suture over the tendon tissue that could occur during load [21, 22].

## Biomechanical testing

All tests were performed using an Instron 3367 electromechanic material-testing machine. By means of the "Test Profiler" option available in the Bluehill software, it was possible to apply a loading protocol which comprised three successive stages:

1. static pre-conditioning by keeping the tendon at a stable tensile load of 50 N for 10 min (kept constant by operating the machine in loading control);
2. fatigue cycling by applying a triangle wave fatigue cycle, between 50 and 250 N, at 1 Hz for 1,000 cycles (the loading cycle limits were kept stable by operating the machine in load control);
3. final monotonic tensile loading up to failure performed in displacement control at a machine crosshead speed of 1 mm/s, in order to maintain the control of the test at the onset of failure.

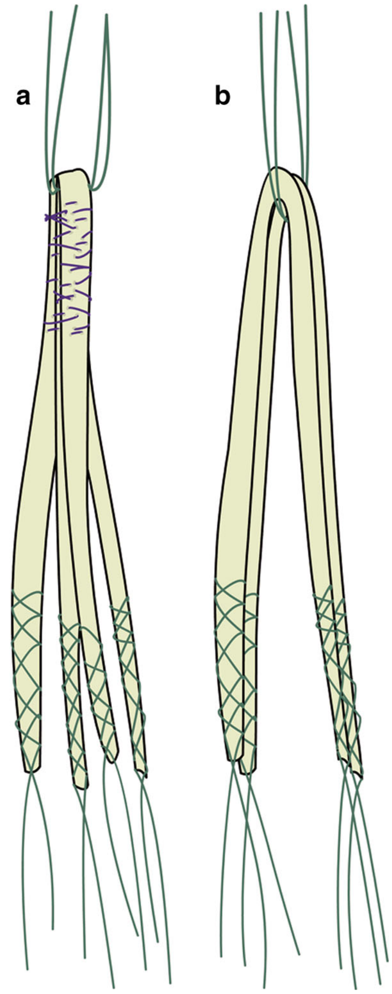


**Fig. 2** Illustration showing two graft constructs tested. Group 1: the looped-over part of the graft was sutured in a whipstitch technique over a distance of 30 mm (**a**). Group 2: the looped-over part was left free from any suture (**b**)

The preconditioning stage was performed in order to stabilize grafts' mechanical properties, while the fatigue loading parameters were chosen after a literature survey aimed at identifying the most typical benchmark conditions for this kind of analysis [19, 24, 35]. Specifically, loads between 50 and 250 N simulate previously measured forces in the ACL during passive extension of the knee [24], while a frequency of 1 Hz simulates the reported frequency of walking [19]. The number of 1,000 cycles was chosen to simulate an aggressive rehabilitation protocol of knee flexion–extension [8]. The final monotonic stage, immediately following the cyclic testing, allowed the evaluation of the residual static strength through the evaluation of the ultimate failure. The amount of graft displacement in response to cyclic loading and load to

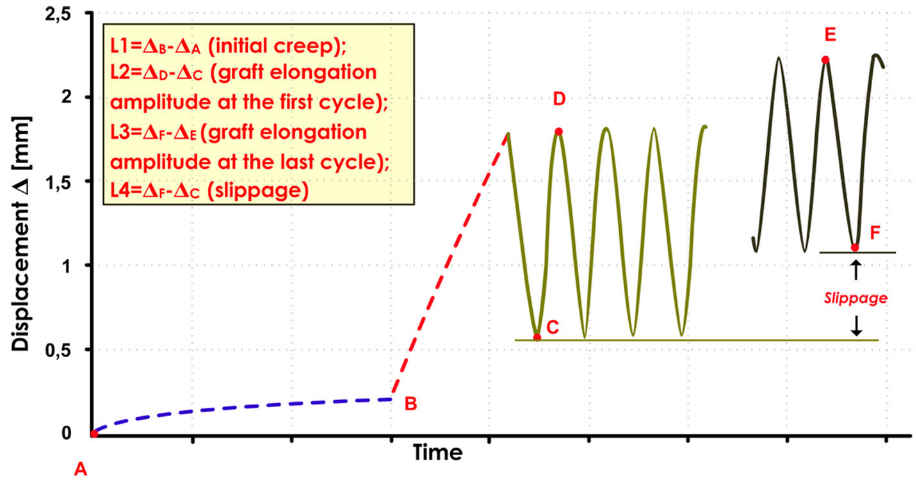


**Fig. 3** Displacement versus time plot

failure was obtained from the testing machine crosshead movement. The firmness of the tibias during mechanical testing was confirmed in four specimens using a linear variable differential transformer directly connected to the electro-mechanic testing machine.

For each specimen, load–displacement curves were recorded and analyzed to determine *cyclic stiffness* [K1] (the slope of the secant line joining minimum and maximum points of the loading phase of the load deformation curve reported from the 500th cycle), *pull-out stiffness* [K2] (the initial slope of the final monotonic load-elongation curve corresponding to the steepest straight-line tangent to the curve), *ultimate failure load* [Fr] (the peak force of the final load–elongation curve), *graft slippage* [L4] (the difference of graft displacement between the last and the first cycle valleys of the cyclic loading). Furthermore, difference between peak-to-peak displacement at the first and last cycle [L2–L3] was calculated (Fig. 3). The mechanism of final static failure for each test was also observed and recorded.

Statistical analysis

Data were analyzed using SPSS statistical software, version 11.0 (SPSS, Inc., Chicago, IL, USA). Grafts tensile properties between two groups were analyzed using a paired Student's $t$ test with a level of significance at $\alpha = 0.05$ and a statistical power of $\beta = 0.80$.

## Results

All specimens in each group were successfully tested and characterized. In all specimens on Group 1 (suture group), failure occurred following to partial breaking and then slipping of the tendons between the screw and the tunnel. Concerning Group 2 (no suture group), in six cases failure occurred as described for Group 1 specimens. In the remaining four cases, failure occurred entirely through the ligament mid-substance. No noticeable displacement of the screw was observed in all cases.

**Table 1** Mechanical properties of sutured and nonsutured grafts at cyclic loads and ultimate failure load

| | Group 1 (suture group) | Group 2 (no suture group) |
|---|---|---|
| Ultimate failure load Fr (N) | 782.2 ± 264.2 | 754.8 ± 142.2 |
| Cyclic stiffness K1 (N/mm) | 121.1 ± 16.7 | 113.9 ± 22.6 |
| Pull-out stiffness K2 (N/mm) | 116.0 ± 18.6 | 104.2 ± 20.7 |
| Slippage L4 (mm) | 0.76 ± 0.20 | 0.82 ± 0.25 |
| Graft elongation amplitude L2–L3 (mm) | 0.05 ± 0.03 | 0.09 ± 0.04 |

Data are presented as mean ± SD. There were no significant differences between the two groups

The mean stiffness at pullout [K2] was 116.0 ± 18.6 N/mm for the Group 1 (suture group) and 104.2 ± 20.7 N/mm for the Group 2 (no suture group), and this difference was not statistically significant (n.s.). Similarly, there was no statistical difference in cyclic stiffness [K1] among Group 1 and Group 2 (respectively 121.1 ± 16.7 N/mm and 113.9 ± 22.6 N/mm, n.s.). The ultimate failure load [Fr] was 782.2 ± 264.2 N for Group 1 and 754.8 ± 142.2 N for Group 2 (n.s.). In addition, no significant differences were found concerning slippage [L4] and peak-to-peak displacement (L2–L3) between two groups. Results are shown in Table 1.

## Discussion

The most important finding of the present study was that in a bovine model without femoral fixation, suturing the intratunnel femoral part of a double-looped graft according to a whipstitching technique does not affect the graft stiffness. Furthermore, no differences were observed between sutured and nonsutured grafts at cyclic loads and ultimate failure load.

Despite several biomechanical studies that improved the knowledge of ACL anatomy and reconstruction, controversy still exists regarding which graft construct gives better clinical results [3, 10]. Currently, the graft behavior is still not completely clear; additionally, a widely used procedure such as suturing the hamstring tendon graft in a whipstitch fashion could influence the strength, stiffness and elongation of a graft construct [12]. This could be assessed on the basis of several variables such as strength and size of the suture, quality of the tissue, and suturing technique [12, 21, 28, 32]. In addition, suturing the looped-over part of the graft is commonly performed by orthopaedic surgeons in order to allow a more even tensioning and load sharing between all four limbs of the graft at the time of tibial fixation [23, 26]. In fact, is well-known that a uniform distribution of forces could provide augmented mechanical characteristics of the reconstruction, possibly improving graft longevity and effectiveness [2, 16]. To our knowledge, only one study addressed the biomechanical properties of sutured and nonsutured grafts [9]. Using the femoral cross-pin fixation technique, it was observed that suturing the looped-over portion of a quadruple tendon graft provides superior initial fixation strength. This is probable due to the mechanical engagement of the cross-pins with suture material, creating a secondary support against graft slippage under tensile loading [9]. In the present study, the authors wanted to evaluate the effect of suturing the looped-over portion of a soft tissue graft using a femoral suspension fixation device. We found that no effective biomechanical disadvantages were noted suturing together the four strands of the graft along its proximal portion. In adding tension, any weakening of the graft during cyclic load was noted. For this reason whipstitching the looped-over part of the graft should be preferable in order to prevent the graft sliding on the femoral suspension fixation device. In fact, if a single strand presents an altered tension, graft sliding on the femoral fixation device could produce a global loss of tension along both the strands.

Furthermore, because tendon grafts used in ACL reconstruction have viscoelastic behavior, with a suspension femoral fixation, the intra-articular and intratunnel femoral portions of the graft may relax and elongate postoperatively. Increasing graft stiffness, the intratunnel graft motion could be reduced allowing faster osseous incorporation with the development of a direct tendon-to-bone insertion [13].

As the graft structure stiffness is inversely proportional to the length of the graft, shorter grafts are preferable to better mimic the mechanical behavior of the intact ACL [20, 29]. In this study, the authors hypothesized that suturing the tendons on both tibial and femoral graft sides could increase the initial graft stiffness, probably due to a shorter free graft. In fact, a whipstitched portion of the quadrupled graft might exhibit a different intrinsic stiffness rather than a free quadruple bundle. The relationship between different tensile elements in series such as a free tendon and a sutured tendon can be studied by using the analogy of two springs in series under tension. A simplistic linear model can be used to get first order predictions of the overall stiffness of a number of structural elements in series (i.e. the spring series model [33]. If $K_i$ is the stiffness of the $i$th element, expressing the linear relationship between applied force $F$ and its elongation in the force direction $u_i$, then the system total stiffness is given by:

$$K = \left( \sum_{i=1}^{n} \frac{1}{K_i} \right)^{-1} = \left( \frac{1}{K_1} + \cdots + \frac{1}{K_i} + \cdots + \frac{1}{K_n} \right)^{-1} \quad (1)$$

From Eq. (1) it is easily observed that if there is a number of $n$ elements of equal stiffness $K_i = k$, then the total stiffness is $K = k/n$; if though just one element of the series has a higher stiffness then $K > k/n$. Considering the intra-articular graft and the femoral intratunnel graft, if a part of it is stitched, and the stitching is able to stiffen the graft locally, the overall stiffness of the graft will then be higher. Even these theoretical assumptions are obviously valid, on our experiment set up substantial mechanical differences were not found between sutured and unsutured graft groups. Probably this could be justified by the small role that the stiffness of the graft has to increase the entire stiffness of the ligament replacement at the time of implantation [33]. On the basis of the results of the study, it is reasonable to assume that suturing in a whipstitch fashion the femoral portion of the graft doesn't affect the mechanical proprieties of the ACL graft. For this reason, the authors suggest to suturing the graft in order to obtain an equal tension in all of the strands of the graft, improving graft longevity and effectiveness.

There are some limitations in this study. First, bovine tissue was used in place of human bone and tendons. This was performed because of their relatively low cost and wide availability. Furthermore, prior studies have noted its similarities to young human cadaveric bones [6]. Similarly, it was reported that stiffness and viscoelastic behavior between bovine digital extensor tendons and young human hamstring tendons are not significantly different [11]. Therefore, the authors believe that the models used in this study, bovine tendons and tibias, are suitable for biomechanical testing of ACL reconstructive procedures. However, cancellous BMD of the bovine are reported to be greater than the cancellous BMD of the tibia in a young human [25]. This could overestimate fixation values such as strength and stiffness that would be achieved in human bones. Second, an in vitro model without a femoral tunnel was used. Data obtained could be affected by the absence of contact between femoral graft and tunnel and by the tunnel's size and orientation. Therefore, great caution should be taken correlating our results to clinical practice. Additionally, it must be noted that the effective biological effects on the incorporation of the suture material into the bone is not completely investigated.

Despite limitations mentioned above, the findings of this study may help to understand the effects of a suture passed along the graft during an ACL reconstruction with semitendinosus and gracilis. In the clinical setting, the surgeon should be aware that whipstitching the looped-over part of the graft doesn't affect the mechanical graft behavior. For this reason, this procedure could be helpful in order to provide equal tension in all of the strands of the graft at time of tibial fixation.

## Conclusion

In this biomechanical study it was observed that suturing in a whipstitch fashion the femoral portion of the graft doesn't affect the mechanical proprieties of the ACL graft using a bovine model. When suspension fixation device is used, suturing the looped-over part of the graft should be preferred in order to obtain an equal tension in all of the strands of the graft at time of tibial fixation, improving graft longevity and effectiveness of ACL reconstruction.

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