



## Original article

## Mechanical advantage of preserving the hamstring tibial insertion for anterior cruciate ligament reconstruction – A cadaver study

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## ABSTRACT

**Introduction:** The best fixation method for an anterior cruciate ligament (ACL) graft is debated. The tibial fixation of tendon grafts is the principal weak point for mechanical and anatomical reasons. Preserving the tibial insertion for hamstring grafts during ACL reconstruction make provide a mechanical benefit. The aim of this study was to compare the strength at the tibial tunnel of a hamstring graft with intact tibial insertion without a screw, to that of a graft with intact tibial insertion and screw fixation, and to that of a free graft with screw fixation. We hypothesized that preserving the graft's tibial insertion increases the maximum resistance of the tibial fixation relative to a free graft.

**Materials and methods:** Five pairs of knees (10 specimens) from frozen human donors were used. The tendons of the semitendinosus and gracilis were prepared as a four-strand graft while preserving their tibial insertion. The graft was passed through the tibial tunnel using standard instrumentation and the usual landmarks. Three conditions were tested: group 1 – graft with intact tibial insertion without interference screw; group 2 – graft with intact tibial insertion and interference screw; group 3 – knees from group 1 in which the tendons were detached (free graft) after the first test and fixed with an interference screw in the tibial tunnel. The screw diameter was chosen based on the graft diameter. The specimens were tested in traction using a materials testing system (Instron<sup>®</sup> 8500 PLUS) in the axis of the tunnel. The main outcome measure was the maximum load at failure (N). The secondary outcome measure was the stiffness. The groups were compared using the Friedman test and the Nemenyi post-hoc test with a 5% threshold.

**Results:** The load at failure was 33% higher in group 1 than group 3 (89.2 N vs. 67.2 N,  $p > 0.05$ ). The load at failure of group 2 was 25% higher than group 1 (111.2 N vs. 89.2 N,  $p > 0.05$ ) and 65% higher than group 3 (111.2 N vs. 67.2 N  $p = 0.005$ ). There were no differences in stiffness between groups 1 and 2 ( $p = 1$ ).

**Discussion:** Our hypothesis was confirmed—preserving the tibial insertion of hamstring tendons intended for ACL reconstruction increases the maximum load to failure at the tibial tunnel. Under these experimental conditions it seems that adding a screw increases the pullout strength of the graft by +25% in absolute terms; however this difference was not statistically significant.

**Level of evidence:** III, controlled laboratory study.

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## 1. Introduction

Various grafts have been used to reconstruct the anterior cruciate ligament (ACL). Using two hamstring tendons—the semitendinosus (ST) and gracilis (G)—is now standard [1]. Various configurations have been described: simple, double, long graft, short graft, free graft or pedicled graft.

When a tendon graft is used, the tibial fixation is the weak point. This can be attributed to both anatomical and mechanical factors. The density of the cancellous bone at the proximal tibial epiphysis is less than that of the distal femoral epiphysis. The pullout strength of an interference screw is directly related to the bone quality [2]. Moreover, tensile loads are applied to the graft in the axis of the tibial tunnel, contrary to the femur where the tunnel is angled. This explains the most common failure mechanism at the tibia when the fixation involves an interference screw—sliding of the tendon graft along the screw [3].

Thus preserving the tibial insertion of the hamstring tendons could have both mechanical and biological advantages. The biological benefit was demonstrated in an animal model; no postoperative avascular necrosis occurred when the STG insertion was preserved [4]. Two studies have confirmed these findings in humans. Zaffagnini et al. [5] showed that the tibial insertion of the STG tendons has copious vascularization and innervation. Ruffili et al. [6] used MRI to compare the ligamentization of hamstring graft tibial insertion preservation versus detachment at 6 months postoperative. The ligamentization scores were significantly better in the group with an intact tibial insertion [7].

The mechanical benefit consists of higher load to failure and pullout strength when the tibial insertion of the STG graft remains intact. Improving the primary fixation of the graft allows rehabilitation to start earlier. To our knowledge, no study has evaluated this aspect.

The aim of our study was to evaluate the mechanical advantage that could result from preserving the tibial insertion of a hamstring graft. We carried out a biomechanical study with cadaver specimens to compare the tibial pullout strength “of a hamstring tendon with intact tibial insertion without screw” to that “of a hamstring tendon with intact tibial insertion fixed by an interference screw” and to that “of a free hamstring graft fixed with an interference screw”. The main outcome measure was the maximum load at failure of the graft’s tibial fixation. The secondary outcome measure was the stiffness. We hypothesized that preserving the graft’s tibial insertion increases the resistance to rupture of the tibial fixation.

## 2. Material and methods

### 2.1. Study design

This cadaver study was performed at the GEBOAS-ICube Biomechanics Laboratory of the Institute of Anatomy of Strasbourg. Five pairs of fresh-frozen cadaver legs (10 knees) were used. The donors were three men and two women with a mean age of 78 years (66–89 years). The specimens were stored at  $-20^{\circ}$ , which does not alter the mechanical properties of the tissues [8,9]. The cadaver legs were cut at the junction of the proximal and middle third of the thigh and at the junction of the middle and distal third of the lower leg. None of the knee had visible incisions (no history of knee surgery), ligament damage and osteoarthritis [10].

The specimens were prepared after being thawed for at least 12 hours at room temperature ( $21^{\circ}\text{C}$ ) [9]. The ST and G tendons were harvested with a stripper, after extensive dissection. They were left attached to their tibial insertion, folded over to make a four-strand construct, then shaped into a tube by placing sutures



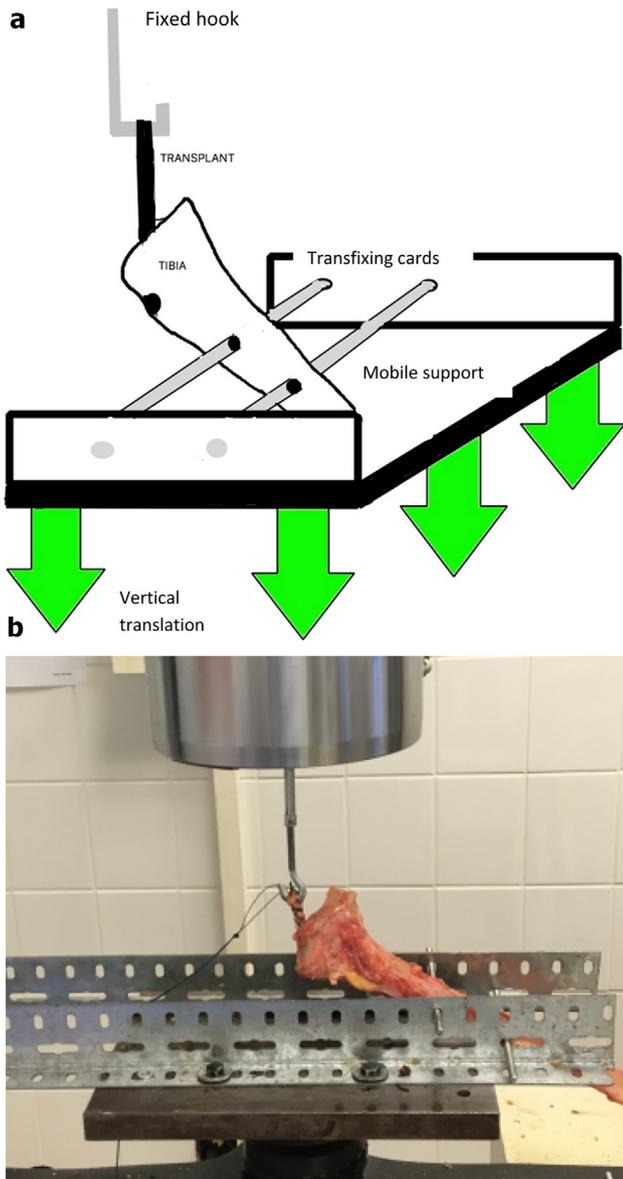
**Fig. 1.** Appearance of a cadaver specimen, immediately before the mechanical testing.

at each end. The graft was calibrated for press-fit using standard instrumentation (Groupe Lépine, Genay, France). Only the tibia and graft were used for the testing. A K-wire was positioned along the desired path of the tibial tunnel, with its intra-articular opening located in the footprint of the native ACL and its extra-articular opening located proximal to the graft’s insertion. The tunnel was made using arthroscopic tibial instrumentation (Groupe Lépine) under visual control using standard arthroscopic landmarks. The size of the tunnel was the same as the diameter of the graft measured previously. The graft was passed through the tibial tunnel using relay sutures. (Fig. 1).

Three groups of five knees were configured randomly from the five pairs of knees. Group 1 ( $n=5$ ) – the graft’s tibial insertion was preserved, without additional screw fixation; group 2 ( $n=5$ ) – the graft’s tibial insertion was preserved and fixed by an interference screw. The knees in groups 1 and 2 were matched. Group 3 ( $n=5$ ) consisted of knees from group 1 – after the traction test was performed on group 1, the graft was detached (free graft). A tibial interference screw was added. Thus in this 3rd group, the graft was free and fixed by screw.

The mean diameter of the grafts (thus the bone tunnels) was 9 mm in each of the three groups (range: 8–10 mm). The mean graft length was 12.5 cm (10.5–15 cm) in groups 1 and 3, and 12 cm (10.5–13.5 cm) in group 2. There were no significant differences between the three groups.

The interference screw used was made from absorbable material (100% poly-L-lactide) (Bioviscon<sup>®</sup> screw, Groupe Lépine<sup>®</sup>). The screw diameter was the same size as the graft diameter and related to the drill bit diameter, which is consistent with current surgical practices. The screw had a conical shape and was 30 mm long.



**Fig. 2.** a: jig used for the traction test; b: final set-up use to determine the load to failure.

## 2.2. Mechanical testing

The testing was carried out on a servohydraulic materials test system (Instron® 8500 plus, Instron, Canton, MA, USA) in uniaxial traction.

The free end of the graft was knotted and attached to a fixed hook. The tibia was secured in three planes using two 6-mm full-length diaphyseal pins to a jig corresponding to the moving portion of the construct (Fig. 2).

Traction was applied in the axis of the tibial tunnel. The load to failure test was initiated by applying a preload (10 N) followed by traction at a constant speed (10 mm/min) until failure, using a standard sequence [9,10].

The load–elongation curve was recorded at 50 Hz. The maximum load at failure (top of the curve) was determined. The failure mode was recorded for all the tests performed: failure of graft, tibial detachment or bone failure. The stiffness was calculated in groups 1 and 2 only. Since the grafts in group 3 had already been subjected to traction once, we did not calculate the stiffness due to a potential methodological bias.



**Fig. 3.** Detachment of the semitendinosus and gracilis tendons.

## 2.3. Statistical analysis

The groups were compared overall using the Friedman test. Pairwise comparisons (group 1 versus group 2, group 1 versus group 3, group 2 versus group 3) were done using the post-hoc Nemenyi test with a 5% threshold.

## 3. Results

All the tests were performed without incident.

In group 1, the failure mode was always tibial detachment of the ST and G tendons (Fig. 3). In group 2, the failure mode was detachment of the graft in all cases then slid along the interference screw inside the tibial tunnel. In group 3, the failure mode was sliding of the graft along the screw inside the tunnel.

The maximum load at failure was  $89.2\text{ N} \pm 31.6$  (49–122 N) in group 1,  $111.2\text{ N} \pm 28.8$  (71–143 N) in group 2 and  $67.2\text{ N} \pm 30.9$  (31–108 N) in group 3. The average load to failure in group 1 was 33% higher than the one in group 3. The average load to failure in group 2 was 25% higher than in group 1 and 65% higher than in group 3. There was a significant difference between groups 2 and 3 ( $p = 0.005$ ), while the differences between groups 1 and 2, and between groups 1 and 3 were not significant (Table 1). There were no difference in stiffness between groups 1 and 2 ( $p = 1$ ) (Table 2).

**Table 1**  
Load to failure in traction (N).

Specimen	Group 1	Group 2	Group 3
1	78	102	46
2	49	71	31
3	76	105	64
4	122	135	87
5	121	143	108
Mean	89.2	111.2	67.2
Standard deviation	31.6	28.8	30.9
<i>p</i> -value	Group 1 versus 2: <i>p</i> > 0.05 Group 1 versus 3: <i>p</i> > 0.05 Group 2 versus 3: <i>p</i> = 0.005		

**Table 2**  
Stiffness (N/mm).

Specimen	Group 1	Group 2
1	3.6	4.0
2	1.7	3.2
3	2.5	4.5
4	6.1	3.4
5	6.2	2.9
Mean	4.0	3.6
Standard deviation	2.1	0.6
<i>p</i> -value	1	

#### 4. Discussion

The main finding of this cadaver study is that preserving the hamstring graft's tibial insertion increases the pullout strength at the tibia with a significant difference between "preserved insertion with screw" and "free graft with screw fixation" ( $p = 0.005$ ), which is proof of the mechanical advantage of keeping the tibial insertion intact. While not statistically significant, the 33% absolute difference between groups 1 and 3 also showed the benefit of preserving the tibial insertion. While not statistically significant, the 25% absolute difference in absolute value between groups 1 and 2 may support the benefit of adding an interference screw to a graft even when the tibial insertion is preserved. We found no difference in stiffness between the grafts in group 1 and 2 ( $p = 1$ ). In group 1, the failure mode was always tibial detachment of the ST and G tendons. In group 2, the failure mode was detachment of the graft in all cases then slid along the interference screw inside the tibial tunnel. In group 3, the failure mode was sliding of the graft along the screw inside the tunnel. Under these experimental conditions, our working hypothesis was confirmed.

Comparisons with published data are difficult as there are few publications on hamstring grafts with the tibial insertion preserved. Most of the studies analyze different fixation methods for the tendon-based grafts and the mechanical properties of the graft itself [11–14]. These publications suggest that double fixation is the best solution, especially for pure tendon grafts, which our data confirms. Adding a bone graft in press-fit combined with a fixation strip [15] or interference screw through the cortex, helps to increase the load to failure and reduce the risk of sliding within the tibial tunnel [3,16–18]. These tests were performed with bovine or porcine bone, without paying attention to preserving the insertion. Another element to consider is the screw itself. Selby et al. [19] showed that the length of the screw was fundamentally important to the graft's fixation. In their study with cadaver tibial bones from young subjects, they reported a pullout strength ranging from 594 N to 824 N depending on the screw length. All samples failed the same way: sliding of the graft along the screw. However, it is important to clarify that bone quality plays a major role. In the same

study, the hold in tibias from older subjects (mean 50 years) was much less (340 N). Lastly, Weiler et al. [20] highlighted the benefits of combining a large diameter and a long screw length, with a mean pullout strength ranging from 367 to 537 N for tendon grafts inside a tibial tunnel.

In our study, adding an interference screw increased the load to failure by 25% (111.2 N vs. 89.2 N,  $p > 0.05$ ). Given the absolute difference (+25%) between the group 1 and 2, under our experimental conditions, adding a screw increases the pullout strength of a hamstring graft with its insertion preserved.

Noyes et al. estimated the ACL was subjected to a load of 454 N during activities of daily living [12]. Weiler et al. reported a maximum load to failure of  $385 \pm 185$  for a hamstring graft secure to bovine bone with an interference screw [21]. The absolute values found in our study are lower than in these two studies. This may be explained by two factors. One is the advanced age of our donors, which have lower bone mineral density. The correlation between the maximum strength of interference screw fixation and bone mineral density has been established [2]. Woo et al. showed that the strength of the femur–ACL–tibia complex decreased greatly with age [22]. The other factor contributing to the lower values in our study may be the screw itself (30 mm). As mentioned previously, Selby et al. [19] pointed out the mechanical benefit of longer screws, with 35-mm long screws being preferred.

Our study has certain limitations. 1. The sample size was small due to the limited availability of cadavers at the Anatomy Institute. Consequently, no power calculation was done. This lack of power likely explains the lack of statistical difference between groups 1 and 2. 2. This was a cadaver study with older donors. Although we know that mechanical properties are altered [12], the experimental conditions were consistent with other published studies [2,8–11,13], which allowed us to validate our findings. 3. The main limitation of this study is that the knees in group 1 were reused in group 3. However, for the knees in group 1, the tunnels were blank along the entire screw footprint and the failure mode was always pullout from the tibial insertion, not intratendinous rupture, which allowed us to reuse them. Conversely, reusing the graft may have impacted the stiffness values, thus we chose not to calculate the stiffness in group 3.

Our study also has its strong points:

- to our knowledge, this is the first time mechanical testing has been done on a hamstring graft with intact tibial insertion;
- the study protocol reproduces some of the loading observed clinically;
- the specimens and tunnels were prepared using standard practices.

#### 5. Conclusion

This study provides initial information on the entheses of the tibial insertion of hamstring grafts used in a surgical scenario. Preserving the anatomical tibial insertion of the ST and G tendons increases the load to failure of the graft. Under these experimental conditions, preserving the tibial insertion is beneficial from a mechanical point of view. These findings will need to be confirmed by clinical studies.

#### Disclosure of interest

DB and HF declare that they have no competing interest.

PC: educational consultant for Tornier®, associate editor for OTSR.

MO: consultant for Arthrex®, Newclip®, Stryker®.

SL: educational consultant for Medacta<sup>®</sup>, Smith & Nephew<sup>®</sup>, Amplitude<sup>®</sup>, Tornier<sup>®</sup>.

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## Author contributions

DB, HF, PC, ME: performed the mechanical testing.

DB, ME, MO: wrote the manuscript.

SL, FB: reviewed the manuscript.

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