



ACL repair with a single or double tunnel : a comparative laboratory study of knee stability using computer navigation

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The purpose of the study was to investigate the biomechanical differences between single bundle (SB), single tunnel-twisted hamstring graft (ST-TG) and double bundle (DB) reconstruction of the anterior cruciate ligament (ACL), using computer navigation for data acquisition.

Anterior translation in the medial compartment was corrected to near normal levels at 30° and 90° with all techniques. Anterior translation in the lateral compartment was corrected to near normal levels at 30° and 90°. However, the ST-TG and the DB were overcorrected to below-preoperative levels.

The DB significantly overconstrained internal rotation at different angles. Anterior translation in the lateral compartment on maximum internal rotation was significantly overconstrained using a DB.

We conclude that ACL reconstruction restores near normal knee kinematics. Our data suggest that the ST-TG and the DB better control anterior translation in the lateral compartment. It also suggests that DB carries a risk of overcorrection.

This study has a small sample size and should be considered as a pilot study.

Keywords : ACL reconstruction ; single tunnel-twisted graft ; biomechanical study ; computer navigation ; pilot study.

INTRODUCTION

Over the last decade attempts have been made to improve the techniques of intra-articular anterior

cruciate ligament (ACL) reconstruction. The most important concepts were those of the double bundle ACL reconstruction and the anatomical single bundle repair. The anatomical position of the ACL is believed to be a better replication of the native ACL. Adding a second bundle in a DB repair creates a three-dimensional structure and is believed to create better rotational and translational control (6). However, this is technically challenging and carries the danger of higher complication rates. Four bony tunnels need to be drilled leading to increased loss of bone stock. This also renders a possible revision more difficult (14,34).

We investigated the effect of twisting an anatomical ACL bundle along its longitudinal axis. The idea is that a single tunnel-twisted graft offers the advantage of a relatively 'easy' single bundle technique and adds the advantages of the double bundle technique : 'better rotational control' (12).

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Table I. — Demographic data of the 9 knee specimens

	gender	age (yrs)	side	medial comp	lateral comp	pat-fem	ACL	PCL	menisci
ST-ACL	M	70	L	normal	normal	Grade 1	intact	intact	med men tear
ST-ACL	M	73	R	Grade 2	Grade 2	Grade 2	intact	intact	normal
ST-ACL	M	85	R	normal	normal	normal	intact	intact	normal
ST-TG ACL	F	77	R	Grade 1	Grade 1	Grade 1	intact	intact	med men degen
ST-TG ACL	F	82	L	Grade 1	Grade 1	normal	intact	intact	med men degen
ST-TG ACL	F	79	R	Grade 1	Grade 2	normal	intact	intact	lat men degen
DB-ACL	F	67	R	Grade 1	Grade 2	normal	intact	intact	lat men degen
DB-ACL	F	71	R	Grade 1	Grade 1	Grade 1	intact	intact	normal
DB-ACL	M	70	L	normal	normal	Grade 4	intact	intact	normal

ST : single tunnel ; TG : twisted graft ; DB : double bundle ; ACL : anterior cruciate ligament.

This pilot investigation looked at the difference in biomechanical behaviour and rotational control between an anatomical single bundle ACL reconstruction, a single bundle ACL reconstruction using a twisted graft (the single tunnel-twisted graft) and a double bundle reconstruction. Computer navigation was used for data acquisition.

MATERIAL AND METHODS

Nine fresh frozen knee specimens with a mean age of 74.8 years ($SD \pm 6.2$) were available (5 female - 4 male). The descriptive data can be found in table I.

The lower extremities were disarticulated in the hip joint and the entire length of the femur and upper leg musculature was available. Specimens were stored at -80° Celsius and defrosted at room temperature (18° Celsius) 24 hours prior to surgery. The femur was attached horizontally to a knee laboratory workstation using 2 Steinmann pins. The distal third of the femur, the knee and the lower leg were not restrained and were able to move over full range of motion (Fig. 1).

A diagnostic arthroscopy was performed in all specimens. Cartilage condition was scored according to Outerbridge (26). Meniscal damage was documented. The quality and integrity of the cruciate ligaments was evaluated. Knee specimens that presented with scars or a history of previous surgery were excluded. Knees with macroscopic meniscal loss, cartilage damage grade 3 or higher and/or cruciate ligament injury were excluded (Table I). Two of eleven initial specimens were excluded.

Set up

The Praxim Medivision Surgetic System (Praxim, La Tronche, France) was applied. A femoral and tibial navigation frame was fixed with one Steinmann pin 15 cm from the joint line (Fig. 1). The Surgetics ACL Logistics Software (Praxim) was used to measure knee kinematics. The Cartesian coordinate system was constructed from knee flexion/extension kinematic data and surface landmarks acquired by use of a pointer equipped with a navigation array, as described by Colombet *et al* (4,5).

Measurements acquired were anterior tibial translation in the medial and lateral compartment as well as coupled rotation at 30° and 90° . Tibial internal and external rotation and coupled translation in extension, at 30° and at 90° were also acquired. We believe the pivot shift cannot be recreated reliably in disarticulated specimens and as such it was not studied (4,5,27).

The neutral AP position and the neutral tibial internal-external rotation position were defined as the unconstrained resting position of the tibia in the ACL intact knee. All subsequent measurements were acquired from this point (16). The navigation system was used to ensure the knee flexion angle for all measurements.

Stability measurements were performed after diagnostic arthroscopy (native knee setup), after ACL resection (Pre-ACL setup) and after ACL reconstruction (Post-ACL setup). For reconstruction, one of three ACL techniques was performed : the single tunnel technique (ST-ACL), the single tunnel-twisted graft technique (ST-TG ACL) or the double bundle technique (DB-ACL). Specimens were randomized by selecting a closed envelope containing the technique (Table I). A single surgeon

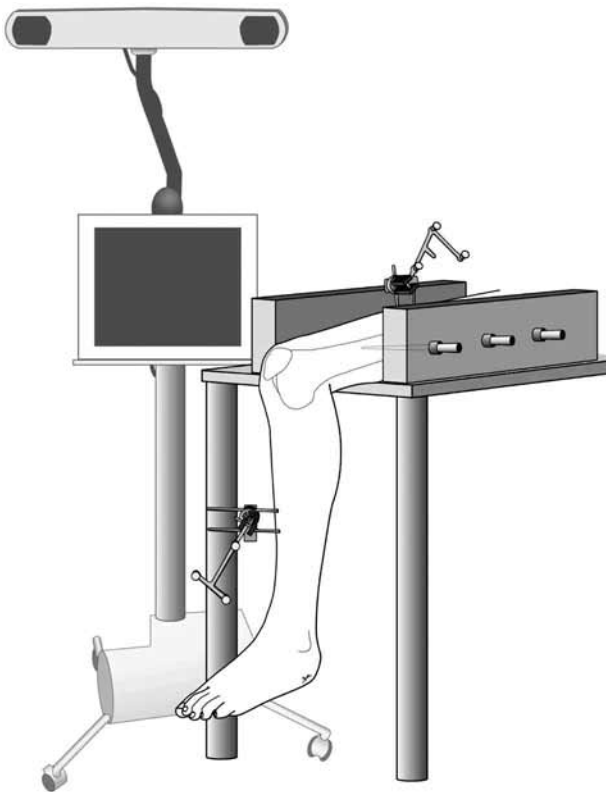


Fig. 1. — Illustration of the study setup showing the fixation of the upper leg and the position of the navigation arrays and the navigation receiver. (reproduced with permission from Van der Bracht H, Verhelst L, Goubau Y *et al.* The lateral tibial tunnel in revision anterior cruciate ligament surgery : a biomechanical study of a new technique. *Arthroscopy* 2012 ; 28 : 818-826).

performed all operations. The investigator acquiring measurements was blinded for the type of reconstruction. This investigator acquired all measurements by applying maximum manual force.

ACL reconstruction methods

The semitendinosus and gracilis tendons were harvested for ACL reconstruction. For the ST-ACL and ST-TG ACL the grafts were superimposed and fixed at both ends using a whip stitched Ethibond 2 suture (Ethicon, Johnson and Johnson, Sommerville, NJ, USA). The grafts were doubled (4-strand) and a traction suture was used on the proximal end. For the ST-ACL the graft was tied together in the proximal 2.5 centimetres by using a vicryl 2/0 suture (Ethicon, Johnson and Johnson, Sommerville, NJ). For the ST-TG ACL, both strands of the doubled graft were color-coded using a white and

green Ethibond 2/0. For the double bundle technique, an Ethibond 2 suture was applied individually on both ends of the grafts. They were doubled and a traction suture was used on the proximal end. The gracilis graft was used as the posterolateral bundle (PL) and the semitendinosus graft was used as the anteromedial bundle (AM) (37,40).

Single tunnel ACL reconstruction (ST-ACL)

The tibial drill guide was placed at the centre of the tibial footprint and set at a 55° angle. The femoral tunnel was drilled through the anteromedial portal to a depth of 30 mm. This was done in an anatomical position according to Bedi *et al* (1,15,24,30,39). The tunnel diameter corresponded to the graft size as determined using sizing tubes. The graft was fixed at the femoral side using the Rigid Fix system (DePuy Mitek, Johnson and Johnson, Sommerville, NJ, USA). A 30 mm non-resorbable interference screw -1 mm oversized- was used for tibial fixation. Tibial fixation was performed after 20 cycling manoeuvres, with the knee in 30° flexion and applying maximum manual load.

Single tunnel ACL reconstruction with rotational alignment of the graft : Single tunnel-twisted graft ACL reconstruction. (ST-TG ACL)

The tibial and femoral tunnels were placed in the same way as the ST-ACL. However, the femoral and tibial Bio-Intrafix system (DePuy Mitek, Johnson and Johnson, Sommerville, NJ, USA) was used for fixation. This allows for the individual strands of the graft to be positioned on opposite sides of the bony tunnel. After inserting the graft, the AM and PL bundles were rotated and fixed to correspond with the double bundle position of the native femoral footprint. Secondly, the AM and PL bundles were twisted along their longitudinal axis (counter-clockwise twist for left knees and clockwise for right knees) to correspond with the double bundle position of the native tibial footprint (10) (Fig. 2).

Double bundle ACL reconstruction (DB-ACL)

Following the technique described by Yasuda *et al* (37), the femoral tunnels were pre-drilled with K-wires with the knee in deep flexion after identifying the femoral footprint and the individual AM and PL insertion. The K-wires were then overdrilled to fit the graft size. The tibial tunnels were drilled using a tibial ACL guide (Mitek, Johnson and Johnson, Sommerville, NJ, USA). The AM tunnel was drilled at 55° at approximately

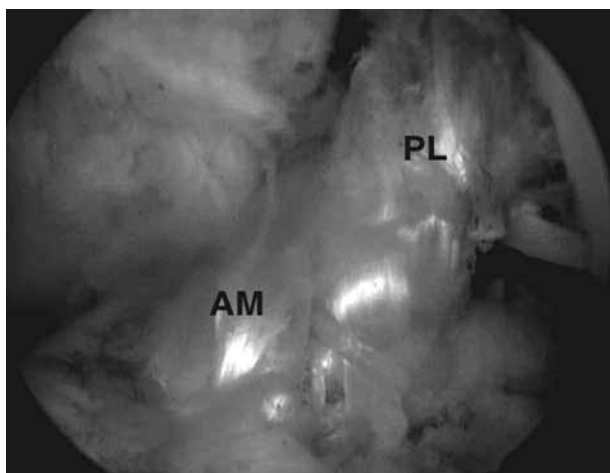


Fig. 2. — Arthroscopic view of a single tunnel double bundle rotationally aligned graft in a left knee in flexion : the anteromedial (AM) and posterolateral (PL) bundles are visualized.

1.5 cm from the tibial tuberosity. The PL tunnel was drilled at 50° and closer to the postero-medial border of the tibia. A 1.5 cm bridge was left between both tunnels.

The grafts were fixed at the femoral and tibial side using metal screws (Mitek). The knee was cycled through range of motion for 20 repetitions. The PL bundle was tightened first at 30° whilst maintaining traction on the AM bundle. The AM bundle was fixed at 60° (40).

Statistical methodology

For each group of measurements differences between the three conditions (native knee, pre-ACL, post-ACL) were analyzed using a linear model for repeated measures with a direct likelihood approach. Confidence intervals (CI) were constructed for differences with the intact knee-level. P-values were considered significant if smaller than 0.05. Due to the exploratory character of the study, no corrections were made for multiple testing. All analyses were performed using SAS software, version 9.2 of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA).

RESULTS

Isolated antero-posterior stability

Anterior translation in the medial compartment

Anterior translation in the medial compartment increased significantly at 30° (5.3 mm ± 2.4)

(Lachman) and 90° (3.7 mm ± 2.3) (anterior drawer) after resecting the ACL. This was restored to near normal pre-section values at 30° (0.9 mm ± 2.16 increase compared to pre-section) and 90° (0.2 mm ± 2.7 increase compared to pre-section). The correction post-section/post-implant was statistically significant at 30° (p = 0.0003) and 90° (p = 0.002).

Looking at the individual techniques, they corrected the anterior translation in the medial compartment significantly at 30° and 90°. However, the amount of correction between techniques did not differ significantly at 30° (p = 0.08) and at 90° (p = 0.78).

Anterior translation in the lateral compartment

Anterior translation in the lateral compartment increased significantly after resecting the ACL at 30° (3.3 mm ± 2.1) and at 90° (1.6 mm ± 1.2). A significant correction was obtained at these angles (30° = 3.3 mm ± 0.41 / 90° = 1.6 mm ± 1.7 increase compared to pre-section). The correction post-section/post-implant was statistically significant at 30° (p = 0.008) and 90° (p = 0.002).

Looking at individual techniques, the post-implant values at 30° and 90° were negative for the ST-TG ACL and the DB-ACL, compared to a near normal positive value for the ST-ACL. For example at 30°, translation was corrected from 4.2 mm ± 2.4 (post-section increase) to 1.5 mm ± 1.3 (post-implant increase compared to pre-section) for the ST-ACL. The ST-TG ACL corrected from 3.8 mm ± 0.7 (post-section increase) to -1.2 mm ± 2.2 (post-implant decrease compared to pre-section). The DB-ACL corrected from 1.9 mm ± 2.4 (post-section increase) to -1.7 mm ± 2.0 (post-implant decrease compared to pre-section).

Isolated rotational stability

At 0° and 30°, only the DB-ACL repair obtained a significant difference between the post-section knees and the post-implant knees. At 0°, internal rotation increased a mean 1.5° ± 1.6° after ACL section. After DB-ACL there was a mean -1.3° ± 0.2° decrease in internal rotation compared to the native knee (p = 0.05). At 30°, internal rotation

increased a mean $0.9^\circ \pm 2.0^\circ$ after ACL section. After DB-ACL there was a mean $-2.6^\circ \pm 3.9^\circ$ decrease in internal rotation compared to the native knee ($p = 0.03$). The DB-ACL created a statistically significant over-correction. However, differences between techniques at post-implant were not shown to be significant ($p = 0.45$ for 0°).

Coupled motion analysis

The medial and lateral associated coupled translation on maximum external rotation was not significantly affected after resecting the ACL at 30° or 90° . The post-section/post-implant changes were not significant overall or between the different techniques.

Only the lateral coupled translation at 30° on maximum internal rotation was significantly increased after resecting the ACL ($1.3 \text{ mm} \pm 1.5 \text{ mm} / p = 0.02$). The post-section / post-implant difference was only statistically significant for the DB-ACL (post-section : $0.6 \text{ mm} \pm 0.9 \text{ mm} /$ post-implant : $-2.1 \text{ mm} \pm 1.3 \text{ mm} / p = 0.03$). The DB-ACL decreased coupled lateral translation compared to the native knee. This was not the case for the ST-ACL or the ST-TG ACL.

After resection of the ACL, there was a significant decrease in coupled rotation when applying maximum translation at 30° and 90° . At 30° this was only shown to be significant for the DB-ACL (post-section : $0.1^\circ \pm 1.7^\circ /$ post-implant : $-3.1^\circ \pm 1.5^\circ / p = 0.04$). Coupled rotation was relatively constrained with the DB-ACL. However, differences between techniques at post-implant were not shown to be significant ($p = 0.25$).

DISCUSSION

This study has demonstrated that different techniques of ACL reconstruction significantly reduce anterior translation in the medial compartment. Anterior translation of the lateral compartment was undercorrected by the ST-ACL compared to the ST-TG ACL and the DB-ACL. The latter techniques overcorrected to below preoperative levels, although this difference did not reach statistical significance.

The DB-ACL overconstrained for isolated internal rotation at 0 and 30° ($p = 0.03$), coupled lateral translation with maximum internal rotation at 30° ($p = 0.03$) and coupled rotation with maximum translation at 30° ($p = 0.04$).

Many aspects of ACL surgery are still being questioned such as ideal age group, return to sports (36), type of graft used (21) and long term outcome (7,8,20,22). It is not clear from the current literature which kind of repair provides the best short and long-term results. The 2008 meta-analysis by Meredith *et al* concluded that double bundle reconstruction does not result in a clinically significant difference in KT-1000 measurements or pivot shift testing (19). This has been confirmed by Gobbi *et al* who found no difference in outcome after three years (11). Recently Claes *et al* and Tsarouhas *et al* looked at *in vivo* kinematic data and the difference in rotational control between ST-ACL and DB-ACL, and couldn't find a difference between both techniques (3,32,33). Ho *et al* again found no added rotational stability between single and double bundle ACL (13). In theory, reconstruction of both the AM and PL bundle (DB-ACL) should allow for better control of translation, rotation and coupled motions (38). This has been shown by Branch *et al* in a matched pair *in vivo* study comparing ST and DB-ACL (2). Plaweski *et al* demonstrated better control of lateral translation and internal / external rotation at 20° with a DB-ACL (29). Musahl *et al* emphasized better lateral control of translation using a double bundle repair (23). This is in line with our data, however we demonstrated that DB-ACL overconstrained lateral translation, internal rotation and coupled lateral rotation and translation near extension. Musahl *et al* had already shown this overconstraint of rotations using a DB-ACL (25). This risk of overconstraint is brought to light very clearly in the 2009 report by Markolf *et al*. They state that the addition of a PL bundle does reduce rotation and translation but differences are very small. Moreover they found that near extension very high forces could be measured in the PL bundle, which might be a cause of early failure. For these authors, the possible benefit of DB ACL does not outweigh the added risks (17,18). Seon *et al*

confirmed this overloading of the posterolateral bundle in their laboratory study (31).

Although studies both pro and con can be found, it is clear from this data that there is at least a risk of overconstraining both translations and rotations. This is again in line with our data. Both the DB-ACL and the ST-TG ACL had better lateral translation, however only the DB-ACL showed overconstraint of rotations. We hypothesize that it is the addition of the PL bundle in a separate tunnel that causes this problem of overconstraint near extension.

The use of two bundles within one femoral and tibial socket might offer substantial advantages compared to a DB-ACL. ST-TG relies on the standard ST ACL technique, which is more straightforward and should carry less complications and lead to easier revision. Gadikota *et al* compared ST-ACL to ST-TG ACL and found better translational control at low flexion angles. However, it overconstrained the knee at deeper flexion angles. Both techniques overconstrained internal rotation (9,10). This data is in contrast with our results showing equal control of translation on the medial side, better control of translation on the lateral side and no overconstraint of internal rotation after ST-TG ACL. We believe the difference with our study lies in our data acquisition. The navigation system gave us the opportunity to look in more detail at isolated movements.

There is only one report comparing the ST-TG ACL with DB-ACL. Petersen *et al* concluded that the DB-ACL gave better control of translation at time zero as well as better control of translation with combined rotatory load. However, the difference was small. They did not mention overconstraint (28).

Although our data is not conclusive, we believe it does add to the insight on possible pro's and con's of single or double bundle techniques. We are convinced that this single tunnel-twisted graft concept might bring together what is conceptually good about the double bundle technique, with the ease and speed of our standard single tunnel technique.

There are limitations to our study. The cadaveric specimens were old with a mean age of almost 75 years. All specimens were checked for meniscal

damage and/or cartilage defects. Secondly, testing the pivot shift with these specimens was not possible because in these disarticulated lower extremity specimens the muscle or ligament attachments to the pelvis were disrupted (27). We did not use a mechanical test-bench nor did we use muscle load for this study (16,35). A single investigator using maximum manual load performed all tests.

The most important study weakness is the small sample size. This is caused by the scarcity of human bodies available for research in Belgium. Results should be viewed accordingly and values should not be seen as absolute figures.

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