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ORIGINAL PAPER

Reconstruction of the anterior cruciate ligament: a clinical comparison of bone-patellar tendon-bone single bundle versus semitendinosus and gracilis double bundle technique

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Abstract The study hypothesis was that the outcome of semitendinosus gracilis double bundle (STG-DB) anterior cruciate ligament (ACL) reconstruction is advantageous in terms of clinical results and restoration of anterior-posterior and rotational laxity in comparison to bone-patellar tendon-bone single-bundle (PTB-SB) ACL reconstruction. We analysed 41 PTB-SB and 51 STG-DB patients using the Tegner, IKDC and WOMAC scores preoperatively and at a minimum follow-up of two years. At follow-up, there was no significant difference in the clinical scores. The KT 1000 side-to-side measurement showed no significant difference between groups. The STG-DB group was significantly superior in terms of the pivot-shift sign and anterior knee pain. We conclude that the outcome of STG-DB reconstruction in the mid-term was not advantageous in terms of clinical scores and anterior-posterior laxity evaluated by the KT 1000. Nevertheless, the restored rotational laxity measured by the pivot shift test was significantly superior in the STG-DB technique.

Level of evidence: Level II-1

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Introduction

The anterior cruciate ligament (ACL) consists of two different functional bundles [1]. Despite these dual functional units, the gold standard treatment of ACL tears is a single bundle reconstruction with hamstring or bone-patellar tendon-bone autografts [2]. Biomechanical studies have proven the importance of the posterolateral bundle in near full extension, and under anterior tibial and rotatory loads by demonstrating superior restoration of native knee kinematics with double bundle reconstruction [1, 3]. On the other hand, these theoretical advantages may be obscured by the added complexity of the surgical procedure [4]. Various studies have compared the outcome of semitendinosus gracilis single bundle (STG-SB) with semitendinosus gracilis double bundle (STG-DB) or bone-patella tendon-bone single bundle (PTB-SB) ACL reconstructions in mid-term follow-up [5–8], but up until now, few papers have analysed the comparative outcome between PTB-SB and STG-DB ACL reconstruction [3]. Our manuscript contributes to further understanding of this comparative setting and verification of previous investigations in literature.

Our aim was a prospective comparative cohort analysis of PTB-SB versus STG-DB with a focus on their clinical outcome with a minimum follow-up of two years. The study hypothesis was that the outcome of STG-DB reconstruction in the mid-term is advantageous in terms of subjective and objective clinical results and restoration of anterior-posterior and rotational laxity in comparison to PTB-SB reconstruction.

Patients and methods

Study design and recruitment

We present a prospective cohort study of two consecutive series comparing PTB-SB with STG-DB ACL reconstructions performed by a single surgeon. We included patients with unilateral ACL ruptures fulfilling the criteria to undergo arthroscopically assisted reconstruction (60 PTB-SB and 60 STG-DB). Exclusion criteria were additional knee ligament injuries, previous knee ligament operations, and fractures of the femur or tibia. Concomitant medial collateral ligament injuries (grade I–III) were treated conservatively and not excluded from the study. Thereafter, we included 41 PTB-SB and 51 STG-DB ACL reconstructions in this analysis. Ethical approval was obtained from the internal review board (AUVA, Unfallkrankenhaus Linz, Austria) and all patients gave written informed consent.

Demographic data

Comparison of groups was given in terms of demographic data, length of hospital stay, meniscal injuries and repairs, concomitant medial collateral ligament injuries, interval between injury and operation, preoperative activity levels (Tegner [9]), clinical scores (WOMAC [10], IKDC [11]) and the pivot shift sign (Table 1). The same rehabilitation pathways were used for all patients according to Shelbourne and Nitz [12].

Surgical techniques

Bone-patella tendon-bone single bundle (PTB-SB) reconstruction (Fig. 1)

The senior author operated on 41 patients according to Mariani et al. [13]. Harvesting of the graft was done through an 8-cm longitudinal skin incision centred over the medial patellar tendon in 90° of knee flexion. The central third of the patella tendon was removed from distal to proximal with an average width of 10 mm. The proximal and distal bone block were trimmed according to a specific diameter of the tibial or femoral bone tunnel with a range from 8–11 mm. The tibial guide wire was placed in the middle of the tibial footprint of the ACL. Drilling of the tibial tunnel was achieved with a cannulated reamer of previously measured size (ranging from 8 to 11 mm). Insertion of the femoral guidewire was achieved using size-specific femoral aimers with a 7-mm step-off through the transtibial approach with a knee flexion of about 80°.

Table 1 Demographic data and clinical scores of patients of the bone-patellar tendon-bone single bundle (PTB-SB) group and semitendinosus gracilis double bundle (STG-DB) group. Note that preoperative data show no statistical significant difference between groups

Demographic data	PTB SB; *n*=41	STG DB; *n*=51	Difference (*P* value)
Age, years [a]	30; 17–45	29; 16–46	*P*>0.5
Height, m [a]	173; 156–190	172; 160–187	*P*>0.5
Weight, kg [a]	73; 48–99	76; 55–100	*P*>0.1
Length of inpatient stay, days [a]	3.29; 1–10	3.75; 1–7	*P*>0.5
Length of outpatient clinical care, days [a]	56.6; 1–119	56.1; 5–159	*P*>0.5
Meniscal injury	30	34	*P*>0.1
Meniscal repair	18	20	*P*>0.5
Concomitant medial collateral ligament injuries	2	4	*P*>0.5
Interval between injury and operation, months [a]	3.8; 0.5–19	4; 0.5–22	*P*>0.1
Tegner [a]	1.54; 0–4	1.53; 0–3	*P*>0.5
WOMAC [a]	35; 22–64	38; 23–65	*P*>0.5
Subjective IKDC Score [a]	55; 40–65	58; 35–60	*P*>0.1
Objective IKDC Score			*P*>0.5
C (abnormal)	9%	8%	*P*>0.5
D (severely abnormal)	91%	92%	*P*>0.1
Pivot shift sign			*P*>0.5
2+ (clunk)	9%	10%	*P*>0.1
3+ (gross)	91%	90%	*P*>0.5
Follow-up, months [a]	25; 24–31	26; 24–32	*P*>0.5

[a] Numbers reported as mean; range

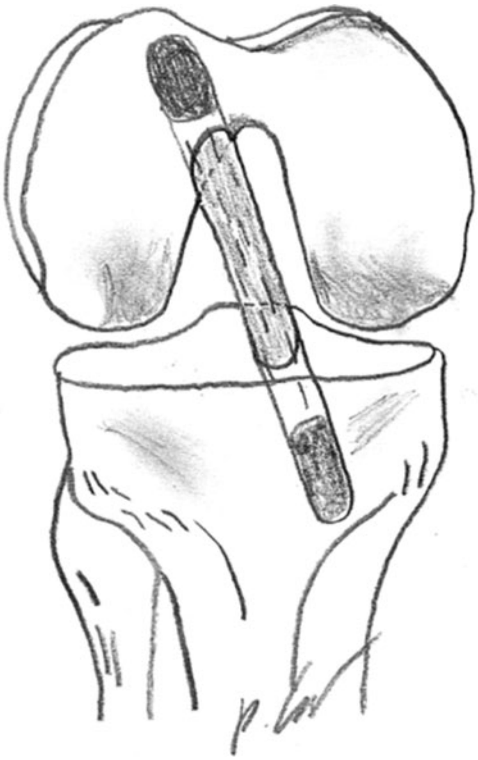

Fig. 1 Bone-patellar tendon-bone single bundle anterior cruciate ligament reconstruction

Reaming was performed at about 11 o'clock in right and 1 o'clock in left knees. Femoral fixation was achieved with a RIGIDFIX® ACL cross pin system (Johnson & Johnson, New Brunswick, NJ) and tibial fixation using titanium interference screws with a tension spring balance loaded at 30N (Milago; DePuy Mitek Inc, Norwood, MA).

Semitendinosus-gracilis double bundle (STG-DB) reconstruction (Fig. 2)

The senior author performed 51 STG-DB ACl reconstructions according to Christel et al. [14]. The harvested semitendinosus tendon (for reconstruction of the antero-medial [AM] bundle) and the gracilis tendon (for reconstruction of the postero-lateral [PL] bundle) were looped over a 20 mm EndoButton CL (Smith & Nephew Endoscopy, Mansfield, MA) and sutured with interlocking stitches. The guidewire for the AM bundle was placed first just medial to the insertion site of the anterior horn of the lateral meniscus in the footprint of the ACL. The guidewire for the PL bundle was placed through the guiding instrument of Pascal Christel [14] which led to an intra-articular exit point posterior and lateral of the AM canal and slightly anterior to the PCL. Tibial tunnels of the AM and PL bundle were drilled at angles of 50° and 45°, respectively, to the plateau and placed in the anterior intercondylar area of the native tibial ACL footprint. Drilling of the femoral AM bone tunnel was achieved through the medial portal with a range of 5–6 mm inferior to the "over the top" position at the origin of the AM bundle with 120° of knee flexion. The AM tunnel was drilled with respect to the landmarks, described by Petersen and Zantop [15, 16], who identified the AM bundle as the transition between the intercondylar line and the cartilage border. The bone tunnel for the PL bundle was drilled using the instruments (Smith & Nephew, London, UK) from Pascal Christel [14] with a range from 5 to 7 mm posterior to the anterior cartilage of the lateral femoral condyle via the anteromedial portal. The guiding instrument for the PL bundle was rotated till it pointed to the remnants of the PL bundle. We used a 4.5-mm reamer for the button and a reamer fitted to the size of the graft of the socket. Femoral fixation was done with EndoButton CL (Smith & Nephew Endoscopy, Mansfield, MA) and tibial fixation with biodegradable interference screws (Milago; DePuy Mitek Inc, Norwood, MA) by use of a tension spring balance loaded at 30N. Whereas the AM bundle was fixed at a flexion of 30–40°, the PL bundle was fixed at an angle of 10° of knee flexion. Total range of motion of the knee was tested under arthroscopic view to exclude any possible notching of the graft. We found no impingement or notching and did not perform a notch plasty in any patient of either group.

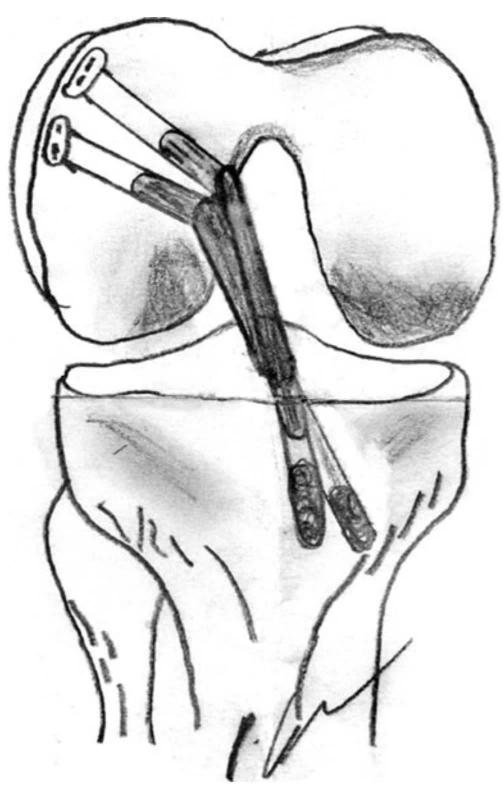

Fig. 2 Semitendinosus gracilis double bundle anterior cruciate ligament reconstruction

Clinical evaluation

At preoperative assessment all patients suffered from clinically unstable knees with "giving way" and positive Lachman and pivot shift tests [17] but without positive dial tests [17]. Magnetic resonance imaging (MRI) definitely confirmed ACL rupture. All operations were performed at least two weeks after the initial trauma (mean 28 weeks, range 2–23) and only in patients with a range of motion (ROM) of more than 90 degrees with full extension. Patients had to be able to walk without pain and without crutches before surgery. The pre-oparative evaluation showed no significant difference between either group (Table 1).

At minimum follow-up of two years the main examiner who was independent in terms of financial interest or relation to a company evaluated the patients using the Tegner [9], WOMAC [10] and IKDC scores [11], as well as the KT 1000 knee arthrometer® [18] (MEDmetric Corporation, San Diego, CA, USA). Complications were analysed according to Goslings and Gouma [19].

Rehabilitation

The same integrated clinical care pathway was started for both groups without drains or braces the first day after surgery according to Shelbourne and Nitz [12]. Walking with partial weight bearing was allowed immediately after surgery. Cycling and swimming were allowed four to five months after surgery and sports with a high impact on knees were not recommended earlier than one year after surgery.

Statistical analysis

Differences between the groups were analysed for ordinal variables, with independent sample *t* tests for continuous variables and Fisher's exact test for categorical variables. We calculated observed power, used SPSS 13.0 (SPSS Inc., Chicago, IL) for statistical analyses and a *P* value <0.05 was considered to be significant.

Results

Evaluation of subjective clinical scores and measurements

The Tegner [9], WOMAC [10], and subjective IKDC scores [11] showed no significant differences between groups at follow-up (Table 2). All patients were able to walk without crutches two weeks postoperatively. The pivot-shift sign was significantly superior in the DB group with $P=0.0008$. There was significant benefit in the STG-DB group concerning anterior knee pain in contrast to the PTB-SB group ($P=0.001$).

Evaluation of objective clinical scores and measurements

The operation time was significantly longer in the STG-DB technique (Table 3). The side-to-side anterior laxity-measurement (KT 1000) showed no significant difference between the groups ($P=0.57$). Comparison of the objective IKDC score showed no significant difference with a $P=0.055$. The one leg hop test, flexion and extension deficit showed no significant differences between groups with *P* values >0.5.

Complications

Complications were classified according to Goslings and Gouma [19] using a severity scale of "grade 1" to "grade 5". Five complications occurred in the entire patient

Table 2 Clinical evaluation of the bone-patellar tendon-bone single bundle (PTB-SB) and semitendinosus gracilis double bundle (STG-DB) group at follow-up using subjective scores (Tegner, IKDC, WOMAC) and measurements (pivot-shift, anterior knee pain)

Evaluation	PTB-SB; $n=41$	STG-DB; $n=51$	*P* value
Tegner (postoperative)[a]	5.32; 2–10	5.53; 3–10	$P>0.5$
Tegner (difference)[a, b]	3.78; 0–8	3.8; 1–8	$P>0.5$
IKDC subjective[a]	69; 0–100	79; 25–100	$P>0.1$
WOMAC [a]	96.2; 75–100	97.7; 83.3–100	P>0.1
Pivot shift sign[c]			$P<0.001$
0 (equal)	49%	84%	
1+ (glide)	51%	14%	
2+ (clunk)	0	2%	
3+ (gross)	0	0	
Harvest site pathology[c]			$P<0.001$
0 (none)	48%	75%	
1 (mild)	52%	25%	
2 (moderate)	0	0	
3 (severe)	0	0	

[a] Numbers reported as mean; range

[b] Difference between Tegner (postoperative) and Tegner (accident) in terms of an improvement in joint function

[c] This is a part of the objective IKDC score

Table 3 Clinical examination of the bone-patellar tendon-bone single bundle (PTB-SB) and semitendinosus gracilis double bundle (STG-DB) group at follow-up using objective clinical scores and measurements

Evaluation	PTB SB; *n*=41	STG DB; *n*=51	*P* value
Operation time, minutes [a]	61.3; 40–93	84.3; 56–117	$P<0.05$
Side-to-side difference, mm [b]	+1.38;−3.0–+7.0	+1.16;−4.0–+7.0	$P>0.5$
IKDC objective			$P>0.05$
A (normal)	16%	36%	
B (nearly normal)	79%	55%	
C (abnormal)	3%	9%	
D (severely abnormal)	3%	0	
One leg hop test [c]			$P>0.5$
>90%	69%	68%	
89–75%	28%	30%	
74–50%	3%	2%	
<50%	0	0	
Passive extension deficit [c]			$P>0.5$
<3°	90%	91%	
3–5°	10%	9%	
6–10°	0	0	
>10°	0	0	
Passive flexion deficit [c]			$P>0.5$
0–5°	92%	91%	
6–15°	8%	9%	
16–25°	0	0	
>25°	0	0	

[a] Numbers reported as mean; range

[b] Side-to-side difference was measured with use of the KT1000® arthrometer at 143N at 20° flexion. Positive values represent more laxity in comparison to the contralateral normal knee and negative values represent less laxity

[c] This is part of the objective IKDC score

population. Two graft failures as a result of a new trauma in sports in PTB-SB were "grade 3". One male patient in PTB-SB refused further investigations because of dissatisfaction with clinical results ("grade 2"). There were two complications in STG-DB in terms of haematoma around the harvested graft, one of which required surgical evacuation ("grade 2"). We report no wound complications or deep infections.

Discussion

The study aim was a prospective comparative cohort analysis of PTB-SB versus STG-DB with a focus on their clinical outcome with a minimum follow-up of two years.

Our hypothesis was that the outcome of STG-DB reconstruction in the mid-term is advantageous in terms of subjective and objective clinical results in addition to restoration of anterior-posterior and rotational laxity in comparison to PTB-SB reconstruction.

Recent studies have discussed the need to reconstruct the torn ACL using the STG-DB technique [3, 5, 6, 20]. As the initial results in comparison to PTB-SB reconstructions were inferior [8], further analyses proved a need to evaluate the type of graft fixation, to be able to compare those two different techniques more appropriately [21]. After introduction of new fixation devices in hamstring techniques, the clinical results of the STG-DB technique improved in terms of subjective and objective measurements [22] and therefore, some surgeons prefer the STG-DB technique because less anterior knee pain and a higher rotational stability can be achieved [5, 7, 23]. The mechanical properties of hamstring tendons seem to be preserved with increasing age whereas the bone-patellar tendon-bone grafts seem to weaken with age; but on the other hand there are potential problems associated with harvesting the hamstring tendons from the patients [23].

We chose rigidfix transcondylar pins (Johnson & Johnson, New Brunswick, NJ) for fixation in the PTB-SB group in a transtibial technique which has been recognised to give less rotational stability in contrast to a medial portal technique in single bundle reconstructions. Therefore, facing the risk of aiming a too vertical and too anterior "high noon" position via this transtibial technique (12 o'clock), we tried to aim for the most inferior position on the wall of the femoral notch and placed the femoral guidewire 5 mm anterior to the posterior cortex to allow a 1–2 mm posterior cortical wall after reaming at about 11 o'clock in right and 1 o'clock in left knees.

Whilst the pivot shift sign is a part of the objective IKDC score [11], it is a subjective method, depending on the examiner's impressions [24]. Kocher et al. reported a significant relationship between patients' satisfaction and the pivot shift grades, whereas anterior-posterior laxity has less influence on patients' satisfaction [25]. Therefore, one of the main targets of ACL reconstruction should be an exact reconstruction of transverse plane rotational laxity.

Although the anterior knee pain is part of the objective IKDC score, the patients answer it subjectively and we cannot quantify these findings. However, whenever extensor mechanisms are used significantly (for example, in jumping) or when a patient must often kneel or squat, they report less anterior knee pain after STG-DB or STG-SB than after PTB-SB reconstructions [24]. As the senior author performed a longitudinal 8-cm incision in the PTB-SB surgical approach, there is a risk of potential injury to branches of the saphenous nerve. This is a matter of concern and therefore should be mentioned to the patients.

The KT 1000 measurements, ROM and one leg hop test are objective reliable methods for comparison of ACL reconstructions. However, we found no significant difference between the groups in terms of the objective IKDC score. Translation of the tibia after reconstruction of an ACL tear is affected by several variables, including cycling of the graft, degree of knee flexion, tension on the graft at fixation, healing of bone to bone versus tendon to bone, and the proper rehabilitation pathway [13]. However, in order to determine the ideal value of tibial anterior translation the contralateral uninjured knee should aid in orientation [5]. According to Siebold et al. there might be a risk of over tightening the reconstruction using the STG-DB technique [5]. These more normal results in the STG-DB group might occur because of the additional PL bundle which adds restored anterior laxity between 0 and 30° of knee flexion [5]. Nevertheless, our results show no statistically significant difference between both groups in terms of anterior-posterior laxity.

Limitations and benefits

As this study presents a mid-term minimum follow-up of two years we cannot give precise information about long-term outcome and associated developments. In addition, we lack objective methods evaluating the rotational laxity and quantifying anterior knee pain. Furthermore, our comparison discusses two different graft positions with two different types of fixation as the senior author reconstructed the torn ACL using a transtibial technique in PTB-SB and a medial portal technique in STG-DB. We believe that this might add to the superior outcome in terms of rotational laxity in STG-DB ACL reconstruction as a transtibial SB technique gives less restored rotational laxity than a medial portal SB technique.

It should be noted that all patients have been operated upon by one surgeon. In addition, with the sample size of 41 for PTB-SB and 51 for STG-DB, the magnitude of the difference in the pivot shift test was large enough that post hoc power analysis revealed over 80%. Although we evaluated two different graft positions and types of fixation, these techniques are both used by ACL surgeons and are therefore worth being clinically compared. Last, we were able to present the data from our whole patient population at follow-up.

Conclusion

We conclude that the outcome of STG-DB reconstruction in the mid-term was not advantageous in terms of subjective clinical scores, objective clinical scores, and anterior-posterior laxity evaluated by the KT 1000. Nevertheless, the restored rotational laxity measured by the pivot shift test was significantly superior in the STG-DB technique.

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