Original Research

Young men undergoing anterior cruciate ligament reconstruction with patellar tendon autograft and anteromedial drilling outperform at 5- to 10-year follow-up in terms of graft stability and activity levels compared to those undergoing reconstruction with hamstring autograft and transtibial drilling

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ABSTRACT

Objective: To compare 5- to 10-year outcomes of anterior cruciate ligament (ACL) reconstruction in young men performed with bone-patellar tendon bone (BPTB) autograft and anteromedial portal to reconstruction with hamstring autograft and transtibial technique. It was hypothesised that in young adult men, at 5- to 10-year follow-up, superior restoration of knee laxity and activity levels would be demonstrated using BPTB autograft and anteromedial portal technique.

Methods: Ninety-four men who had ACL reconstruction with BPTB autograft and anteromedial portal were eligible for comparison to 106 men who had reconstruction with hamstring autograft and transtibial technique. Inclusion criteria were: (1) age 18–35 years, (2) ACL tear caused by sports trauma only, (3) no concomitant ligament reconstruction and (4) 5- to 10-year follow-up. Outcome measures compared between the two groups included Lachman and pivot shift tests, KT side-to-side difference, Tegner and Marx scores, International Knee Documentation Committee (IKDC)-subjective score, Knee Osteoarthritis Outcome Scale (KOOS), Short Form (SF)-36, and single hop test for distance. P value < 0.05 indicated statistical significance.

Results: Forty-five patients with BPTB and 55 patients with hamstring ACL reconstruction were available for in-person assessment at 5-10 years after surgery. Outcomes in the BPTB group compared to the hamstring group showed KT difference 1.4 ± 1.9 mm vs. 2.8 ± 2.3 mm (p < 0.01), pivot shift grade 2–3 in 4% vs. 34% (p < 0.01), return to preinjury Tegner level in 51% vs. 36% (p = 0.1) and to preinjury Marx score in 29% vs. 11% (p = 0.02), and IKDC-subjective 88 ± 10 vs. 82 ± 13 vs (p < 0.01), respectively. Statistically significant inter-relationships were found between KT side-to-side difference and the Tegner, Marx and IKDC-subjective scores at follow-up (r = -0.314, p < 0.01; r = -0.263, p < 0.01; r = -0.218, p = 0.03, respectively).

Conclusion: Young men undergoing ACL reconstruction with patellar tendon autograft and anteromedial drilling outperform at 5- to 10-year follow-up in terms of graft stability and activity levels compared to young men undergoing reconstruction with hamstring autograft and transtibial drilling.

Level of Evidence: III (Retrospective cross-sectional comparative study).

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What are the new findings

- A selective age and sex-specific group of young active men is evaluated in person at 5–10 years after anterior cruciate ligament reconstruction, while a myriad of outcome measures is compared between reconstruction performed with bone-patellar tendon-bone and anteromedial portal and reconstruction performed with hamstring autograft and transtibial drilling.
- Superior restoration of knee laxity and activity levels are documented when anterior cruciate ligament reconstruction is performed using bone-patellar tendon-bone and anteromedial portal compared to using hamstring autograft and transtibial drilling, and these measures are inter-related.
- Suboptimal Knee Osteoarthritis Outcome Scale and Short Form-36 scores in both graft choices and techniques without clear superiority to one of them imply that, except knee laxity, broader spectrum of measures that affect sports maintenance and quality of life in medium term, such as rehabilitation programs, kinesiophobia, proprioception and others should draw our attention in order to optimise long-term satisfaction.

INTRODUCTION

The primary goal of anterior cruciate ligament (ACL) reconstruction is to restore preinjury knee laxity and enable active individuals maintain their sports activities. Failure to achieve these goals in a substantial proportion of the patients has driven ongoing research seeking the optimal technique for reconstruction. The two most widely explored factors in this respect include: (1) graft choice and (2) femoral tunnel drilling technique. In 2015, the American Academy of Orthopaedic Surgeons’ evidence-based guideline on management of ACL injuries proposed that young adults aged 18–35 years comprised the most suitable group of patients to consider ACL reconstruction, and that using autograft single-bundle reconstruction and applying either transtibial or anteromedial portal drilling technique were appropriate surgical options [1]. Since then, large-scale studies have further tried to identify the most effective autograft and tunnel preparation technique in order to minimise failure rates and optimise the outcomes of surgery. With regard to choosing wisely between the two most popular autografts, a recent national registry showed that bone-patellar tendon-bone (BPTB) was associated with reduced rates of revision ACL reconstruction compared to hamstring autograft [2], and this echoed the findings of other national registries [3,4]. On the other hand, a systematic review and meta-analysis also published recently, showed similar rates of return to preinjury levels of performance as well as graft rupture rates for both autografts [5]. Moreover, hamstring remains the most popular autograft choice for many surgeons world-wide, although this is reported without clear specificity to patient age and activity levels [6,7]. With regard to tunnel preparation technique, while some of the studies did not indicate clear advantage in reducing failure rates by using either transtibial or anteromedial technique [8,9], recent meta-analyses showed better reproducibility of knee stability and improved clinical outcomes when using anteromedial portal instead of transtibial drilling technique [10], as well as lower proportion of posttraumatic arthritis at 5- to 10-year follow-up [11]. Furthermore, recent large-scale surveys among sports surgeons showed that the anteromedial portal technique gained popularity, although the transtibial technique still remains an accepted technique adopted by many surgeons [6,7]. It therefore seems that the debate about optimal surgical technique with regard to these two factors (i.e. graft choice and femoral tunnel drilling technique) has not arrived at its final destination and more research may therefore be warranted, with greater specificity to patient population and follow-up times. The purpose of this study was therefore to compare 5- to 10-year outcomes of ACL reconstruction with BPTB autograft and anteromedial portal to reconstruction with hamstring autograft and transtibial technique in young men. It was hypothesised that in these specific circumstances, better restoration of knee laxity and activity levels would be demonstrated using BPTB autograft and anteromedial portal technique.

METHODS

Study population

For the purpose of this study, primary ACL reconstructions performed in adults in a single sports clinic between 2004 and 2017 were identified. For all ACL reconstructions performed between 2004 and 2010, quadrupled hamstring autograft (gracilis and semitendinosus tendons) and transtibial femoral tunnel drilling technique (TT-GST group) were consecutively used as described [12]: For tibial tunnel preparation, the internal tip of the ACL tibia guide was placed 7 mm anterior to the posterior cruciate ligament, in line with the posterior edge of the anterior horn of the lateral meniscus, between the medial and lateral tibial eminences, planning the exit of the guide-pin at the postero-medial aspect of the native ACL footprint. The external starting point of the guide-pin on the tibia was midway between the tibial tubercle and the posteromedial border of the tibia. Once the guide-pin was in place, the knee was brought from flexion to extension to verify guide-pin direction to avoid roof impingement and enable later preparation of femoral socket in a desired location through the tibial tunnel. Guide-pin location was modified as needed to achieve this goal. The femoral socket was planned to aim towards the 10:30 clockface position in the inter-condylar notch and against the posterior femoral condyle cortex. For the femoral fixation of the graft, a suspensory device was used (i.e. Transfix pin), whereas for the tibial fixation, interference screw was used in the tunnel, alongside a backup fixation using titanium staple on the anteromedial tibia cortex. Tibial fixation of the graft was finalised while applying approximately 80 lbs force and the knee held at 10° flexion. For all ACL reconstructions performed between 2011 and 2017, 10-mm wide BPTB autograft and anteromedial portal femoral tunnel drilling technique were consecutively used (AM-BPTB group). In this group, the femoral socket was prepared first. While tunnel aperture was aimed at the 10:30 clockface position in general, the central ACL femoral footprint and the lateral intercondylar ridge were further used as reference landmarks in these cases, aiming the femoral socket to cover part of the AM bundle and part of the PL bundle attachments. This was followed by preparation of the tibial tunnel, planning the exit of the guide-pin at the postero-medial aspect of the native ACL footprint, and confirming the avoidance of roof impingement during extension with the guide-pin in place. The graft was fixed in the femoral socket with a 7 × 20-mm interference screw, and in the tibial tunnel with a 9 × 20-mm interference screw, applying approximately 80 lbs force and the knee held at extension in order to avoid risk of extension loss in cases of slightly non-isometric high-resiliency patellar tendon graft. This change in the surgical technique of ACL reconstruction relating to autograft choice and tunnel drilling was decided upon at the end of 2010 in the specific sports service, based on global trends and systematic reviews that provided some evidence for
reduction in failure rates when using BPTB compared to hamstring autograft [13], and improved restoration of knee laxity by using the anteromedial portal technique compared to transtibial technique [14]. Imaging was not used intraoperatively to verify desired tunnel locations, but postoperative radiographs provided information of tunnel and hardware positions. All operations were performed at one surgical site and the senior author (GM) was involved in both groups from 2004 to 2017. Postoperative guidelines included using crutches and weight-bearing as tolerated for 2–4 weeks without limiting the range of knee motion. Closed kinetic chain strengthening was recommended during the first three months alongside implementing individualised task-based instead of time-based rehabilitation principles in order to decrease the risk of re-injury at the early phases before graft healing and maturation and allow neuromuscular recovery [15]. In cases of a meniscus repair, a knee brace was applied for the first month to limit knee flexion up to 90°, and crutches were used for 4–5 weeks with partial weight bearing. Running was generally allowed at 4 months postoperatively. Patients were also recommended avoiding return to cutting-pivoting sports before 9–12 months after surgery.

Outcome assessment

At 5–10 years after surgery, patients were contacted and invited for a follow-up assessment at the clinic. Because outcomes of ACL reconstruction may be affected by patient age [16,17] and sex [18,19], and because knee neuromuscular control is sex-specific [20], in order to decrease selection bias related to such factors, the inclusion criteria for this study were aimed to address a specific and relatively homogenous group of active patients as follows: (1) men only, (2) age 18–35 years, (3) only sports-induced ACL tear, (4) no concomitant ligament reconstruction and (5) 5- to 10-year follow-up. Exclusion criteria for a follow-up evaluation were: (1) contra-lateral ACL tear, (2) revision ACL reconstruction during follow-up or MRI-documented ACL graft tear with instability awaiting revision and (3) another lower limb injury or disease which impaired limb function at follow-up.

Demographic and injury variables which were collected included: type of sport activity at the injury event, time interval between injury and surgery, smoking status, patient age at operation, follow-up time, and menisci and chondral lesions identified during surgery. Chondral lesion was considered “positive” when the Outerbridge score was Grade II or higher [21], in accordance with other long-term studies [22]. Tegner level [23] and Marx score [24] were recorded before the injury and at the latest follow-up. Postoperative anteroposterior (AP) and lateral knee radiographs were used to assess tunnel locations. Tibial tunnel mid-aperture location was assessed on the lateral view as per cent from anterior to posterior [25] and on the AP view as per cent from medial to lateral. For the femoral tunnel, mid-aperture location was assessed on the lateral view as per cent from posterior to anterior along the notch roof line [25] in addition to measuring coronal obliquity of the tunnel on the AP view [26]. Of note, for femoral tunnel position assessment, tunnel margins could be clearly seen in the hamstring group since it is soft tissue in a bone socket, whereas in the BPTB group a bone plug was filling the short femoral socket and therefore tunnel margins could not be clearly seen. In these cases, therefore, the titanium femoral screw was the tunnel reference used to assess tunnel position, acknowledging that this screw was eccentric to the patellar tendon graft itself. Patient-reported outcome scores included International Knee Documentation Committee (IKDC)–subjective score [27], Knee Outcome and Assessment Tool (KOOS) [28], and Short Form (SF)-36 score [29]. Side-to-side anterior knee laxity difference was measured with the KT-1000 knee arthrometer (MED- metric Corp, San Diego, CA) with the knee at 25° flexion and 30 lbs anteriorly-directed force. The arthrometer was checked for accuracy according to the manufacturer user’s guide. Pivot shift test [30], was graded “0” (no pivot shift), “+1-” (pivot glide), “+2-” (clear pivot shift clunk), “+3-” (explosive pivot) [31]. All measurements and physical examinations were performed in all patients by one independent investigator (IH). In addition, the single-legged hop test for distance limb symmetry index (LSI) was measured as recommended for this population [18,32]. The Institutional Review Board (Meir Medical Center, approval I D 0215-13-MMC) approved the study protocol and all participants signed informed consent.

Statistical analysis

Patient demographics, injury characteristics, concomitant operative findings and outcome measures were compared between the two surgical techniques. Data included numbers with percentages for non-numeric variables and means with standard deviations and ranges for continuous variables. Continuous variables were checked for normality using Shapiro–Wilk test. The Student’s t-test was used for comparing mean values between variables with normal distribution. The Mann–Whitney non-parametric test was used for comparing variables where the assumption of normality was rejected. Nominal variables were analysed with Chi-Square or Fisher’s exact tests. Minimal clinically important difference (MCID) value was calculated as one-half the standard deviation above the mean value as an accepted formula in ligament reconstruction population [23]. Also, because the primary goal of changing the surgical technique was to lead to superior restoration of knee laxity, and as a result of this change, lead to improved functional outcomes, correlation coefficients were calculated with Pearson rank test between the KT side-to-side difference and all functional outcome measures at follow-up. P value < 0.05 was regarded as indicating statistical significance. Statistical analyses were performed using IBM SPSS-28 software package (Armonk, NY, USA).

RESULTS

Study time-axis is presented in Fig. 1.

Two hundred patients (94 AM-BPTB and 106 TT-GST ACLRs) fulfilled the inclusion criteria. In order to perform the evaluation at exactly 5- to 10-year follow-up in both groups, the follow-up examinations of the TT-GST group (operations performed between 2004 and 2010) were performed between 2014 and 2015, while the follow-up examinations of the AM-BPTB group (operations performed between 2011 and 2017) were performed between 2021 and 2022. Flowchart of the study cohort is presented in Fig. 2.

In the TT-GST group, 106 patients fulfilled initial inclusion criteria, of which 26 met exclusion criteria during the follow-up, leaving 80 patients eligible for study evaluation at 5–10 years after the operation. Of these 80 patients, 55 (68%) were available for study-specific follow-up evaluation. In the AM-BPTB group, 94 patients fulfilled initial inclusion criteria, of which 20 met exclusion criteria during the follow-up, leaving 74 patients eligible at 5–10 years after the operation. Of these 74 patients, 49 (66%) were available for study-specific follow-up evaluation. Also, because preinjury Tegner level was between 6 and 10 in the TT-GST group (which was the first group that was evaluated, i.e. during 2014–2015, as mentioned earlier), 4 patients in the AM-BPTB group who had preinjury Tegner level below 6 were excluded in order to assure equivalent range of preinjury activity level in both groups (i.e. Tegner level between 6 and 10). Patient and injury demographics are presented in Table 1.

Similarities were demonstrated between the groups, including age (average 25, range 18–34 years), follow-up (average 7 years, range 5–10 years), preinjury Tegner level (median 7, range 6–10), time interval injury-surgery (13 ± 20 vs. 10 ± 15 months), proportion of patients who had isolated ACL reconstruction (33 vs. 31%) as opposed to those having concomitant meniscus and cartilage procedures as a whole, proportion of patients who did not require meniscus treatment (40 vs. 29%) or those who underwent partial meniscectomy (49 vs. 33%). Nevertheless, meniscus repair without partial meniscectomy was less common in the TT-GST compared to the AM-BPTB group (9 vs. 44%, p < 0.01). Follow-up rates and smoking status were also similar between the groups. Tibial tunnel aperture location on the lateral view was 46 ± 3.2% (range 38–51%) in the TT-GST compared to 35 ± 3.8% (range 30–40%) in the
AM-BPTB group ($p < 0.01$). Tibial tunnel aperture location on the AP view was $46 \pm 1.4\%$ (range $43–48\%$) in the TT-GST compared to $46 \pm 2.3\%$ (range $42–49\%$) in the AM-BPTB group ($p = 0.4$). Femoral tunnel aperture location on the lateral view was $26 \pm 4.7\%$ (range $22–35\%$) in the TT-GST compared to $29 \pm 4.1\%$ (range $22–38\%$) in the AM-BPTB group ($p = 0.1$). Femoral tunnel coronal obliquity on the AP view was $63 \pm 7.8\%$ (range $52–79\%$) in the TT-GST compared to $46 \pm 6.5\%$ (range $35–57\%$) in the AM-BPTB group ($p < 0.01$). These findings implied more posterior tibial tunnel aperture and less oblique femoral tunnel in the TT-GST group. Graft failure rates, knee laxity and surgical complications are presented in Table 2.

Statistically significant superiority in the AM-BPTB group was demonstrated in normalising the pivot shift test compared to the TT-GST group ($4 \%$ vs. $34 \%$ of patients with grossly abnormal pivot shift at follow-up, i.e. grade 2–3, accordingly, $p < 0.01$). Normal KT side-to-side difference (i.e. $< 3 \text{ mm}$) was more common in the AM-BPTB group compared to the TT-GST group ($78 \%$ vs. $49 \%$, respectively, $p < 0.01$). Sixteen patients in the TT-GST group and 15 patients in the AM-BPTB group underwent minor surgical interventions during the follow-up. These included cyclops removal (one case in the TT-GST and 2 in the AM-BPTB group), partial meniscectomies (5 cases in the TT-GST and 2 in the AM-BPTB group), one case of adhesiolysis (in the AM-BPTB group) and removal of painful metal hardware (3 cases in the TT-GST and 2 in the AM-BPTB group). In relation to the 5 cases who underwent partial meniscectomy in the TT-GST group during the follow-up period, none of these was preceded by a meniscus repair, and all demonstrated KT side-to-side difference between 0 and 3.5 mm without high-grade pivot shift. Regarding the 2 cases in the AM-BPTB group who underwent partial meniscectomy during the follow-up period, both were preceded by a meniscus repair, whereas their KT side-to-side difference was 0 and 3 mm at follow-up. These two cases may therefore represent a biological failure of the meniscus repair in young adults who returned to cutting-pivoting activities after their ACL reconstruction surgery. Anterior knee laxity and functional outcome scores at follow-up are presented in Table 3.

In the AM-BPTB group, KT side-to-side difference at follow-up was lower compared to the TT-hamstring group ($1.4 \pm 1.9$ vs. $2.8 \pm 2.3$, $p < 0.01$). The AM-BPTB group as opposed to the TT-GST group showed statistically significant higher proportion of return to preinjury Marx activity levels ($29 \%$ vs. $11 \%$, $p = 0.02$). Among the subjective outcome measures, the IKDC-subjective showed the most substantial and statistically significant difference between the groups with $88 \pm 10$ in the AM-BPTB group and $82 \pm 13$ in the TT-GST group ($p < 0.01$). In terms of MCID, which corresponded to achieving 90.6 points on the IKDC-subjective score, about one-half the patients in the AM-BPTB group as opposed to less than a third in the TT-GST group passed this value, although this difference did not reach the threshold of statistical significance ($p = 0.07$). Correlation coefficient graphs representing statistically significant inter-relationships identified between KT side-to-side difference and functional outcome measures at follow-up appear in Fig. 3 and in Fig. 4.

Lower KT side-to-side difference was correlated with higher Tegner, Marx and IKDC-subjective scores at follow-up.

**DISCUSSION**

The main finding of this study was that ACL reconstruction in young men performed with BPTB autograft and anteromedial portal technique resulted in better restoration of knee laxity alongside improved maintenance of preinjury activity levels at 5- to 10-year follow-up compared to using hamstring autograft and transtibial drilling technique. Because of the similarities in patient demographics and concomitant lesions between the groups, differences in outcomes may be attributed primarily to (1) the change made in graft choice, (2) the change made in tunnel preparation technique, or both. Regarding graft choice, several factors which may have favoured the outcomes of ACL reconstruction when using BPTB compared to hamstring autograft in this series can be mentioned: (1) Hamstring tendons harvest, as opposed to harvesting BPTB, may contribute to increased valgus knee laxity [34], and this could contribute to ACL graft stretch-out [35]; (2) BPTB is a “flat graft” forming a ribbon-like configuration which could lead to better restoration of native ACL anatomy and mechanics compared to round hamstring graft [36]; (3) bone-to-bone healing of BPTB plug in the tunnels is completed earlier compared to hamstring autograft soft tissue incorporation,
thereby decreasing the risk of graft–tunnel interface failure during the early phases of rehabilitation [37]; and (4) quadrupled hamstring graft may be subjected to some inconsistency of the final graft construct diameter which may affect tissue resiliency. Of note in this regard, graft diameter was 8 mm in all cases in this series but one, and this corresponds to the accepted diameter threshold associated with reduced failure rates in hamstring ACL reconstruction [38]. Regarding femoral tunnel preparation technique, improved stability of the ACL graft in the AM-BPTB group in this study with decreased pivot shift and KT side-to-side differences can be attributed to the more anterior tibial aperture (range 30–40%) as measured on the lateral knee view as opposed to the more posterior tibial tunnel aperture in the TT-GST group (range 38–51%). This corresponds to the desired tibial tunnel aperture location of ≤40% from anterior to posterior as recently summarised [39]. With regard to femoral tunnel aperture and tunnel obliquity in this series, it is less certain whether and to what extent these have contributed to graft stability since both groups showed similar tunnel aperture on the lateral view, while it still remains controversial how to optimise tunnel

Fig. 2. Flowchart of the study cohort. TT-GST, transtibial drilling technique with gracilis-semitendinosus hamstring graft; AM-BPTB, anteromedial portal with bone-patellar tendon-bone graft. * This patient underwent surgery for a tumour resected of his tongue during the follow-up. A muscle flap was transferred from the leg and therefore follow-up evaluation was not applicable for the purpose of the study due to concomitant leg morbidity. PVNS = pigmented villonodular synovitis.
TT-GST group because this is associated with lower rates of progression to improved knee stability and functional outcomes at follow-up in the choice and tunnel preparation technique which differed between the posterior tibial aperture [25]. The may have been adhering to earlier recommendations of slightly more drilling technique [10,40]. And last but not least, in addition to graft to be more common using transtibial compared to anteromedial portal may be echoed by recent analyses that found femoral tunnel malposition technique which allows more flexibility in tibial tunnel aperture location without impending a desired femoral tunnel aperture which depends on the tibial tunnel direction as opposed to the transtibial technique, but it may also be attributed to increasing awareness of the surgeon to the evolving global concept of preferred ACL tunnel apertures during this decade between 2011 and 2017 compared to the TT-GST group which was performed between 2004 and 2010. In that earlier decade surgeons may have been adhering to earlier recommendations of slightly more posterior tibial aperture [25]. The findings of this study in this regard may be echoed by recent analyses that found femoral tunnel malposition to be more common using transtibial compared to anteromedial portal drilling technique [10,40]. And last but not least, in addition to graft choice and tunnel preparation technique which differed between the groups, another factor which should be noted and could have contributed to improved knee stability and functional outcomes at follow-up, the TT-GST group because this is associated with lower rates of progression to knee osteoarthritis and potentially better function at medium-term follow-up after acute injuries [41].

Statistically significant associations were found between lower KT side-to-side difference and higher activity levels as represented by Tegner and Marx scores as well as higher IKDC-subjective scores at 5–10 years after the ACL reconstruction. This finding emphasises the critical importance of normalising anterior knee laxity in order to maintain long-term active life. In addition, it supports the value of the KT arthrometer as a clinically valuable objective measuring tool even at relatively long time periods after surgery, during which multiple factors could have led to changing one’s lifestyle and affect activity levels, regardless of knee laxity by itself. The variation in the KT side-to-side measurements in this study at follow-up is consistent with another observation at seven years after autologous ACL reconstruction [42]. As opposed to the findings of the current study, other investigators did not identify significant association between KT side-to-side difference and level of activity at minimum two-year follow-up and concluded that only elimination of the pivot-shift but not normalisation of KT-difference was a valuable measure of liga- ment laxity which was associated with higher activity levels at follow-up [31]. That study, however [31], was not specific in relation to sex (57% men), age (range 14–60 years) and instrumented knee laxity examinations which were performed by four assistants as opposed to one inves- tigator in the current study, all of which may have been masking existing relationships between instrumented knee laxity tests and maintenance of activity levels. Thus, the clinical value of a standard KT arthrometer is

### Table 1
Patient, injury and surgery demographics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TT-GST (n = 55)</th>
<th>AM-BPTB (n = 45)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at operation [mean] (range)</td>
<td>25 (18–34)</td>
<td>25 (18–34)</td>
<td>0.8</td>
</tr>
<tr>
<td>Follow-up, years [mean] (range)</td>
<td>7.1 (5–10)</td>
<td>7.2 (5–10)</td>
<td>0.8</td>
</tr>
<tr>
<td>Tegner level at preinjury [median] (range)</td>
<td>7 (6–10)</td>
<td>7 (6–10)</td>
<td>0.05</td>
</tr>
<tr>
<td>Marx score at preinjury [median] (range)</td>
<td>12 (8–16)</td>
<td>12 (4–16)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI [mean ± SD]</td>
<td>24 ± 2</td>
<td>25 ± 3</td>
<td>0.01</td>
</tr>
<tr>
<td>Interval injury-surgery, months [mean ± SD]</td>
<td>15 ± 20</td>
<td>10 ± 15</td>
<td>0.1</td>
</tr>
<tr>
<td>Isolated ACL tear [%]</td>
<td>18/55 = 33</td>
<td>14/45 = 31</td>
<td>0.9</td>
</tr>
<tr>
<td>No concomitant meniscus treatment required [%]</td>
<td>22/55 = 40</td>
<td>13/45 = 29</td>
<td>0.2</td>
</tr>
<tr>
<td>Concomitant partial meniscectomies [%]</td>
<td>27/55 = 49</td>
<td>15/45 = 33</td>
<td>0.1</td>
</tr>
<tr>
<td>Concomitant meniscus repair without meniscectomy [%]</td>
<td>5/55 = 9</td>
<td>20/45 = 44</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Follow up rate [%] (final cohort/all eligible patients)</td>
<td>55/80 = 68</td>
<td>45/71 = 63</td>
<td>0.5</td>
</tr>
<tr>
<td>Smokers [%]</td>
<td>15/55 = 27</td>
<td>13/45 = 29</td>
<td>0.9</td>
</tr>
<tr>
<td>Tibial tunnel aperture, lateral view [%] [mean ± SD] (range)</td>
<td>46 ± 3.2 (38–51)</td>
<td>35 ± 3.8 (30–40)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Tibial tunnel aperture, AP view [%] [mean ± SD] (range)</td>
<td>46 ± 1.4 (43–48)</td>
<td>46 ± 2.3 (42–49)</td>
<td>0.4</td>
</tr>
<tr>
<td>Femoral tunnel aperture, lateral view [%] [mean ± SD] (range)</td>
<td>26 ± 4.7 (22–35)</td>
<td>29 ± 4.1 (22–38)</td>
<td>0.1</td>
</tr>
<tr>
<td>Femoral tunnel obliquity, AP view [%] [mean ± SD] (range)</td>
<td>63 ± 7.8 (52–79)</td>
<td>46 ± 6.5 (35–57)</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

SD = standard deviation; BMI = body mass index.

### Table 2
Graft failure rates, knee laxity and surgical complications.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TT-GST (n = 55)</th>
<th>AM-BPTB (n = 45)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Graft failures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revision ACL reconstruction and MRI-documented ACL graft rupture during the follow-up period [%]</td>
<td>9/106 = 8.5</td>
<td>6/94 = 6.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Pivot shift grade 2–3 at follow-up [%]</td>
<td>19/55 = 34</td>
<td>2/45 = 4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pivot shift grade 1 ± at follow-up [%]</td>
<td>24/55 = 44</td>
<td>8/45 = 18</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pivot shift grade 0 at follow-up [%]</td>
<td>12/55 = 22</td>
<td>35/45 = 78</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>KT side-to-side difference &gt; 5 mm at follow-up [%]</td>
<td>8/55 = 15</td>
<td>2/45 = 4</td>
<td>0.1</td>
</tr>
<tr>
<td>KT side-to-side difference 3-5 mm at follow-up [%]</td>
<td>20/55 = 36</td>
<td>8/45 = 18</td>
<td>0.04</td>
</tr>
<tr>
<td>KT side-to-side difference &lt; 3 mm at follow-up [%]</td>
<td>27/55 = 49</td>
<td>35/45 = 78</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>Minor surgical interventions during follow-up</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclops removal [n.]</td>
<td>1</td>
<td>2</td>
<td>–</td>
</tr>
<tr>
<td>Meniscectomies [n.]</td>
<td>5</td>
<td>2</td>
<td>–</td>
</tr>
<tr>
<td>Adhesiolysis [n.]</td>
<td>0</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>Removal of painful hardware (tibia metal screw, staple) [n.]</td>
<td>3</td>
<td>2</td>
<td>–</td>
</tr>
<tr>
<td>Sum of all the above minor interventions [%]</td>
<td>9/55 = 16</td>
<td>7/45 = 15</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Joint infection</strong> [n.]</td>
<td>1</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*These cases were not examined at follow-up as part of the final cohort.*
supported by the current findings, at times when objective measuring tools that quantify the pivot shift translation are still evolving \[43\], and may be less readily available for sports physicians.

Based on the SF-36 questionnaire which represents more holistic measures of health-related quality of life and is not specific just to the knee injury by itself, both groups showed similarities in outcomes. This signifies that the general health, social life, well-being and mental health perceptions, were not different between the groups and therefore the differences observed in Tegner and Marx activity levels between the two surgical techniques can largely be attributed to the differences observed in the knee condition in terms of laxity and sense of stability. This is important because the time elapsed between the operation and follow-up assessment point in such a study may be subjected to introducing other factors than just the knee injury and surgery, which could as well affect the maintenance of activity levels. One exception in this regard was “Role limitations due to physical health” sub-score which showed statistically significant higher scores in the BPTB group. This is likely the result of the fact that this sub-score more specifically represents sports function, as
opposed to the other measures of the SF-36 questionnaire which relate more to general physical and mental health perceptions.

In this study, KOOS sub-scores were not significantly different between the groups. Thus, it appears that while patients better maintain their preinjury sports activities at 5–10 years after ACL reconstruction performed with BPTB and anteromedial portal compared to reconstruction using hamstring autograft and transtibial drilling, when confronted with very specific questions about knee pain and knee function, both groups reveal that there is substantial room for improvement, either in surgical terms or during the rehabilitation phase, and no single technique shows clear superiority.

The uniqueness of this study which explores the clinical impact of implementing a debatable technical change in ACL reconstruction is represented by providing a wide spectrum of outcome measures and health-related quality of life assessments, specific in-person evaluation of the patients at medium to long-term follow-up, limiting the heterogeneity of the subjects (i.e. specific active age group, men only, sports trauma), and avoiding inter-observer variability of the physical tests (i.e. single investigator performing all tests), while addressing a most suitable group for considering ACL reconstruction in terms of age and activity levels.

Limitations of this investigation should be acknowledged. First, since changing the surgical technique included both a change in autograft choice as well as in tunnel preparation drilling technique, it is not possible to determine which of the two factors had greater contribution to the improvement observed in the clinical outcomes. Second, there was no strict control on the implementation of rehabilitation guidelines and the patients were not directed to a single rehabilitation centre. And last but not least, it is important to acknowledge that evolving surgical techniques for ACL reconstruction such as accompanying anterolateral reinforcement procedures or tibial slope realignment osteotomies did not take place in this study, although these may further become introduced in upcoming years and affect the way ACL reconstruction is executed, particularly in high-risk populations [44–46].

CONCLUSION

Young men undergoing ACL reconstruction with patellar tendon autograft and anteromedial drilling outperform at 5- to 10-year follow-up in terms of graft stability and activity levels compared to young men undergoing reconstruction with hamstring autograft and transtibial drilling.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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