

# Long-Term Results of Anterior Cruciate Ligament Reconstruction Using Hamstring Grafts and the Outside-In Technique

## A Comparison Between 5- and 15-Year Follow-up

Antonio Ponso,<sup>\*†</sup> MD, Edoardo Monaco,<sup>†</sup> MD, Luca Basiglini,<sup>†</sup> MD, Raffaele Iorio,<sup>†</sup> MD, Ludovico Caperna,<sup>†</sup> MD, Piergiorgio Drogo,<sup>†</sup> MD, Fabio Conteduca,<sup>†</sup> MD, and Andrea Ferretti,<sup>†</sup> MD

*Investigation performed at Kirk Kilgour Sports Traumatology Center, Sant'Andrea Hospital, La Sapienza University of Rome, Rome, Italy*

**Background:** Increased femoral tunnel widening and weakness of the hamstring muscles postoperatively have been described as potential adverse events after anterior cruciate ligament (ACL) reconstruction (ACLR) with a hamstring graft. Meniscectomy and cartilage lesions are important factors for the development of degenerative osteoarthritis.

**Purpose:** To compare 15-year follow-up data with 5-year follow-up data from the same cohort of patients after ACLR with a hamstring autograft using an outside-in technique.

**Study Design:** Case series; Level of evidence, 4.

**Methods:** A total of 72 patients who underwent anatomic ACLR with a quadruple hamstring graft and an outside-in technique were selected for this prospective study. Patients were reviewed at a minimum follow-up of 15 years. Results were compared with the same series of patients previously reviewed at 5 years after surgery. Lysholm, International Knee Documentation Committee (IKDC), and Tegner scores as well as KT-1000 arthrometer measurements were obtained at final follow-up. Comparative weightbearing radiographs were obtained and analyzed according to the Fairbank, Kellgren-Lawrence, and IKDC classifications and used for the tunnel evaluation.

**Results:** No significant difference was detected on the subjective evaluation. Objectively, patients categorized as A or B according to the IKDC score were not significantly different at 5 and 15 years ( $P < .01$ ). A KT-1000 arthrometer side-to-side manual maximum difference  $>5$  mm, a pivot shift  $>2+$ , any giving-way episode, and ACL revision surgery were considered as failures, and these were noted in 6 patients at 5 years and 6 patients at 15 years. The radiological evaluation at 15 years showed a higher rate of osteoarthritis in 2 of 3 radiological scales used in the study compared with results at 5-year follow-up ( $P < .01$ ). At 15-year follow-up, there was a statistically significant reduction in the mean tibial tunnel diameter ( $P < .01$ ).

**Conclusion:** Endoscopic single-bundle ACLR using hamstring grafts and an outside-in technique demonstrated good results at 15-year follow-up in terms of subjective, objective, and radiographic evaluations. As compared with 5-year follow-up, clinical results remained stable both subjectively and objectively. However, a progression of osteoarthritis changes was observed, especially in patients in whom meniscectomy had been performed.

**Keywords:** anterior cruciate ligament reconstruction; knee; long-term outcome

A rupture of the anterior cruciate ligament (ACL) is a common injury in amateur and professional sports. ACL deficiency is characterized by severe difficulty in athletic performance and sometimes in daily activities, such that restabilization is generally accepted and requested.<sup>7,27,35,50</sup>

Meniscectomy, cartilage lesions, or a prolonged interval from injury to reconstruction are important factors for the development of degenerative osteoarthritis (DOA). Therefore, the restoration of long-term stability and free knee joint function remain basic treatment principles so as to avoid serious sequelae such as meniscus and cartilage changes and the progression of DOA.<sup>13,18,25,37,60</sup>

ACL reconstruction (ACLR) has changed over the past decades. Despite several graft choices,<sup>21</sup> reconstructions

The Orthopaedic Journal of Sports Medicine, 6(8), 2325967118792263  
DOI: 10.1177/2325967118792263  
© The Author(s) 2018

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For article reuse guidelines, please visit SAGE's website at <http://www.sagepub.com/journals-permissions>.

using a bone–patellar tendon–bone (BPTB) autograft and hamstring autograft (semitendinosus and gracilis graft) are the most commonly used procedures for ACL surgery.<sup>48</sup>

Both graft types have morbidity. The major benefits of using a hamstring graft compared with a BPTB graft are less anterior knee pain, less kneeling discomfort, and less potential damage to the extensor mechanism.<sup>1,20,54</sup> On the other hand, increased femoral tunnel widening and weakness of the hamstring muscles postoperatively have been described as potential adverse events after reconstruction with a hamstring graft.<sup>8,16</sup>

The choice of ACLR technique is not straightforward. One issue concerns the method of drilling the tunnel into the femur. Traditionally, the femoral tunnel is drilled from outside to inside the knee joint, and an incision is made in the outward aspect of the thigh to reach the bone (2-incision technique).<sup>5</sup> In this procedure, the graft is fixed to the femur from outside to inside the joint by direct visualization of the tunnel through the thigh incision.

The 1-incision arthroscopic technique consists of drilling the femoral tunnel from inside the knee joint under arthroscopic visualization, thereby sparing the thigh incision and quadriceps (anterior muscles of the thigh) dissection.<sup>31</sup> The graft is fixed to the femur from inside to outside the joint through arthroscopic guidance and then fixed. Thus, the only incision needed is the one for drilling the tibial tunnel, which is done (as in the 2-incision technique) through an anterior incision below the knee.

In the past 2 decades, the most commonly used method worldwide has been the transtibial technique<sup>10</sup>; most studies on tunnel enlargement with suspension devices have investigated the transtibial technique, and little is known of the outside-in technique.<sup>40,44</sup> To overcome tunnel-related problems, especially for hamstring autografts, the outside-in technique may reduce the risk of noncorrect graft positioning.<sup>40</sup>

The aim of this study was to report the long-term clinical and radiological outcomes at 15-year follow-up compared with the same series of patients previously evaluated at 5-year follow-up after ACLR with a hamstring autograft using an outside-in technique. The primary hypothesis was that there would be no differences in knee laxity or clinical outcomes in the ACL-reconstructed knee at 15-year follow-up compared with 5-year follow-up.<sup>19</sup> Our secondary hypothesis was that there would be a higher incidence and severity of DOA in the ACL-reconstructed knee at 15-year follow-up compared with 5-year follow-up.

## METHODS

### Patient Selection

This was a prospective series of 72 consecutive patients who underwent anatomic ACLR with a doubled semitendinosus

and gracilis tendon (DGST) autograft and an outside-in technique performed by a single orthopaedic senior surgeon (A.F.). All patients underwent ACLR from January 2001 to December 2002. Inclusion criteria were complete ACL lesions evaluated by the Lachman test and rotatory ACL deficiency as evaluated by the pivot-shift test (positive: 1+, 2+, 3+), ACL lesions confirmed by magnetic resonance imaging, and surgery within 10 days from trauma. Exclusion criteria were body mass index >29 kg/m<sup>2</sup>, age >50 years, associated ligamentous injuries as documented by laxity tests other than the Lachman test and pivot-shift test, cartilage damage (grade 3 or 4 according to the Outerbridge classification<sup>51</sup>), previous knee surgery, rheumatological disorders, and associated malalignment (severe valgus >7° or varus knee deviation >10°).

The same series of patients was assessed preoperatively and evaluated at 1 year, at 5 years (follow-up), and at a minimum final follow-up of 15 years (medium-term long-term follow-up). All patients accepted and signed appropriate informed consent forms to be included in the study. All procedures performed involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

### Surgical Technique

An arthroscopically assisted anatomic single-bundle 2-incision technique using DGST autografts was used. The tibial tunnel was created with a standard guide at 65°. The point of entry of the femoral tunnel, as described by the outside-in technique, was selected, independently of the tibial tunnel, in the center of the anatomic femoral footprint of the ACL, which was located midway between the raised bony landmark commonly visualized just anterior to the femoral attachment of the ACL<sup>53</sup> and the over-the-top position. The tendons were passed using an outside-in technique by direct visualization of the tunnel through the thigh incision and manually tensioned before fixation. The bundles were fixed on the femur using the Swing Bridge as a suspension device (Citieffe) and on the tibia using the Evolgate as a cage-reinforced screw device (Citieffe). The aim was to create a tight fit of the graft in the bone tunnel for all patients.

### Postoperative Rehabilitation

The involved knee was placed in a full extension brace for 2 weeks postoperatively; during this time, patients were permitted to bear weight on the knee with the assistance of crutches, as tolerated, and they were prescribed daily isometric and isotonic exercises. After 2 weeks, progressive range of motion exercises, in synergy with isometric and

\*Address correspondence to Antonio Ponzo, MD, Kirk Kilgour Sports Traumatology Center, Sant'Andrea Hospital, La Sapienza University of Rome, Via Di Grottarossa 1035-1039, 00189 Roma, Italy (email: antonio.ponzo@hotmail.it) (Twitter: @antonioponzo3).

<sup>†</sup>Kirk Kilgour Sports Traumatology Center, Sant'Andrea Hospital, La Sapienza University of Rome, Rome, Italy.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

Ethical approval for this study was obtained from La Sapienza University of Rome.

isotonic exercises, were encouraged. At 4 weeks postoperatively, patients were permitted full weightbearing on the knee without crutches or a brace, continuing muscular and proprioceptive recovery. From the second month postoperatively, a heavier muscle-strengthening program was prescribed. From approximately 4 to 6 months postoperatively, a gradual return to athletics and sports-specific training was encouraged. From the fifth month postoperatively, as soon as the trainer deemed the patient to be “ready to go,” a full return to sports was allowed.

## Follow-up

At 1-year follow-up, patients were assessed only subjectively and objectively. The medium- and long-term follow-ups after ACLR were performed by 2 observers (L.C. for 5-year follow-up and A.P. for 15-year follow-up), who were independent and not involved in the initial surgery. The activity level was assessed using the Tegner score.<sup>61</sup> The Lysholm score<sup>46</sup> was used to evaluate the subjective functional status of the patient, and the International Knee Documentation Committee (IKDC) score<sup>28</sup> was used to evaluate clinical outcomes.

Patients underwent a standardized bilateral knee examination: stability testing was performed using the Lachman test, the pivot-shift test, and the KT-1000 arthrometer (Medmetric). Bilateral weightbearing anteroposterior radiographs in full extension and lateral views were obtained and evaluated using the Fairbank classification,<sup>17</sup> the Kellgren-Lawrence classification,<sup>38</sup> and the IKDC grading system.<sup>28</sup> An analysis of tunnel enlargement was performed with the method described by L'Insalata et al,<sup>44</sup> an analysis of the position of the tibial tunnel was determined with the method described by Howell and Clark,<sup>30</sup> and an analysis of the femoral tunnel position was performed with the method described by Sommer et al.<sup>58</sup>

These measurements were performed by a radiologist who used dedicated digital radiology software (Centricity PACS/AW Suite; GE Healthcare) and corrected for magnification. The ratio between the actual value and the intraoperatively determined tunnel diameter, according to medical records, was used to assess tunnel widening. Results at 15-year follow-up were compared with the results previously evaluated at 5-year follow-up.

## Statistical Analysis

The paired Student *t* test and chi-square test (Pearson test) were used to analyze the data for the patients in this series. The Pearson correlation was also assessed to identify the DOA grade according to the Kellgren-Lawrence classification, Fairbank classification, and IKDC score.

To evaluate the primary study outcomes (subjective, objective, arthrometer, and radiographic evaluations), the power to detect a difference between 5-year follow-up and 15-year follow-up mean scores was determined. For all power analyses, the alpha value for a type I error was 0.05.

TABLE 1  
15-Year Follow-up Data (N = 72 Patients)

	n (%)
Lost at follow-up	5 (6.9)
Telephone interview	5 (6.9)
Clinical evaluation	62 (86.1)
Radiological examination	62 (86.1)

TABLE 2  
Demographic Data<sup>a</sup>

	5-Year Follow-up (n = 62)	15-Year Follow-up (n = 62)
Age, y	31.6 (21-55)	41.6 (31-65)
Sex, male/female, n	47/15	47/15
Follow-up, mo	65 (60-71)	185 (180-191)

<sup>a</sup>Values are shown as mean (range) unless otherwise indicated.

For the Lysholm score, the delta value was 0.1759 (sample size: n = 66; 95% CI, 94.61-96.98). For the KT-1000 arthrometer, the delta value was 0 (sample size: n = 62; 95% CI, 2.06-3.74). For the IKDC objective evaluation, the delta value was 0.30171 (sample size: n = 62). For the radiographic evaluation, the delta value was 0.5004, 0.2472, and 0.6268 for the IKDC score, Fairbank classification (sample size: n = 62; 95% CI, 1.76-1.80), and Kellgren-Lawrence classification (sample size: n = 62; 95% CI, 1.28-1.65), respectively.

Statistical analysis was performed using R software (version 3.1.0; R Foundation for Statistical Computing).

## RESULTS

Demographic and follow-up data are summarized in Tables 1 and 2. Patients had a mean age at the time of surgery of 26.6 years (range, 16-50 years). At 15-year follow-up, 62 of the 72 patients (86.1%) underwent complete subjective, clinical, and radiological evaluations and were available for a matched comparison with the results previously reported at 5-year follow-up.

At the time of surgery, partial medial meniscectomy was performed in 7 patients, partial lateral meniscectomy was performed in 9 patients, and partial medial and lateral meniscectomy was performed in 3 patients. At the time of surgery, 33 of 62 patients (53.2%) were involved in high-risk sports.

After surgery, 2 patients presented with septic arthritis that resolved after 1 or 2 instances of outpatient irrigation and 2 weeks of antibiotic therapy. No other complications were observed. No patient underwent revision surgery because of a new injury to the operated knee. At 5-year follow-up, 5 of 62 patients reported an ACL tear to the other knee and 3 of 62 patients at 15-year follow-up; all patients underwent ACLR.

Clinical results are summarized in Table 3.

TABLE 3  
Clinical Results<sup>a</sup>

Outcome Measure	Preoperative (n = 62)	1-Year Follow-up (n = 62)	5-Year Follow-up (n = 62)	15-Year Follow-up (n = 62)
Lysholm	56.00 ± 5.04	96.16 ± 4.50	95.82 ± 26.94	95.80 ± 4.91
IKDC subjective	58.00 ± 7.38	94.64 ± 4.94	93.53 ± 26.88	94.31 ± 6.26
Tegner, median (range)	6 (5-9)	7 (2-9)	6 (3-8)	5 (3-8)
IKDC objective, n (%)				
A	—	49 (79.0)	46 (74.2)	34 (54.8)
B	—	12 (19.4)	15 (24.2)	23 (37.1)
C	39 (62.9)	1 (1.6)	1 (1.6)	5 (8.1)
D	23 (37.1)	—	0 (0.0)	0 (0.0)
KT-1000 arthrometer side-to-side manual maximum difference, mm	—	2.12 ± 2.57	2.65 ± 2.29	2.90 ± 3.33
<3 mm, n (%)	—	46 (74.2)	44 (71.0)	46 (74.2)
3-5 mm, n (%)	—	12 (19.4)	12 (19.4)	10 (16.1)
>5 mm, n (%)	—	4 (6.5)	6 (9.7)	6 (9.7)

<sup>a</sup>Values are shown as mean ± SD unless otherwise indicated. IKDC, International Knee Documentation Committee.

### Subjective Evaluation

All scores improved from the preoperative evaluation, except the Tegner score. No significant statistical differences were detected between the time points for any of the subjective scores.

### Objective Evaluation

The number of patients with an IKDC objective score that was categorized as C or D at 15-year follow-up (5/62; 8.1%) was not statistically significantly higher compared with that at 5-year follow-up (1/62; 1.6%) ( $P > .05$ ).

### Arthrometric Evaluation

The difference in KT-1000 arthrometer evaluations between the time points was not statistically significant ( $P > .05$ ). Considering a KT-1000 arthrometer side-to-side manual maximum difference >5 mm, a pivot shift of 2+ or 3+, any giving-way episode during the follow-up period, and revision surgery as failures, there were 6 patients at 15-year follow-up and 6 patients at 5-year follow-up who were classified as failures ( $P > .05$ ).

### Radiological Evaluation

Overall radiological results are summarized in Table 4. Radiological results of meniscectomized and nonmeniscectomized patients at 5-year follow-up are summarized in Table 5. Radiological results of meniscectomized and nonmeniscectomized patients at 15-year follow-up are summarized in Table 6.

The number of patients who had an IKDC score that was categorized as C or D at 15-year follow-up (7/62; 11.3%) was statistically significantly higher compared with that at 5-year follow-up (0/62; 0.0%) ( $P = .006$ ). The number of patients who had a Kellgren-Lawrence classification of grade II, III, or IV at 15-year follow-up (23/62; 37.1%) was statistically significantly higher compared with that at 5-

TABLE 4  
Overall Radiological Results<sup>a</sup>

	5-Year Follow-up (n = 62)	15-Year Follow-up (n = 62)
IKDC score		
A	52 (83.9)	35 (56.5)
B	10 (16.1)	20 (32.3)
C	0 (0.0)	7 (11.3) <sup>b</sup>
D	0 (0.0)	0 (0.0)
Fairbank classification		
Grade I	37 (59.7)	28 (45.2)
Grade II	20 (32.3)	24 (38.7)
Grade III	5 (8.1)	8 (12.9)
Grade IV	0 (0.0)	2 (3.2)
Kellgren-Lawrence classification		
Grade 0	0 (0.0)	5 (8.1)
Grade I	55 (88.7)	34 (54.8)
Grade II	7 (11.3)	16 (25.8)
Grade III	0 (0.0)	6 (9.7) <sup>c</sup>
Grade IV	0 (0.0)	1 (1.6) <sup>c</sup>

<sup>a</sup>Values are shown as n (%). IKDC, International Knee Documentation Committee.

<sup>b</sup> $P = .006$ .

<sup>c</sup> $P = .0007$ .

year follow-up (7/62; 11.3%) ( $P = .0007$ ). There was no statistically significant difference between 15-year and 5-year follow-up results for the Fairbank classification.

At 15-year follow-up, the number of meniscectomized patients with an IKDC score categorized as C or D (4/19; 21.1%) was statistically significantly higher compared with the number of nonmeniscectomized patients (3/43; 7.0%) ( $P = .04$ ). At 15-year follow-up, the number of meniscectomized patients with a Fairbank classification of grade III or IV (7/19; 36.9%) was statistically significantly higher than the number of nonmeniscectomized patients (3/43; 7.0%) ( $P = .002$ ).

TABLE 5  
Radiological Results at 5-Year Follow-up of Patients  
Who Did and Did Not Undergo Meniscectomy<sup>a</sup>

	Meniscectomy (n = 19)	No Meniscectomy (n = 43)
IKDC score		
A	14 (73.7)	38 (88.4)
B	5 (26.3)	5 (11.6)
C	0 (0.0)	0 (0.0)
D	0 (0.0)	0 (0.0)
Fairbank classification		
Grade I	8 (42.1)	29 (67.4)
Grade II	8 (42.1)	12 (27.9)
Grade III	3 (15.8)	2 (4.7)
Grade IV	0 (0.0)	0 (0.0)
Kellgren-Lawrence classification		
Grade 0	0 (0.0)	0 (0.0)
Grade I	16 (84.2)	39 (90.7)
Grade II	3 (15.8)	4 (9.3)
Grade III	0 (0.0)	0 (0.0)
Grade IV	0 (0.0)	0 (0.0)

<sup>a</sup>Values are shown as n (%). IKDC, International Knee Documentation Committee.

TABLE 6  
Radiological Results at 15-Year Follow-up of Patients  
Who Did and Did Not Undergo Meniscectomy<sup>a</sup>

	Meniscectomy (n = 19)	No Meniscectomy (n = 43)
IKDC score		
A	7 (36.8)	28 (65.1)
B	8 (42.1)	12 (27.9)
C	4 (21.1)	3 (7.0) <sup>b</sup>
D	0 (0.0)	0 (0.0)
Fairbank classification		
Grade I	7 (36.8)	21 (48.8)
Grade II	5 (26.3)	19 (44.2)
Grade III	6 (31.6)	2 (4.7) <sup>c</sup>
Grade IV	1 (5.3)	1 (2.3) <sup>c</sup>
Kellgren-Lawrence classification		
Grade 0	0 (0.0)	5 (11.6)
Grade I	11 (57.9)	23 (53.5)
Grade II	4 (21.1)	12 (27.9)
Grade III	3 (15.8)	3 (7.0)
Grade IV	1 (5.3)	0 (0.0)

<sup>a</sup>Values are shown as n (%). IKDC, International Knee Documentation Committee.

<sup>b</sup> $P = .04$ .

<sup>c</sup> $P = .002$ .

Regarding the meniscectomized patients, the number of them with an IKDC score categorized as C or D at 15-year follow-up (4/19; 21.1%) was statistically significantly higher compared with that at 5-year follow-up (0/19; 0.0%) ( $P = .03$ ). No statistically significant

differences were detected for the Kellgren-Lawrence or Fairbank classifications in meniscectomized patients.

Regarding the nonmeniscectomized patients, the number of them with a Kellgren-Lawrence classification of grade II, III, or IV at 15-year follow-up (15/43; 34.9%) was statistically significantly higher compared with that at 5-year follow-up (4/43; 9.3%) ( $P < .01$ ). No statistically significant differences were detected for the Fairbank or IKDC classifications in nonmeniscectomized patients.

### Tunnel Evaluation

At 15-year follow-up, the analysis on positioning of the tibial tunnel by the method described by Howell and Clark<sup>30</sup> showed that 41% of patients were categorized in group 1 (Blumensaat line falls anterior to the tunnel), 54% were categorized in group 2 (Blumensaat line falls in the anterior 50% of the tunnel), 5% were categorized in group 3 (Blumensaat line falls in the posterior 50% of the tunnel), and no patients were categorized in group 4 (Blumensaat line falls posterior to the tunnel). Also at 15-year follow-up, the analysis on positioning of the femoral tunnel by the method described by Sommer et al<sup>58</sup> showed that 70% of patients were grouped in area 1A (the anatomical area of the ACL femoral insertion that Sommer et al refer to as the “green zone” where the graft should ideally be placed, respectively in sagittal and frontal planes, between 10 and 11 o’clock for the right knee, 1 and 2 o’clock for the left knee), 30% in area 2A (designated the “yellow zone” by Sommer et al, in a more ventral position in the sagittal plane but in the ideal position in the frontal plane); no patients were grouped in the areas B, C, and D, designated the “red zone” locations by Sommer et al.

At the time of surgery, the tibial and femoral tunnels had a diameter of 9 mm. At 5-year follow-up, the mean diameter was  $10.5 \pm 1.30$  mm for the tibial tunnel and  $8.7 \pm 1.22$  mm for the femoral tunnel. At 15-year follow-up, the mean diameter was  $9.7 \pm 1.91$  mm for the tibial tunnel and  $8.6 \pm 1.17$  mm for the femoral tunnel.

In comparing patients with a tibial tunnel diameter  $<9$  mm, we found a statistically significant difference between follow-up at 15 years compared with 5 years (16/62 patients [25.8%] vs 5/62 patients [8.1%], respectively) ( $P < .01$ ). Comparing patients with a femoral tunnel diameter  $<9$  mm, there was not a statistically significant difference between follow-up at 15 years compared with 5 years (41/62 patients [66.1%] vs 37/62 patients [59.7%], respectively).

### DISCUSSION

The first important finding of this study is that clinical results of arthroscopically assisted anatomic single-bundle 2-incision reconstruction using DGST autografts with an outside-in technique remained stable at long-term follow-up (15 years) when compared with medium-term follow-up (5 years). Therefore, our primary hypothesis was confirmed. In fact, neither the overall evaluation nor individual parameters for the IKDC subjective score showed statistically significant differences when a comparison was made with the previous evaluation at 5-year follow-up. Compared with

medium-term follow-up, the observed reduction in the Tegner score may be interpreted as a physiological reduction in the sports activity level that is age and work related. Several long-term follow-up studies have demonstrated a similar decrease in activity levels years after surgery.<sup>2,14,43,49</sup> Given the mean age at the time of injury and at the time of follow-up, the decrease in activity may be more of a reflection of lifestyle changes and not of decreased function.

The absence of surgical reoperations on the operated knee is an important finding, confirming the validity of the surgical technique. In fact, even though the failure rate for the IKDC objective score was increased from 1.1% at 5-year follow-up to 8.6% at 15-year follow-up, there was not a statistically significant difference ( $P > .05$ ). Moreover, when looking at the arthrometric evaluation, the rate of failure was the same at 5-year and 15-year follow-ups. Similar long-term clinical results have been reported by other authors<sup>24,26</sup> such as Leys et al<sup>42</sup>; those findings showed that ACLR using an ipsilateral autograft continued to show excellent results in terms of patient satisfaction, symptoms, function, activity level, and stability. Moreover, Sajovic et al<sup>55</sup> showed that both hamstring and patellar tendon autografts provided good subjective outcomes and objective stability at 11 years, although a positive pivot-shift test (1+) finding was significantly more frequent in the BPTB group. Finally, Leiter et al,<sup>41</sup> in a 14-year follow-up study, reported a high rate of self-reported satisfaction, objective results, and current quality of life.

The second important finding of the study concerns the radiographic evaluation: at 15-year follow-up, ACLR with an outside-in technique showed a higher rate of DOA in 2 of 3 radiological scales used in the study compared with results at 5-year follow-up. Therefore, our secondary hypothesis was partially confirmed.

Studies looking at long-term knee DOA after ACLR have shown various results.<sup>41,62</sup> Daniel et al<sup>14</sup> prospectively compared ACLR and conservative treatment after an ACL rupture and found that patients with a reconstructed ACL had a higher level of DOA detected by radiographs and bone scanning. Kessler et al<sup>39</sup> observed 42% of patients with DOA after ACLR compared with 25% after conservative treatment. The authors postulated that ACL surgery is a new trauma to the knee, which prolongs the already present inflammatory response after an ACL rupture.<sup>14,39</sup> According to Janssen et al,<sup>36</sup> in a long-term follow-up study, even if there was a higher percentage of DOA signs in comparison with previous medium-term evaluations, the global incidence of DOA was slightly lower than that previously reported by other authors. Moreover, Pernin et al,<sup>52</sup> in a 24.5-year follow-up study, reported that patients with “normal” or “nearly normal” radiographic assessment findings at 11.5 years remained stable at final follow-up, so it is possible that the radiological results of this study will not deteriorate significantly over time.

In the literature, the incidence of meniscal lesions associated with an ACL injury varies from 25% to 45% for the medial meniscus and from 31% to 65% for the lateral meniscus.<sup>3</sup> As reported by several authors,<sup>11,14,15,22,23,39,45,47</sup> this study showed that associated meniscal injuries in the knee can result in suboptimal outcomes after ACLR and

increase the rate of DOA. In 1991, Conteduca et al<sup>12</sup> stated that “meniscectomy represents the actual failure of a knee with ACL insufficiency concerning the development of DOA”; also in 1991, Ferretti et al<sup>18</sup> reported that “reconstruction of ACL, even if it may preserve the menisci from subsequent tears, does not completely protect the joint surface from major wear, and degree of DOA changes is inevitable in the long term, particularly if menisci has been removed.” In the subgroup of meniscectomized patients, the increase in DOA signs at 15-year follow-up compared with 5-year follow-up was only found in 1 of 3 scales used; the same results were highlighted for the subgroup of nonmeniscectomized patients. However, the overall rate of DOA at long-term follow-up was statistically higher in meniscectomized than nonmeniscectomized patients.

In recent years, the anatomic positioning of the femoral tunnel has been widely discussed. Proper positioning can be obtained using particular precautions with single-incision transtibial inside-out techniques with a variable malposition. There are a growing number of studies on the possible shortcomings of ACLR using transtibial drilling of the femoral tunnel.<sup>6,29,59,63,64</sup> The difficulty of reproducing an anatomic insertion of the ACL graft is a possible limitation of the coupled drilling technique; the result is nonanatomic placement of the femoral tunnel above the native insertion of the ACL.<sup>57</sup> Moreover, as reported by Inderhaug et al<sup>33</sup> in a long-term study, a vertical orientation of the ACL graft can explain the increase in rotational instability with the transtibial technique<sup>32,56</sup> that was correlated with significantly lower Lysholm and IKDC subjective scores. The outside-in technique appeared to be a simple and reproducible method for correct positioning of the femoral tunnel.<sup>28,46</sup>

An important weakness of the hamstring graft is possibly related to the enlargement of bone tunnels. Several authors<sup>4,9,19,20</sup> have stated that this phenomenon may be caused by the association of mechanical and biological aspects<sup>44</sup> such as “windshield wiper” and “bungee cord” effects, which are related to distant fixation of the graft from the joint surface. In the current study, according to the method suggested by Howell and Clark<sup>30</sup> for tibial tunnel evaluation, we found that 95% of patients were categorized into group 1 or 2 and were therefore considered to have grafts that were well placed. According to the method described by Sommer et al<sup>58</sup> for the femoral tunnel evaluation, we found that all patients were in area 1A or 2A, considered to be the optimal placement. Moreover, comparisons were made with the medium-term evaluation (5 years), and there was a statistically significant reduction in tunnel widening in 20% of patients for the tibial tunnel and in 8% for the femoral tunnel.<sup>19</sup> The outside-in technique with a double incision appears to be able to minimize enlargement of the femoral tunnel; this is a result of a shorter femoral tunnel and a very strong and stiff device, as previously demonstrated by Iorio et al<sup>34</sup> in a computed tomography study.

The strengths of this study include the use of an independent examiner at clinical follow-up, which reduced the possible bias that occurs when a surgeon examines his or her own patients, the same matched series of patients evaluated at medium- and long-term follow-ups, and the

evaluation of tunnel positions and their evolution over a long time period.

The most important limitation of this study includes the lack of a control group. A recruitment bias may have been present because 10 of the patients with current contact information did not respond to all our requests. This is a large series of consecutive patients operated on by the same surgeon, which can be interpreted as either a strength or a weakness of the study. The decrease in sports activity at final follow-up, as documented by the Tegner score, could potentially be a bias. Finally, there was unfortunately no preoperative radiological evaluation for osteoarthritis.

## CONCLUSION

Endoscopic single-bundle ACLR using DGST grafts with an outside-in technique demonstrated satisfactory results, even at a long-term follow-up of 15 years, in terms of knee function and subjective scores, with an acceptable rate of radiological signs of DOA. As compared with medium-term 5-year follow-up, clinical results remained stable both subjectively and objectively. However, a progression of DOA changes was observed, especially in patients in whom meniscectomy was performed.

## REFERENCES

1. Aglietti P, Buzzi R, Zaccherotti G, De Biase P. Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med.* 1994;22(2):211-217.
2. Almqvist KF, Willaert P, De Brabandere S, Criel K, Verdonk R. A long term study of anterior cruciate ligament allograft reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(7):818-822.
3. Amin S, Guerhazi A, Lavalley MP, et al. Complete anterior cruciate ligament tear and the risk for cartilage loss and progression of symptoms in men and women with knee osteoarthritis. *Osteoarthritis Cartilage.* 2008;16(8):897-902.
4. Asik M, Sen C, Tuncay I, Erdil M, Avci C, Taser OF. The mid- to long-term results of the anterior cruciate ligament reconstruction with hamstring tendons using Transfix technique. *Knee Surg Sports Traumatol Arthrosc.* 2007;15(8):965-972.
5. Bach BR Jr. Arthroscopy-assisted patellar tendon substitution for anterior cruciate ligament insufficiency: surgical techniques. *Am J Knee Surg.* 1989;2:3-20.
6. Bedi A, Musahl V, Steuber V, et al. Transtibial versus anteromedial portal reaming in anterior cruciate ligament reconstruction: an anatomic and biomechanical evaluation of surgical technique. *Arthroscopy.* 2011;27(3):380-390.
7. Bobic V. Current concepts in anterior cruciate ligament reconstruction. *Am J Knee Surg.* 1992;10:241-247.
8. Brown CH Jr, Carson EW. Revision anterior cruciate ligament surgery. *Clin Sports Med.* 1999;18(1):109-171.
9. Brown CH Jr, Wilson DR, Hecker AT, Ferragamo M. Graft-bone motion and tensile properties of hamstring and patellar tendon anterior cruciate ligament femoral graft fixation under cyclic loading. *Arthroscopy.* 2004;20(9):922-935.
10. Budny J, Fox J, Rauh M, Fineberg M. Emerging trends in anterior cruciate ligament reconstruction. *J Knee Surg.* 2017;30(1):63-69.
11. Cohen M, Amaro JT, Ejinisman B, et al. Anterior cruciate ligament reconstruction after 10 to 15 years: association between meniscectomy and osteoarthritis. *Arthroscopy.* 2007;23(6):629-634.
12. Conteduca F, Ferretti A, Mariani PP, Puddu G, Perugia L. Chondromalacia and chronic anterior instabilities of the knee. *Am J Sports Med.* 1991;19(2):119-123.
13. Cox CL, Huston LJ, Dunn WR, et al. Are articular cartilage lesions and meniscus tears predictive of IKDC, KOOS, and Marx activity level outcomes after anterior cruciate ligament reconstruction? A 6-year multicenter cohort study. *Am J Sports Med.* 2014;42(5):1058-1067.
14. Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med.* 1994;22(5):632-644.
15. Dejour H, Dejour D, Ait Si Selmi T. Chronic anterior laxity of the knee treated with free patellar graft and extra-articular lateral plasty: 10-year follow-up of 148 cases [in French]. *Rev Chir Orthop Reparatrice Appar Mot.* 1999;85(8):777-789.
16. Ekdhal M, Wang JH, Ronga M, Fu FH. Graft healing in anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2008;16(10):935-947.
17. Fairbank TJ. Knee joint changes after meniscectomy. *J Bone Joint Surg Br.* 1948;30:664-670.
18. Ferretti A, Conteduca F, De Carli A, Fontana M, Mariani PP. Osteoarthritis of the knee after ACL reconstruction. *Int Orthop.* 1991;15(4):367-371.
19. Ferretti A, Monaco E, Giannetti S, Caperna L, Luzon D, Conteduca F. A medium to long-term follow-up of ACL reconstruction using double gracilis and semitendinosus grafts. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(3):473-478.
20. Fu FH, Bennett CH, Lattermann C, Ma CB. Current trends in anterior cruciate ligament reconstruction, part 1: biology and biomechanics of reconstruction. *Am J Sports Med.* 1999;27(6):821-830.
21. Fu FH, Bennett CH, Ma CB, Menetrey J, Lattermann C. Current trends in anterior cruciate ligament reconstruction, part II: operative procedures and clinical correlations. *Am J Sports Med.* 2000;28(1):124-130.
22. Gerhard P, Bolt R, Dück K, Mayer R, Friederich NF, Hirschmann MT. Long-term results of arthroscopically assisted anatomical single-bundle anterior cruciate ligament reconstruction using patellar tendon autograft: are there any predictors for the development of osteoarthritis? *Knee Surg Sports Traumatol Arthrosc.* 2013;21(4):957-964.
23. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. *Sports Med.* 1999;27(3):143-156.
24. Giron F, Aglietti P, Cuomo P, Mondanelli N, Ciardullo A. Anterior cruciate ligament reconstruction with double-looped semitendinosus and gracilis tendon graft directly fixed to cortical bone: 5-year results. *Knee Surg Sports Traumatol Arthrosc.* 2005;13(2):81-91.
25. Granan LP, Bahr R, Lie SA, Engebretsen L. Timing of anterior cruciate ligament reconstructive surgery and risk of cartilage lesions and meniscal tears: a cohort study based on the Norwegian National Knee Ligament Registry. *Am J Sports Med.* 2009;37(5):955-961.
26. Grassi A, Kim C, Marcheggiani Muccioli GM, Zaffagnini S, Amendola A. What is the mid-term failure rate of revision ACL reconstruction? A systematic review. *Clin Orthop Relat Res.* 2017;475(10):2484-2499.
27. Harner CD, Giffin JR, Duntzman RC, Annunziata CC, Friedman MJ. Evaluation and treatment of recurrent instability after anterior cruciate ligament reconstruction. *Instr Course Lect.* 2001;50:463-474.
28. Hefti F, Muller W, Jakob RP, Stäubli HU. Evaluation of knee ligament injuries with the IKDC form. *Knee Surg Sports Traumatol Arthrosc.* 1993;1(3-4):226-234.
29. Heming JF, Rand J, Steiner ME. Anatomical limitations of transtibial drilling in anterior cruciate ligament reconstruction. *Am J Sports Med.* 2007;35(10):1708-1715.
30. Howell SM, Clark JA. Tibial tunnel placement in anterior cruciate ligament reconstructions and graft impingement. *Clin Orthop Relat Res.* 1992;(283):187-195.
31. Howell SM, Deutsch ML. Comparison of endoscopic and two-incision techniques for reconstructing a torn anterior cruciate ligament using hamstring tendons. *Arthroscopy.* 1999;15(6):594-606.
32. Hussein M, van Eck CF, Cretnik A, Dinevski D, Fu FH. Prospective randomized clinical evaluation of conventional single-bundle, anatomic single-bundle, and anatomic double-bundle anterior cruciate ligament reconstruction: 281 cases with 3- to 5-year follow-up. *Am J Sports Med.* 2012;40(3):512-520.



33. Inderhaug E, Strand T, Fischer-Bredenbeck C, Solheim E. Long-term results after reconstruction of the ACL with hamstrings autograft and transtibial femoral drilling. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(9):2004-2010.
34. Iorio R, Vadalà A, Argento G, Di Sanzo V, Ferretti A. Bone tunnel enlargement after ACL reconstruction using autologous hamstring tendons: a CT study. *Int Orthop.* 2007;31(1):49-55.
35. Ireland ML. The female ACL: why is it more prone to injury? *Orthop Clin North Am.* 2002;33(4):637-651.
36. Janssen RP, du Mée AW, van Valkenburg J, Sala HA, Tseng CM. Anterior cruciate ligament reconstruction with 4-strand hamstring autograft and accelerated rehabilitation: a 10-year prospective study on clinical results, knee osteoarthritis and its predictors. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(9):1977-1988.
37. Keene GC, Bickerstaff D, Rae PJ, Paterson RS. The natural history of meniscal tears in anterior cruciate ligament insufficiency. *Am J Sports Med.* 1993;21(5):672-679.
38. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. *Ann Rheum Dis.* 1957;16:494-502.
39. Kessler MA, Behrend H, Henz S, Stutz G, Rukavina A, Kuster MS. Function, osteoarthritis and activity after ACL-rupture: 11 years follow-up results of conservative versus reconstructive treatment. *Knee Surg Sports Traumatol Arthrosc.* 2008;16(5):442-448.
40. Lanzetti RM, Lupariello D, De Carli A, et al. Can the outside-in half-tunnel technique reduce femoral tunnel widening in anterior cruciate ligament reconstruction? A CT study. *Eur J Orthop Surg Traumatol.* 2017;27(5):659-664.
41. Leiter JR, Gourlay R, McRae S, de Korompay N, MacDonald PB. Long-term follow-up of ACL reconstruction with hamstring autograft. *Knee Surg Sports Traumatol Arthrosc.* 2014;22(5):1061-1069.
42. Leys T, Salmon L, Waller A, Linklater J, Pinczewski L. Clinical results and risk factors for reinjury 15 years after anterior cruciate ligament reconstruction: a prospective study of hamstring and patellar tendon grafts. *Am J Sports Med.* 2012;40(3):595-605.
43. Lidén M, Semert N, Rostgård-Christensen L, Kartus C, Ejerhed L. Osteoarthritic changes after anterior cruciate ligament reconstruction using bone-patellar tendon-bone or hamstring tendon autografts: a retrospective, 7-year radiographic and clinical follow-up study. *Arthroscopy.* 2008;24(8):899-908.
44. L'Insalata JC, Klatt B, Fu FH, Harner CD. Tunnel expansion following anterior cruciate ligament reconstruction: a comparison of hamstring and patellar tendon autografts. *Knee Surg Sports Traumatol Arthrosc.* 1997;5(4):234-238.
45. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med.* 2007;35(10):1756-1769.
46. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. *Am J Sports Med.* 1982; 10(3):150-154.
47. Marcacci M, Zaffagnini S, Giordano G, Iacono F, Presti ML. Anterior cruciate ligament reconstruction associated with extra-articular tenodesis: a prospective clinical and radiographic evaluation with 10- to 13-year follow-up. *Am J Sports Med.* 2009;37(4):707-714.
48. Mascarenhas R, MacDonald PB. Anterior cruciate ligament reconstruction: a look at prosthetics—past, present and possible future. *McGill J Med.* 2008;11(1):29-37.
49. Mihelic R, Jurdana H, Jotanovic Z, Madjarevic T, Tudor A. Long-term results of anterior cruciate ligament reconstruction: a comparison with non-operative treatment with a follow-up of 17-20 years. *Int Orthop.* 2011;35(7):1093-1097.
50. Miyasaka KC, Daniel DM, Stone ML. The incidence of knee ligament injuries in the general population. *Am J Knee Surg.* 1991;4:3-8.
51. Outerbridge RE, Dunlop JA. The problem of chondromalacia patellae. *Clin Orthop Relat Res.* 1975;(110):177-196.
52. Pernin J, Verdonk P, Si Selmi TA, Massin P, Neyret P. Long-term follow-up of 24.5 years after intra-articular anterior cruciate ligament reconstruction with lateral extra-articular augmentation. *Am J Sports Med.* 2010;38(6):1094-1102.
53. Purnell ML, Larson AI, Clancy W. Anterior cruciate ligament insertions on the tibia and femur and their relationships to critical bony landmarks using high-resolution volume-rendering computed tomography. *Am J Sports Med.* 2008;36(11):2083-2090.
54. Sachs RA, Daniel DM, Stone ML, Garfein RF. Patellofemoral problems after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1989;17(6):760-765.
55. Sajovic M, Strahovnik A, Dernovsek MZ, Skaza K. Quality of life and clinical outcome comparison of semitendinosus and gracilis tendon versus patellar tendon autografts for anterior cruciate ligament reconstruction: an 11-year follow-up of a randomized controlled trial. *Am J Sports Med.* 2011;39(10):2161-2169.
56. Scanlan SF, Lai J, Donahue JP, Andriacchi TP. Variations in the three-dimensional location and orientation of the ACL in healthy subjects relative to patients after transtibial ACL reconstruction. *J Orthop Res.* 2012;30(6):910-918.
57. Silva A, Sampaio R, Pinto E. ACL reconstruction: comparison between transtibial and anteromedial portal techniques. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(5):896-903.
58. Sommer C, Friederich NF, Müller W. Improperly placed anterior cruciate ligament grafts: correlation between radiological parameters and clinical results. *Knee Surg Sports Traumatol Arthrosc.* 2000; 8(4):207-213.
59. Strauss EJ, Barker JU, McGill K, Cole BJ, Bach BR Jr, Verma NN. Can anatomic femoral tunnel placement be achieved using a transtibial technique for hamstring anterior cruciate ligament reconstruction? *Am J Sports Med.* 2011;39(6):1263-1269.
60. Tandogan RN, Taser O, Kayaalp A. Analysis of meniscal and chondral lesions accompanying anterior cruciate ligament tears: relationship with age, time from injury, and level of sport. *Knee Surg Sports Traumatol Arthrosc.* 2004;12(4):262-270.
61. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res.* 1985;(198):43-49.
62. Thompson SM, Salmon LJ, Waller A, Linklater J, Roe JP, Pinczewski LA. Twenty-year outcome of a longitudinal prospective evaluation of isolated endoscopic anterior cruciate ligament reconstruction with patellar tendon or hamstring autograft. *Am J Sports Med.* 2016; 44(12):3083-3094.
63. Tompkins M, Milewski MD, Brockmeier SF, Gaskin CM, Hart JM, Miller MD. Anatomic femoral tunnel drilling in anterior cruciate ligament reconstruction: use of an accessory medial portal versus traditional transtibial drilling. *Am J Sports Med.* 2012;40(6):1313-1321.
64. Xu Y, Ao Y, Wang J, Yu J, Cui G. Relation of tunnel enlargement and tunnel placement after single-bundle anterior cruciate ligament reconstruction. *Arthroscopy.* 2011;27(7):923-932.