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# Selective bundle reconstruction in partial ACL tears leads to excellent long-term functional outcomes and a low percentage of failures

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ABSTRACT

Background: The optimal treatment of partial anterior cruciate ligament (ACL) tears continues to be debatable. Short-term results of selective bundle reconstruction have already been widely shown. The purpose of this study was to assess functional outcomes, subjective satisfaction and the failure rate of selective bundle reconstructions for partial ACL tears over a five to nine year follow-up period.

Methods: Patients who underwent ACL selective bundle reconstruction between October 2008 and October 2012 were studied. Functional assessment was performed with the objective International Knee Documentation Committee (IKDC) ligament evaluation form, the Lysholm knee scale and the Tegner activity level scale. Cumulative failure and level of satisfaction have also been investigated.

Results: Seventy-six patients were included. The average follow-up period was 85 months (range 65–110). Thirty-four had AMB tear and 42 had PLB tears. An overall statistically significant improvement ($p < 0.001$) was obtained in terms of the subjective IKDC and the Lysholm questionnaire between preoperative and last follow-up. The same or no more than one level lower Tegner score was restored in 97.3% of the cases. Cumulative failure was observed in two patients (2.6%). Dissatisfied patient percentage was 15% (4/76).

Conclusions: Selective bundle reconstruction in partial ACL tears leads to excellent long-term functional outcomes, a low percentage of failures and a high degree of subjective satisfaction in patients.

Level of evidence: Therapeutic case series; level 4.



## 1. Introduction

Partial anterior cruciate ligament (ACL) tears were first described almost five decades ago. However, since the initial description, there remains no consensus on the prevalence and classification for these injuries [1,2].

Depending on the reports, the rate of partial tears ranges from 15% to 35% of distortional traumas of the knee with hemarthrosis and from 10% to 28% of all other ACL lesions [3].

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Moreover, the optimal treatment continues to be a subject of considerable debate. Non-surgical attitude would seem logical, if natural history is favourable. However, Pujol et al., in a systematic review, have shown that 26.3% (five to 51%) of partial ACL lesion patients managed with conservative treatment developed a positive Pivot Shift Sign (negative at preoperative evaluation) at the five-year follow-up. Moreover, the mean rate of secondary meniscectomy was 7.2% (0–10%) and only 52% (21–60%) of those patients had returned to sport at their previous level. Residual pain was frequent in this population, especially while making an effort. As described in the literature on the functional management of complete ACL tears, patients who had limited their sports activities showed the best subjective results [4]. Moreover, Johnson et al. have shown that any injury to the ACL, no matter how significant, carries a similar prognosis for knee joint health with minimal significant differences in the joint pattern damage between complete and partial tears of the ACL [5]. Biological approaches appear to be one possible future treatment for a subset of orthopaedic injuries. There has been a recent interest in the development of new biological treatment techniques to address partial injuries of intra-articular structures, such as the ACL. However and with regard to the possibility of repairing a partial lesion, we have to keep in mind that the ACL possesses limited intrinsic capacity for spontaneous healing after an injury, unlike other ligaments of the knee such as the posterior cruciate ligament (PCL) and medial collateral ligament (MCL) [6].

The use of the new biological ACL repair techniques, including growth factors, platelet reach plasma (PRP), stem cells, and bioscaffolds, have been reported to result in promising preclinical and short-term clinical outcomes [1,7]. Yet, there are still no clear long-term results and randomized controlled trials (RCT) that affirm the superiority of these kinds of treatment over surgical options [1]. Therefore, the most intuitive treatment, for the time being, remains the surgical one. While surgical options for complete ruptures of the ACL have been well studied, treatment course for partial ACL tears remains undetermined and questions remain as to the value in conserving residual fibres [8].

Residual ACL fibre conservation has several theoretical advantages: biomechanical [9], vascular [10], and proprioceptive [11]. Moreover, it has been shown that anterior laxity is better controlled over the short-term when the remnant fibres of one bundle are conserved [8].

Therefore, the principles of modern anatomic ACL reconstruction consist in recreating the native ligament insertions, conserving whatever remnants may be present. Techniques conserving the native ACL footprint have been developed, and partial reconstruction is recommended when a bundle seems to have been spared [8,12]. The short-term outcome of this remnant sparring reconstruction has already been reported by several authors [12–14]. However, to the best of our knowledge, no one has described the results at a long-term follow-up in terms of failure and functional outcomes.

Patient reported outcomes (PRO) with established validity, reliability and responsiveness specific to the knee joint and ACL injuries abound [15,16]. PROs measure patient perspectives as to how the knee joint affects daily life and sports activities [17,18], which has a greater influence on patient satisfaction than standard clinical measures [19]. PROs are especially effective in comparing the results of how interventions affect patient perspective after injury, in both clinical practice and research [19,20]. PROs fall into two major categories — self-reported patient performance scales which measure function and symptoms and another that measures of frequency and intensity of activity [21].

The purpose of this study was to assess functional outcomes, subjective satisfaction and the failure rate of selective bundle reconstructions for partial ACL tears over a five to nine year follow-up period.

The hypothesis was that selective bundle reconstruction for partial ACL tears would provide the optimal functionality to restore pre-injury activity levels with a low rate of failure even at long term follow-up.

## 2. Material and method

Patients who underwent ACL selective bundle reconstruction between October 2008 and October 2012 were included. The exclusion criteria were (1) any combined ligament lesion needing surgical intervention, (2) achondral lesion or degeneration grade 3 (Outerbridge), (3) a previous knee surgery and revision and (4) a subtotal or total meniscectomy. The diagnosis was supported by knowing the mechanism of injury, physical examinations, and magnetic resonance imaging. Ultimately, diagnosis of partial tear was done based on the arthroscopic findings, examining both bundles at various knee flexion angles to consider the different tension patterns and anatomical footprints.

All the patients were operated on by two senior surgeons (JCM and PEG) with a standardized selective bundle technique previously described [12]. All the patients followed the same rehabilitation programme, like the one recommended for standard ACL reconstructions. The clinical research ethics committee of our institution approved the study (11/145/1350). All the patients signed informed consent to participate in the study as well as for the evaluation and publication of their results.

### *2.1. Surgical technique*

Once the isolated bundle rupture of the ACL was confirmed, the graft was harvested. From a longitudinal incision two centimetres long and two centimetres medial to the medial border of the tibial tuberosity (TT), the ipsilateral semitendinosus tendon (ST) was harvested and was always triplicated. In the cases of an antero-medial bundle (AMB), reconstruction with a triplicated ST graft thinner than seven millimetres or a postero-lateral bundle (PLB) reconstruction with a triplicated ST graft thinner than six millimetres, following an arbitrary cut-off regardless of the height of the patient or the size of the intercondylar notch, the graft construction was augmented with a gracilis tendon (GT).

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In the case of a PLB reconstruction, if the diameter and the length of the tendon appeared sufficient, only the ipsilateral GT was harvested and subsequently triplicated. In rare cases when the patients did not accept the risks associated with the morbidity of the donor site, they were informed of both the advantages and disadvantages of using non-irradiated ST allograft and all of them accepted this solution. Fixation at the femoral side was obtained with an extracortical fixation implant (XoButton device, ConMed Linvatec, Largo, FL, USA) whereas it was accomplished with a two millimetre oversized bioabsorbable interference screw (BioScrew, ConMed Linvatec) on the tibial side.

Special care was always taken to preserve the intact ACL fibres and the undamaged bundle was used as a landmark for orientation. The centre of the femoral AMB or PLB bone tunnel was located either with the help of a femoral offset guide (ConMed Linvatec), with a BullsEye femoral guide (ConMed Linvatec), or with a freehand technique. For the tibial bone tunnel, the tibial drill guide (ConMed Linvatec) was placed with the intra-articular tip positioned in the anteromedial or posterolateral part of the tibial footprint of the medial tibial plateau four to five millimetres posterior to the anterior rim of the ACL stump for AMB. It was done at an average of four to five millimetres medial to the lateral eminentia intercondylaris and four to five millimetres anterior to the posterior root of the lateral meniscus for PLB. A guidewire was overdrilled, with a conventional reamer, one millimetre smaller than the diameter of the graft without compromising the intact insertion of the remaining bundle. The soft trabeculae of the tibia were finally compressed with a dilator that matched the graft diameter to help compact the surface of the tunnel. Fixation of the graft was done at between 20° and 30° of knee flexion (Figure 1).

### 2.2. Evaluation

Besides a physical examination, three patient-reported questionnaires (PRQ) were given to assess the functional condition of every patient preoperatively. They were the objective International Knee Documentation Committee (IKDC) ligament evaluation form, the Lysholm knee scale and the Tegner activity level scale. For the latter, the patients were asked to also mark the pre-injury activity level.

As the protocol of our institution, a physical examination and an annual Magnetic Resonance (MR) of the knee were carried out prospectively for up to four years (Figure 2). The patients were subsequently asked to participate in a telephone interview and to complete the same preoperative PRQs with the addition of a Level of Satisfaction questionnaire on a yearly basis. Interviews were conducted to investigate clinical failures and to detect any anomalies or inconsistencies in patients' responses to the questions, particularly with reference to “giving way” episodes.

Notably, an endpoint event was set as a graft rupture or clinical failure defined as a feeling of giving-way as reported by the patient. The sum of both was generalized as cumulative failure.

The level of satisfaction with knee function was measured with the question “If you were to spend the rest of your life with your knee function just the way it has been over the last week, would you feel…” The response options were happy, satisfied, mostly satisfied, mixed feelings, mostly dissatisfied, dissatisfied, and unhappy. This question has been used in previous research to investigate patient satisfaction with the outcome of treatment for neck, low-back and pelvic pain and ACL reconstruction [22–25]. The preoperative functional evaluation as well as the one at final follow-up were performed by a single sports medicine surgeon (FI) who was independent of the study and blinded to the type of ACL surgery (AMB or PLB reconstruction, graft size, concomitant lesions) that had been performed.

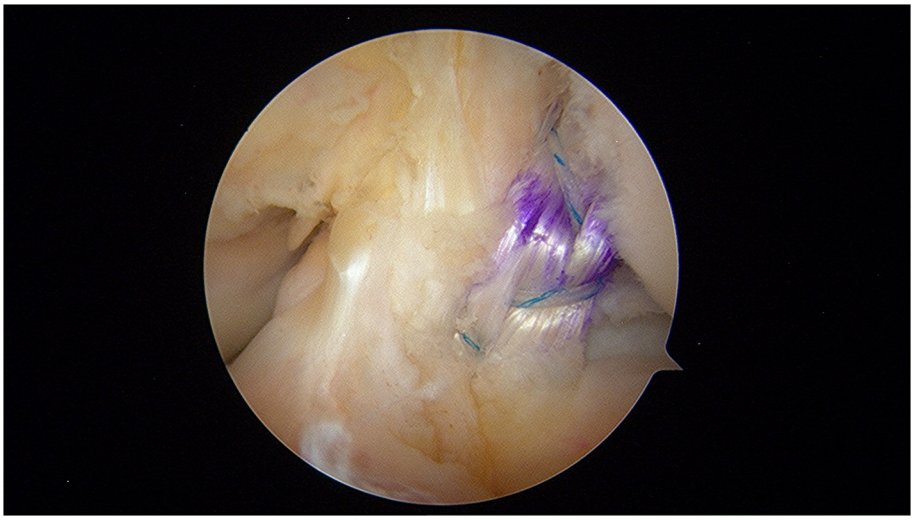

**Figure 1.** Reconstructed posterolateral bundle of partial ACL tear.

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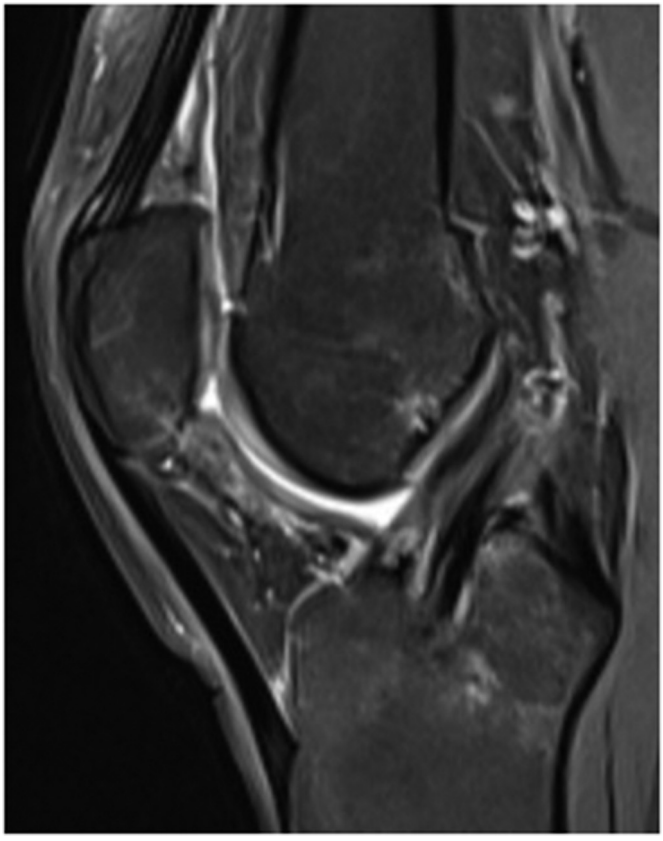

**Figure 2.** MRI of selective posterolateral bundle reconstruction at 4 years follow up.

### *2.3. Rehabilitation protocol*

Full weight-bearing and full range of motion were encouraged from the beginning. Apart from isometric exercises with the knee in full extension, quadriceps-strengthening exercises were restricted to closed kinetic chain exercises during the first 12 weeks. Sport-specific drills were started and gradually progressed after three months. Full activities and a return to contact sport were only allowed at least six months after surgery depending on the physical examination, strength and the MRI aspect of the graft.

### *2.4. Statistical analysis*

Continuous variables are presented as mean, standard deviation (SD), maximums and minimums. Categorical variables are presented as percentages and frequencies.

Because of the small sample number, statistical tests were not utilized to evaluate normality. Instead, the assessment was performed with non-parametric equivalents, which showed no discrepancies in terms of significance. The relationship between the variables was described with contingency tables for the categorical one, and the inference was studied with the chi-square test or Fisher's exact test depending on what corresponded. The inference in continuous variables was calculated with the paired-samples T-test and their results are presented with their 95% confidence interval (95% CI). The level of significance was set at five percent ($\alpha = 0.05$), bilateral approximation. All the analyses were performed with the SPSS 19 (SPSS Inc., Chicago, Illinois).

## 3. Results

A selective bundle reconstruction was carried out on 89 patients between October 2008 and October 2012 in our institution. Four patients were excluded from the study, two for a previous meniscectomy, one for a chondral lesion grade 3 (Outerbridge) and one for a consensual subtotal medial meniscectomy.

At an average of 85 months (range 65–110/5.4–9.2 years), 76 out of 85 cases (89.4%) were available for follow-up. An AMB reconstruction was performed on 34 patients (44.7%) and a PLB augmentation procedure on the remaining 42 cases (55.2%). The series comprised 52 men (68.4%) and 24 women (31.5%) with a mean age of 32.8 years (range 16 to 51) at the time of

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surgery. Of those, 42 surgeries (55.2%) were performed on the right knees and the remaining 34 cases (44.7%) were done on the left knee.

Overall, the mean diameter of the grafts was 7.5 mm. In 27 patients, the reconstructions were performed with a triplicated semitendinosus tendon with a mean diameter of 7.4 mm (SD 1.00). In 12 patients, only gracilis with a mean 6.5 mm diameter (SD 0.71) was used. Double semitendinosus and gracilis tendon grafts (quadrupled hamstring graft) with a mean diameter of 7.9 mm (SD 0.82) were used in 33 patients. Another four patients had a non-irradiated ST allograft reconstruction with a mean diameter of 7.6 mm (SD 1.11) as shown in Table 1.

Those grafts used in AM bundle reconstructions had a mean diameter of 7.4 mm while the mean diameter of those grafts corresponding to PL bundle reconstructions was 7.6 mm.

Relative to concomitant lesions, 19 patients had meniscal tears. The treatment was a partial meniscectomy in 15 cases and meniscal suturing in three cases. In all three cases of meniscal suturing, an all-inside suture with two FasT-Fix sutures (Smith & Nephew, Andover, MA) was performed. Only five of the patients had minor injuries in the articular cartilage that were left untreated. The mean operation time was 70 min (SD, five minutes). No complications were observed during the surgeries.

### 3.1. Cumulative failure

Cumulative failure was observed in two patients (2/76, 2.6%). In detail, no clinical failure was observed while a graft rupture was present in two patients. One of those two had a motorcycle accident some five years after the surgery. Diagnosis and surgical treatment were performed at the hospital where he was evaluated following the polytrauma. The second patient referred a re-rupture following a traumatic contact event (Soccer) five years after surgery. The diagnosis of graft rupture was only based on magnetic resonance imaging. The patient decided not to be operated on again because of his low-demand daily activities and he had stopped practicing sports.

All the patients complained, preoperatively, of recurrent giving-way episodes, none of them reported the sensation when questioned about it at the last follow-up.

### 3.2. Functional outcome

An overall statistically significant improvement ($p < 0.001$) was obtained in terms of the subjective IKDC, the Lysholm questionnaire and the Tegner activity level scale between preoperative and postoperative periods (Table 2).

For each type of graft used, a statistically significant variation was found between the preoperative and postoperative values of the subjective IKDS and Lysholm questionnaire as shown in Tables 3a, 3b, 4a and 4b ($p < 0.001$).

**Table 1**
Diameter of the grafts.

| Graft | Mean | SD |
|---|---|---|
| ST | 7.44 | 1.00 |
| GT | 6.50 | 0.71 |
| ST + GT | 7.97 | 0.82 |
| Allograft | 7.63 | 1.11 |

**Table 2**
Functional outcome.

| | Obs | Mean | Std. Err. | 95% Conf. | Interval | p-Value |
|---|---|---|---|---|---|---|
| IKDC — Pre op. | 76 | 56.45 | 0.86 | 54.74 | 58.16 | <0.001 |
| IKDC — Post op. | 76 | 82.86 | 0.42 | 82.02 | 83.69 | |
| Lysholm — Pre op. | 76 | 64.09 | 0.58 | 62.94 | 65.24 | <0.001 |
| Lysholm — Post op. | 76 | 95.93 | 0.65 | 94.63 | 97.24 | |
| Tegner — Pre op. | 76 | 3.36 | 0.07 | 3.21 | 3.50 | <0.001 |
| Tegner — Post op. | 76 | 6.01 | 0.22 | 5.58 | 6.45 | |

**Table 3a**
IKDC pre-op.

| Graft | Mean | SD |
|---|---|---|
| ST | 57.89 | 5.23 |
| GT | 57.08 | 7.93 |
| ST + GT | 55.48 | 8.64 |
| Allograft | 52.75 | 9.29 |

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**Table 3b**
IKDC post-op.

| Graft | Graft | SD |
|---|---|---|
| ST | 82.11 | 4.53 |
| GT | 83.67 | 1.78 |
| ST + GT | 82.94 | 3.47 |
| Allograft | 84.75 | 0.96 |

**Table 4a**
Lysholm pre-op.

| Graft | Mean | SD |
|---|---|---|
| ST | 63.70 | 5.12 |
| GT | 64.58 | 4.64 |
| ST + GT | 64.09 | 5.13 |
| Allograft | 65.25 | 6.70 |

**Table 4b**
Lysholm post-op.

| Graft | Mean | SD |
|---|---|---|
| ST | 95.44 | 4.77 |
| GT | 98.08 | 3.15 |
| ST + GT | 95.36 | 7.14 |
| Allograft | 97.50 | 2.89 |

The mean pre-injury Tegner Value was 6.57 (SD 1.1), and the last follow-up value was 6.01 (SD 1.4). Pre-injury Tegner scores were restored in 66 out of 76 (86.8%) patients. It decreased a single level in comparison to the pre-injury Tegner activity score in eight out of 76 (10.5%). In the two patients (2.6%) with a graft rupture, the Tegner activity score decreased by two levels from 7 and 6 to 5 and 4, respectively.

Relative to the linear regression model, there were no significant differences between scores and graft dimensions, combined injuries, time from injury to surgery, kind of bundle reconstruction, and age. However, in terms of gender, there is a slight statistical significance in male patients (Figures 3–5). Therefore, except for gender, the other variables calculated are not potential predictors of cumulative failure.

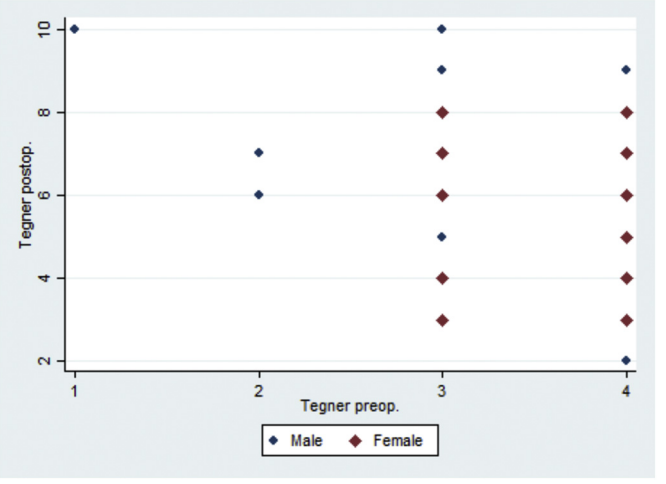


**Figure 3.** TEGNER linear regression model. Graft dimensions (P = 0.185), combined injuries (P = 0.598.), time from injury to surgery (P = 0.738), kind of bundle reconstruction (P = 0.146), age (P = 0.971), sex (P = 0.008).

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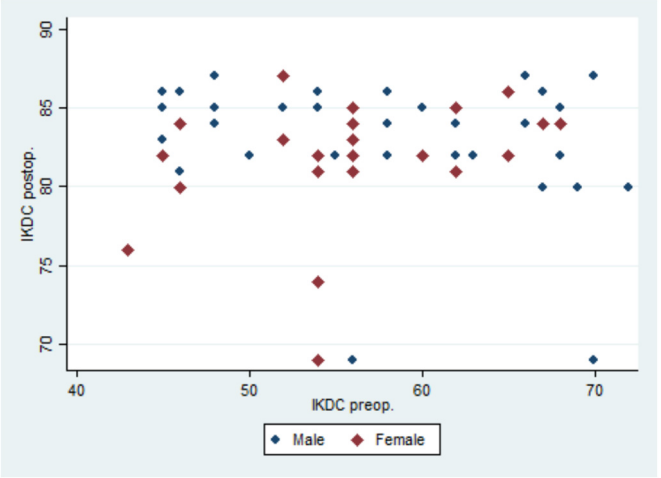


**Figure 4.** IKDC linear regression model. Graft dimensions (P = 0.247), combined injuries (P = 0.121), time from injury to surgery (P = 0.428), kind of bundle reconstruction (P = 0.922), age (P = 0.319), and sex (P = 0.098).

### *3.3. Level of satisfaction*

As for satisfaction with knee function, the largest proportion of patients (n = 62, 81.5% of 76) reported they would be happy (n = 42) or satisfied (n = 20) if they were to spend the rest of their life with their knee function the way it had been over the previous week. The mostly satisfied group was made up of 10 participants (13.1%).The dissatisfied group comprised four participants (5.2%). In detail, two patients (2.6%) had mixed feelings and two patients (2.6%) said that they were mostly dissatisfied. The last two are the patients who reported the rupture of the graft. No patient ticked dissatisfied or unhappy.

## 4. Discussion

The main finding of the present study was that selective bundle reconstruction for partial ACL tears provides optimal functionality and restores pre-injury activity levels with a low rate of failure at long-term follow-up.

Physical examination provides a proper data relative to evolution although functional scores are equally or even more important because they express subjective sensations experienced by the patients, regardless of whether they have a good or bad result.

PROs are frequently used to report outcomes in large scale studies of knee injuries, including in registries and multicentre trials due to their confirmed validity and reliability as well as their ease in application and standardization [26,27].

Briggs et al. [28] and Higgins et al. [29] described how questionnaires have become an important measure of clinical outcomes based on the relevance of comparing outcomes related to symptoms, function and activity levels across different knee conditions and patients' populations.

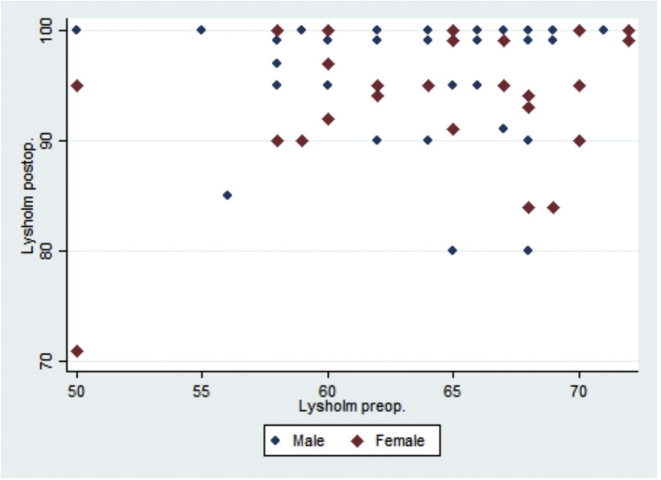


**Figure 5.** LYSHOLM linear regression model. Graft dimensions (P = 0.710), combined injuries (P = 0.319), time from injury to surgery (P = 0.303), kind of bundle reconstruction (P = 0.945), age (P = 0.047) and sex (P = 0.005).

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Lynch et al., in a consensus about the criteria for defining a successful outcome after ACL reconstruction, argued that PROs, the absence of giving-way and a return to sport are considered important for identifying the quality of the outcomes [21].

Moreover, the fact that there is a strong correlation between patient satisfaction, the subjective and objective measures after an ACL reconstruction have already been shown [19,30]. So far, no data have been published about long-term clinical or functional results for selective bundle reconstruction of partial ACL tears. In a series of 76 consecutive partial ACL tears treated with selective AM or PL bundle reconstruction, we report high PRO values, the absence of giving way and a high percentage of return to pre-injury sports activity levels over a five to nine year follow-up period. Furthermore, only 2.6% of the cases suffered a re-rupture. The lack of another long-term follow-up of a selective bundle ACL reconstruction prevents a comparison of the failure rates. Nevertheless, a 0 to three percent re-tear rate was reported at short-term follow-up in the largest study of selective bundle reconstruction [12,13,31]. Therefore, it seems that the re-rupture rate does not increase with time. Moreover, the results are not very different when compared to a complete lesion of the ACL given that also the long-term cumulative failure rate of a full ACL tear reconstruction has been shown to be between 2.5% and 24% with follow-up periods ranging from six to 20 years [32–36]. Excellent results have also been obtained as far as patient satisfaction with the outcome at long-term follow-up. This is a very important point in postoperative evaluation since it also considers the psychological aspect and expectations of the patients.

To our knowledge, there is no study that shows the level of satisfaction after selective bundle reconstruction for partial ACL tears. Previous studies have reported contradictory results in terms of satisfaction with the outcome after single bundle reconstruction of complete ACL tear. Ardern et al. have shown that only 44% of the patients referred to being satisfied [22] whereas Kocher et al. reported a dissatisfied patient percentage of 15%, more like the findings of the present study [37]. Almost all the patients in the present study were able to return to the previous level of sport and work activity like what has been shown in prior case series of selective bundle reconstruction for partial ACL tears [2,37]. This is a point that may have affected the high satisfaction rate reported by patients.

The main limitations of this study are (1) the absence of a control group, for example with a non-remnant sparring ACL reconstruction technique, and (2) the lack of a clinical assessment of the patients at the last follow-up. A minor limitation is the difference in follow-up duration within the sample.

## 5. Conclusion

Selective bundle reconstruction in partial ACL tears leads to excellent long-term functional outcomes, a low percentage of failures and a high degree of subjective satisfaction in patients.

## Declaration of competing interest

There has been no significant financial support for this work that could have influenced its outcome.

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