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*Original article*

# Functional evaluation of the double-bundle vs single-bundle anterior cruciate ligament ligamentoplasty. Prospective comparative study.

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**Abstract:** Background: The anatomical reconstruction of the anterior cruciate ligament is of great interest because its function is directly related to its anatomy. The aim of the study was to compare double-bundle with single-bundle ligamentoplasty of the anterior cruciate ligament using a biomechanical analysis of gait and balance.
Methods: Prospective comparative experimental clinical study on 64 people, 27 health subjects and 37 patients with anterior cruciate ligament injury. 19 injured subjects were assigned to single-bundle and 18 to double-bundle technique. Gait biomechanical analysis in all individuals were performed by means of four test and injured subjects ones were repeated at 3, 6 and 12 months after surgery: 1) kinematic test, to characterize gait pattern; 2) kinetic test, to characterize forces against floor, duration of treads, symmetry of both legs, and the reproducibility of the gait; 3) pivot-shift gait test, to analyze the rotational stability of the knee in the sagittal axis; and 4) equilibrium test.
Results: The two surgical techniques achieved an improvement of the functional alteration (gait pattern, changes in the forces against floor, duration of treads, symmetry of both legs, and the reproducibility of the gait, and changes in bipedal standing equilibrium), with little differences between the two techniques, with neither being superior to the other.
Conclusion: Reconstruction of the anterior cruciate ligament with the double-bundle technique offered very similar improvement in functional recovery than the single-bundle technique. At 12-months after surgery, double-bundle technique did not result in better rotational stability of the knee.

**Keywords:** anterior cruciate ligament; functional evaluation; gait kinetics; gait kinematics; single-bundle ligamentoplasty; double-bundle ligamentoplasty

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## 1. Introduction

The anatomical reconstruction of the ACL has been an object of interest, since its function is directly related to its anatomy [1,2] and this in turn is directly related to the function of the knee and, consequently, to the gait pattern. There is still great controversy about which is the best procedure for repair, which focuses on the number of fascicles (single-bundle, double-bundle or even triple fascicle); the choice of graft (allograft or autograft; goosefoot tendons, patellar tendon or quadriceps tendon); the fixation system to be used and the number and position of the tibial and femoral tunnels, with numerous conformations and variables described [3–7].

Many authors defend the existence of 2 anatomical fascicles (anteromedial and posterolateral), based on the ACL tibial insertion and on the orientation and tension behavior of the various ACL fibers during the range of motion [1,8]; some authors even described 3 different fascicles [3]. However, other authors defend that the division according to the tension of the fibers in extension and in flexion is only a functional division and that anatomically, the ACL is formed only by a fiber bundle [9–11]. Various techniques have been described for the reconstruction of the ACL with 2 fascicles [12–14] and for the reconstruction with 1 fascicle both with transtibial techniques [15,16], and using an anteromedial accessory portal or "anatomical reconstruction" [16,17]. Numerous studies have been published that compare these techniques, without reaching a consensus on whether any of them is superior to the others [14,18,19].

In a previous work we have described the functional changes that occur in patients with ACL tears through a biomechanical analysis of gait and balance [20]. Now, the working hypothesis was that reconstruction of the ACL with 2 fascicles results in a better functional recovery than 1 fascicle techniques. To test it, we compared ACL double-bundle ligamentoplasty with single-bundle ligamentoplasty by means of a biomechanical analysis of gait and balance.

## 2. Materials and Methods

A prospective comparative experimental clinical study was conducted with 64 subjects, 27 healthy subjects (Control group) and 37 patients with ACL injury. All the patients were treated in a labor mutual, so their injuries were the result of an occupational accident. Subjects with ACL injury were divided into two groups, consecutively assigning one or the other group, discarding only those that did not meet the inclusion criteria. 19 patients were assigned the single-bundle as a surgical technique and 18 patients the double-bundle technique. Seven of them were excluded after the surgical intervention (because a partial rupture was found and an augmentation technique was performed or a suturable meniscal rupture was found), for which, finally, 30 individuals with ACL rupture were included, 16 operated with the single-bundle ligamentoplasty technique (SBT) and 14 with the double-bundle technique (DBT). The study was approved by the ethics committee of our center and all the individuals signed the corresponding informed consent for inclusion in the study.

The following inclusion / exclusion criteria were used:

- Inclusion criteria for healthy individuals: 1) adult male younger than 40 years and older than 16 years; and 2) without previous or current pathology at the level of the lower limbs.
- Inclusion criteria for pathological individuals: 1) adult male younger than 40 years and older than 16 years; 2) without previous pathology at the level of the lower limbs; 3) clinical suspicion of ACL rupture (anamnesis and physical examination, which includes positive Lanchman and anterior drawer tests); and 4) MRI suspicion of complete ACL rupture.
- Exclusion criteria for pathological individuals: 1) meniscal tear requiring suturing; 2) absence of surgical confirmation of ACL rupture, either because it does not exist or because the rupture is partial; and 3) appearance of some other pathology that may alter the functional evaluation of the knee.

Patient data regarding age, height, and body weight were collected.

All the subjects underwent a functional assessment using the protocol described by Sánchez-Alepuz et al. [20], and the subjects with ACL rupture underwent a preoperative assessment and three postoperative assessments, 3, 6 and 12 months after the intervention.

For the functional evaluation of the knee, the subjects carried out 4 tests, based on 3D measurements of the relative movements between the femur and the tibia and on the analysis of the reaction forces with the soil registered by means of a dynamometric platform20: 1) kinematic gait test; 2) kinetic gait analysis test; 3) pivot-shift gait test; and 4) equilibrium test. The tests were carried out in our medical-surgical center, with the equipment and material provided by the Institute of Biomechanics of Valencia (IBV).

Surgical technique [13,15]: Two surgical techniques have been chosen that use autologous graft with gracilis and semitendinosus, which is obtained from the same injured leg. Ligamentoplasty of ACL using the transtibial SBT [15] was performed in one group and ACL ligamentoplasty using the DBT [13] in the other group. In both techniques, femoral tunnels were done through the tibial tunnels.

Statistical analysis: the data collection was carried out respecting the confidentiality and anonymity of the patients, and they were incorporated into a Microsoft Excel 2013 database. Once the results were obtained for each of the tests, the statistical treatment was carried out with the package SPSS 22 statistic. For each of the variables, the mean and standard error of the mean (SEM) of the subjects belonging to each group were calculated. A normality test was performed for quantitative variables (Shapiro-Wilk test) and for homogeneity of variances (Levene). Comparisons between the means of the variables of each of the groups were made using a one-way analysis of variance (ANOVA) with a post hoc multiple comparisons test (parametric - Bonferroni -, or nonparametric - Mann-Whitney or Kruskal Wallis -, based on the results of the tests of normality and homogeneity of the variances). Statistically significant differences were considered for values of $p < 0.05$.

## 3. Results

The age (30 ± 1 years), weight (82 ± 2 kg) and height (176 ± 1 cm) of the 30 subjects with ACL rupture were not significantly different from the corresponding values of the 27 subjects in the control group (31 ± 1 years, 79 ± 2 kg and 175 ± 1 cm).

*3.1. Kinematic gait test*: values of knee range and angle, maximum angular velocity of the knee, average and maximum angular acceleration of the knee, ankle range, average and maximum angular velocity of the ankle, and average and maximum angular acceleration of the ankle are shown in Figures 1 and 2.

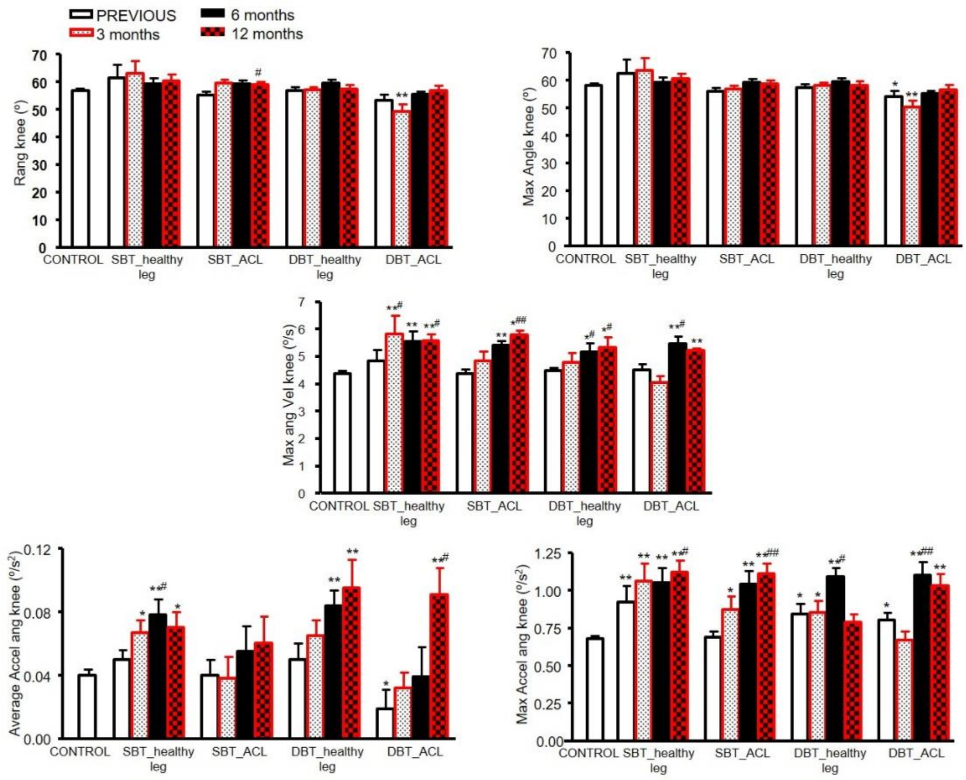


**Figure 1.** Kinematic gait test. Values are expressed as mean ± SEM. * p <0.05 and ** p <0.01, Significantly different from healthy (CONTROL) subjects. # p <0.05; ## p <0.01 Significantly different from its corresponding PREVIOUS.

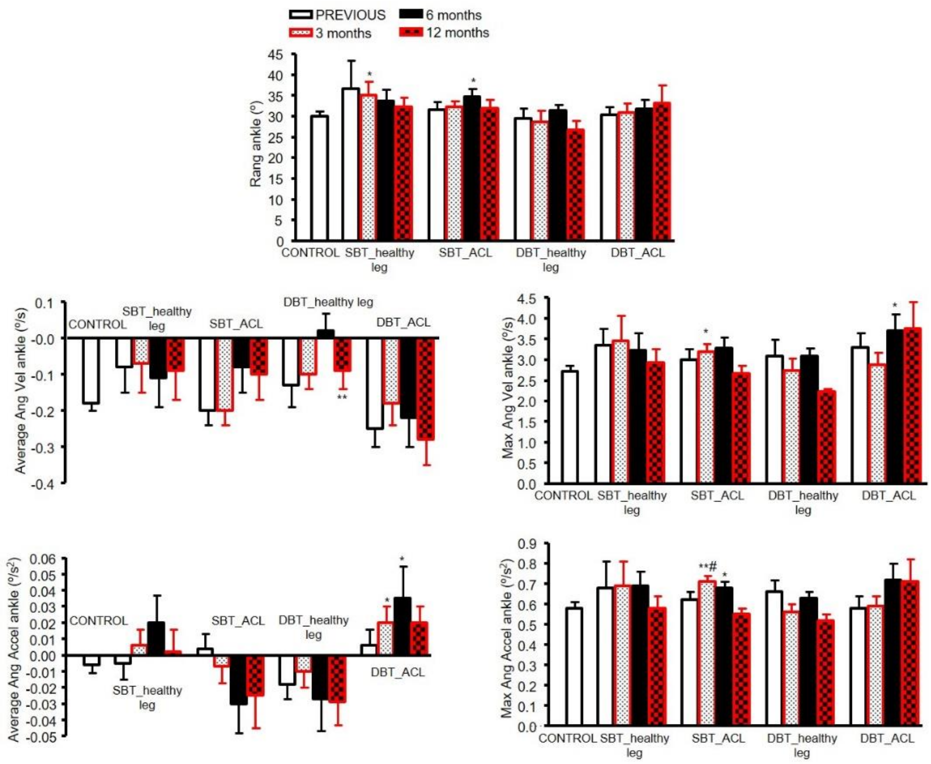


**Figure 2.** Kinematic gait test. Values are expressed as mean ± SEM. * p <0.05 and ** p <0.01, Significantly different from healthy (CONTROL) subjects. # p <0.05 Significantly different from its corresponding PREVIOUS.

*3.2. Kinetic gait analysis test:* patients operated with the SBT presented significantly higher values than control subjects for velocity, braking and propulsion at three months after the intervention, and significantly lower values of support times (Figure 3). No statistically significant differences were observed in the rest of the parameters analyzed with this test for the different times and the two techniques used.

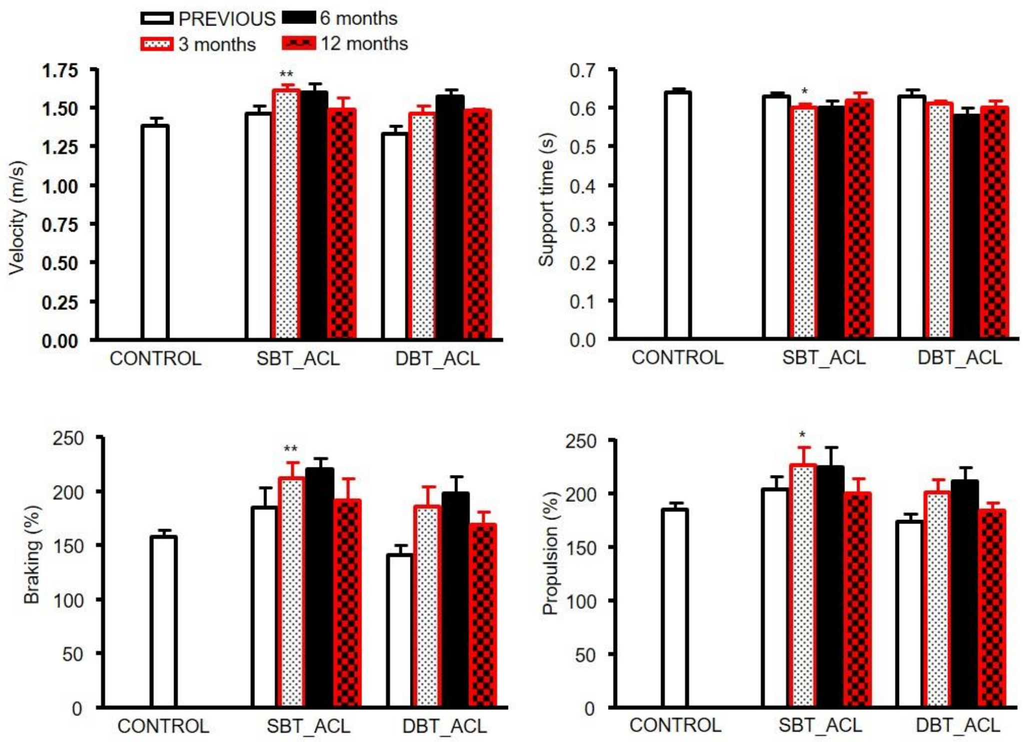


**Figure 3.** Gait kinetic analysis test. Values are expressed as mean ± SEM. * $p < 0.05$ and ** $p < 0.01$, Significantly different from healthy (CONTROL) subjects.

*3.3. Pivot-shift gait test:* both techniques used showed significant differences with respect to control group, both in the support leg and in the starting leg, and in both the healthy leg and the injured leg, in the different measured times, in the strength values in the anteroposterior x, mediolateral y and vertical z axis (Table 1).

*3.4. Equilibrium test:* subjects treated with the SBT presented global assessment values (3 and 6 months), Romberg test on foam rubber with eyes closed (6 months), stability limits (6 months), control and ability (3 and 6 months), and rhythmic and directional control in the mediolateral axis (3, 6 and 12 months) significantly higher and stability values in the mediolateral and anteroposterior axis Romberg test on foam with eyes open (3 months) significantly lower than control group (Table 2). Subjects treated with the DBT presented limits of stability (3 and 6 months), control and ability (3, 6 and 12 months) and rhythmic and directional control in the mediolateral axis (3 and 12 months) significantly higher and Romberg evaluation test values on foam rubber with eyes open (3 months), stability values in the anteroposterior axis Romberg on foam rubber with eyes open (3 months) and closed (6 months) significantly lower than control group (Table 2).

**Table 1**. Pivot-shift gait test. Force values (N) in the anteroposterior x, mediolateral y and vertical z axis, in the support leg and in the exit leg (pis2_) in the pivot-shift gait test, in control subjects and in subjects with ACL rupture, uninjured (healthy) and injured leg, before the intervention (0) and at 3, 6 and 12 months after the intervention, treated with the SINGLE and DOUBLE bundle techniques.

| | | CONTROL | N | SINGLE_HEALTHY | SINGLE_ACL | N | DOUBLE_HEALTHY | DOUBLE_ACL | N |
|---|---|---|---|---|---|---|---|---|---|
| fx | 0 | -0,0043 ± 0,0029 | 50 | -0,0446 ± 0,0279** | -0,0204 ± 0,0069* | 16 | -0,0082 ± 0,0035 | -0,0116 ± 0,0064 | 14 |
| | 3 m | | | -0,0205 ± 0,0050** | -0,0150 ± 0,0087 | 10 | -0,0181 ± 0,0058* | -0,0116 ± 0,0113 | 9 |
| | 6 m | | | -0,0162 ± 0,0071* | -0,0045 ± 0,0028 | 8 | -0,0193 ± 0,0104 | -0,0160 ± 0,0101 | 7 |
| | 12 m | | | -0,0156 ± 0,0078 | -0,0123 ± 0,0073 | 8 | -0,0191 ± 0,0051* | -0,0369 ± 0,0120* | 5 |
| fy | 0 | 0,0138 ± 0,0042 | 50 | 0,0681 ± 0,0378 | 0,0573 ± 0,0373 | 16 | -0,0031 ± 0,0052 | 0,0200 ± 0,0085 | 14 |
| | 3 m | | | 0,0306 ± 0,0140 | 0,0180 ± 0,0207 | 10 | 0,0194 ± 0,0085# | 0,0244 ± 0,0172 | 9 |
| | 6 m | | | 0,0243 ± 0,0126 | 0,0006 ± 0,0079 | 8 | 0,0142 ± 0,0195 | 0,0198 ± 0,0158 | 7 |
| | 12 m | | | 0,0211 ± 0,0103 | 0,0064 ± 0,0138 | 8 | 0,0049 ± 0,0071 | 0,0671 ± 0,0070**, ## | 5 |
| fz | 0 | 0 ,0039 ± 0,0009 | 50 | 0,0117 ± 0,0059* | 0,0120 ± 0,0048* | 16 | 0,0028 ± 0,0010 | 0,0038 ± 0,0015 | 14 |
| | 3 m | | | 0,0028 ± 0,0014# | 0,0037 ± 0,0021 | 10 | 0,0155 ± 0,0093*,# | 0,0041 ± 0,0018 | 9 |
| | 6 m | | | 0,0055 ± 0,0024 | 0,0037 ± 0,0026 | 8 | 0,0059 ± 0,0021 | 0,0061 ± 0,0029 | 7 |
| | 12 m | | | 0,0068 ± 0,0025 | 0,0047 ± 0,0021 | 8 | 0,0095 ± 0,0015*, ## | 0,0146 ± 0,0026**, ## | 5 |
| pis2_fx | 0 | -0,0163 ± 0,0043 | 50 | -0,0133 ± 0,0080 | -0,0272 ± 0,0101 | 16 | -0,0198 ± 0,0070 | -0,0044 ± 0,0129 | 14 |
| | 3 m | | | -0,0241 ± 0,0094 | -0,0462 ± 0,0223 | 10 | -0,0054 ± 0,0085 | -0,0010 ± 0,0180 | 9 |
| | 6 m | | | -0,0338 ± 0,0106 | -0,0208 ± 0,0145 | 8 | -0,0026 ± 0,0035 | -0,0243 ± 0,0114 | 7 |
| | 12 m | | | -0,0264 ± 0,0129 | -0,0324 ± 0,0160 | 8 | -0,0454 ± 0,0190* | -0,0507 ± 0,0150 | 5 |
| pis2_fy | 0 | 0,0111 ± 0,0034 | 50 | 0,0186 ± 0,0076 | 0,0433 ± 0,0126* | 16 | 0,0156 ± 0,0036 | 0,0166 ± 0,0087 | 14 |
| | 3 m | | | 0,0305 ± 0,0075* | 0,0093 ± 0,0064 | 10 | 0,0351 ± 0,0062**, # | 0,0159 ± 0,0095 | 9 |
| | 6 m | | | 0,0238 ± 0,0053 | 0,0193 ± 0,0043 | 8 | 0,0289 ± 0,0105 | 0,0086 ± 0,0060 | 7 |
| | 12 m | | | 0,0146 ± 0,0069 | 0,0079 ± 0,0071 | 8 | 0,0180 ± 0,0102 | 0,0638 ± 0,0198* | 5 |
| pis2_fz | 0 | 0,0003 ± 0,0013 | 50 | -0,0008 ± 0,0022 | -0,0020 ± 0,0020 | 16 | -0,0022 ± 0,0010 | -0,0003 ± 0,0012 | 14 |
| | 3 m | | | -0,0037 ± 0,0012 | -0,0036 ± 0,0030 | 10 | -0,0019 ± 0,0017 | -0,0002 ± 0,0015 | 9 |
| | 6 m | | | -0,0026 ± 0,0013 | -0,0005 ± 0,0020 | 8 | -0,0017 ± 0,0008 | -0,0021 ± 0,0011 | 7 |
| | 12 m | | | 0,0002 ± 0,0013 | 0,0001 ± 0,0024 | 8 | -0,0005 ± 0,0025 | 0,0079 ± 0,0033**, # | 5 |

Values are expressed as mean ± SEM; * $p < 0.05$; ** $p < 0.01$ Significantly different from CONTROL; # $p < 0.05$; ## $p < 0.01$ Significantly different from its corresponding PREVIOUS

**Table 2**. Equilibrium test. Global assessment (GLB), Romberg test with eyes open (REO), and closed (REC), Romberg test on foam rubber with eyes open (RFO) and closed (RFC), stability values in the mediolateral (StML) and anteroposterior (StAP) axis Romberg test on foam rubber with eyes open and closed, stability limits (LimStab), control and ability (CTLAB), and rhythmic and directional control in the mediolateral (RDC_ML) and anteroposterior (RDC_AP) axis in the equilibrium test in control subjects and in subjects with ACL rupture, before the intervention (0) and at 3, 6 and 12 months after the intervention, treated with the SINGLE and DOUBLE bundle techniques.

| | | CONTROL | N | SINGLE ACL | N | DOUBLE ACL | N |
|---|---|---|---|---|---|---|---|
| GLB | 0 | 92,38 ± 0,78 | 26 | 92,74 ± 0,93 | 16 | 92,63 ± 1,33 | 14 |
| | 3 m | | | 95,27 ± 0,57 * | 10 | 94,10 ± 1,27 | 9 |
| | 6 m | | | 95,57 ± 0,82 *, # | 8 | 94,27 ± 1,19 | 7 |
| | 12 m | | | 95,31 ± 0,87 | 8 | 95,57 ± 0,92 | 5 |
| REO | 0 | 97,06 ± 0,50 | 26 | 95,55 ± 0,76 | 16 | 94,49 ± 1,61 | 14 |
| | 3 m | | | 98,07 ± 0,37 # | 10 | 94,23 ± 2,03 | 9 |
| | 6 m | | | 97,46 ± 0,69 | 8 | 95,94 ± 1,54 | 7 |
| | 12 m | | | 96,96 ± 0,82 | 8 | 94,75 ± 1,13 | 5 |
| REC | 0 | 96,42 ± 0,82 | 26 | 96,05 ± 0,88 | 16 | 94,20 ± 2,60 | 14 |
| | 3 m | | | 96,92 ± 0,65 | 10 | 93,18 ± 4,29 | 9 |
| | 6 m | | | 96,95 ± 0,76 | 8 | 96,06 ± 1,43 | 7 |
| | 12 m | | | 95,66 ± 1,53 | 8 | 97,01 ± 1,23 | 5 |
| RFO | 0 | 95,41 ± 0,87 | 26 | 95,24 ± 0,88 | 16 | 93,50 ± 1,03 | 14 |
| | 3 m | | | 95,09 ± 1,17 | 10 | 92,50 ± 1,55 * | 9 |
| | 6 m | | | 96,16 ± 0,84 | 8 | 91,75 ± 2,22 | 7 |
| | 12 m | | | 96,21 ± 1,25 | 8 | 94,16 ± 1,69 | 5 |
| RFC | 0 | 91,61 ± 1,69 | 26 | 92,03 ± 2,27 | 16 | 91,95 ± 2,66 | 14 |
| | 3 m | | | 94,98 ± 2,28 | 10 | 93,99 ± 3,59 | 9 |
| | 6 m | | | 97,45 ± 1,80 * | 8 | 90,19 ± 3,59 | 7 |
| | 12 m | | | 97,44 ± 1,69 | 8 | 97,47 ± 2,28 | 5 |
| StML_RFO | 0 | 98,20 ± 0,46 | 26 | 97,01 ± 0,78 | 16 | 98,22 ± 0,587 | 14 |
| | 3 m | | | 95,82 ± 1,26 * | 10 | 97,48 ± 0,58 | 9 |
| | 6 m | | | 96,95 ± 1,51 | 8 | 96,90 ± 1,136 | 7 |
| | 12 m | | | 97,18 ± 1,31 | 8 | 99,29 ± 0,66 | 5 |
| StAP_RFO | 0 | 98,93 ± 0,37 | 26 | 97,88 ± 0,69 | 16 | 98,34 ± 0,48 | 14 |
| | 3 m | | | 97,56 ± 0,77 * | 10 | 97,23 ± 0,79 * | 9 |
| | 6 m | | | 98,09 ± 0,92 | 8 | 96,88 ± 1,10 | 7 |
| | 12 m | | | 96,93 ± 1,45 | 8 | 98,05 ± 0,80 | 5 |
| StML_RFC | 0 | 92,62 ± 1,34 | 26 | 91,99 ± 1,69 | 16 | 92,99 ± 1,44 | 14 |
| | 3 m | | | 91,68 ± 2,31 | 10 | 96,31 ± 1,49 | 9 |
| | 6 m | | | 94,44 ± 2,15 | 8 | 95,24 ± 1,69 | 7 |
| | 12 m | | | 92,41 ± 3,46 | 8 | 98,01 ± 1,99 # | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| StAP_RFC | 0 | 97,92 ± 0,69 | 26 | 95,51 ± 1,18 | 16 | 97,18 ± 1,24 | 14 |
| | 3 m | | | 95,15 ± 2,56 | 10 | 97,06 ± 1,63 | 9 |
| | 6 m | | | 98,21 ± 0,83 | 8 | 92,25 ± 2,42 * | 7 |
| | 12 m | | | 95,92 ± 2,32 | 8 | 97,83 ± 2,17 | 5 |
| LimStab | 0 | 89,74 ± 0,64 | 26 | 89,87 ± 0,75 | 16 | 89,74 ± 0,96 | 14 |
| | 3 m | | | 91,77 ± 0,83 | 10 | 92,57 ± 0,46 *, # | 9 |
| | 6 m | | | 92,29 ± 0,81 * | 8 | 93,01 ± 0,68 **, # | 7 |
| | 12 m | | | 91,27 ± 1,39 | 8 | 92,84 ± 1,29 | 5 |
| CTLAB | 0 | 90,09 ± 1,13 | 26 | 90,39 ± 1,39 | 16 | 91,23 ± 1,30 | 14 |
| | 3 m | | | 94,11 ± 0,69 *, # | 10 | 94,50 ± 0,51 *, # | 9 |
| | 6 m | | | 94,02 ± 1,25 * | 8 | 94,32 ± 0,98 * | 7 |
| | 12 m | | | 93,92 ± 1,22 | 8 | 94,96 ± 1,06 * | 5 |
| RDC_ML | 0 | 91,48 ± 1,96 | 26 | 93,56 ± 2,79 | 16 | 94,98 ± 2,60 | 14 |
| | 3 m | | | 99,35 ± 0,30 ** | 10 | 99,03 ± 0,57 * | 9 |
| | 6 m | | | 99,45 ± 0,55 **, # | 8 | 96,70 ± 2,58 | 7 |
| | 12 m | | | 98,56 ± 0,96 * | 8 | 99,88 ± 0,12 *, # | 5 |
| RDC_AP | 0 | 89,73 ± 2,43 | 26 | 88,77 ± 3,11 | 16 | 91,94 ± 2,92 | 14 |
| | 3 m | | | 95,88 ± 1,07 | 10 | 95,77 ± 1,29 | 9 |
| | 6 m | | | 93,75 ± 3,54 | 8 | 95,91 ± 1,67 | 7 |
| | 12 m | | | 97,25 ± 1,25 | 8 | 96,41 ± 1,58 | 5 |

Values are expressed as mean ± SEM; * $p < 0.05$; ** $p < 0.01$ Significantly different from CONTROL; # $p < 0.05$ Significantly different from its corresponding PREVIOUS

## 4. Discussion

The most important finding of the present work was that surgical treatment of ligamentoplasty, either by the SBT or by the DBT, achieved an improvement in functional alteration (gait pattern, changes in the forces against floor, duration of treads, symmetry of both legs, and the reproducibility of the gait, and changes in bipedal standing equilibrium) with slight differences between the two techniques, with no one being superior to the other one. Therefore, our results refute the initial hypothesis.

In the kinematic gait test, both techniques offer similar results with respect to the gait pattern, so that neither technique is superior to the other for this pattern. In a meta-analysis carried out by Li et al. [21] it was observed that the DBT obtained significantly better values than the SBT in relation to the extension deficit, without significant differences in relation to the flexion deficit. However, other studies obtain good results in the knee range of motion, with little or no flexion and extension restrictions, and without significant differences between both techniques [22,23]. In the kinematic gait test, in subjects with ACL rupture operated with the DBT, a decrease in the knee mean range of motion and maximum knee angle of the injured leg was observed at three months, which it was normalized at 6 and 12 months, which coincides with previous works, where it is observed that 3 months is little time for the restoration of gait parameters, and that a correct rehabilitation manages to improve these parameters in the following months [24,25]. Furthermore, the present results also showed a tendency to increase angular velocity and acceleration in both the injured and healthy legs in both groups of patients. At 12 months after the intervention, the subjects operated with the SBT presented an increase in the mean and maximum angular acceleration of the knee of the healthy leg, and an increase in the maximum angular velocity of the knee on both legs. However, 12 months after the intervention, the subjects operated with the DBT presented an increase in the maximum angular velocity and the average angular acceleration of the knee in both legs, and an increase in the maximum angular acceleration of the knee only in the injured leg, without significant differences with respect to the control in the rest of the parameters analyzed in this test. The present study suggests, therefore, that both techniques offer similar results regarding the gait pattern, assessed with the kinematic gait test, so that neither technique is superior to the other for this pattern, observing small alterations in the gait patterns in the 2 groups at 12 months, so that, despite the improvement, neither technique manages to restore a normal gait one year after the intervention.

In the test of kinetic analysis of gait, in the subjects operated with the SBT, a decrease in the support time and an increase in speed and of the braking and propulsion forces were observed three months after the intervention, which were completely normalized at 6 and 12 months. In contrast, the subjects operated with the DBT did not show significant differences with respect to the control in any of the parameters and in any of the times measured after the intervention. It should be noted that the parameter of Global Assessment of the gait of the subjects, both pathological and control, presented values above 90% of normality, regardless of the leg analyzed, and without significant differences between the injured leg and the healthy leg of subjects with ACL rupture, nor in either of the two legs with control subjects, at any of the measured times, which indicates that, despite the injury, all the subjects presented normal values in their lower limb with respect to this parameter. A possible explanation for this fact could be that some of the alterations in the parameters observed were not a consequence of the injury, but part of adaptive mechanisms that allow the subject to maintain a normal global gait, despite having alterations in various parameters. With all the above, it could be concluded that no differences were observed between the type of surgical intervention performed in terms of the results of this test.

In the pivot-shift gait test, alterations in the reaction force of the ground were observed in the three axes studied, at the different study times (3, 6 and 12 months after the intervention), both in first tread (support leg) and in the second tread (exit leg), and with the two surgical techniques used. It is interesting to note that some of these alterations persisted 12 months after surgery, more in the subjects operated with the DBT than in the subjects operated with the SBT, which is really surprising since, precisely, the DBT was introduced with the aim of achieving greater rotational stability than that achieved with a SBT [21,24,26]. The present results suggest that ligamentoplasty with the DBT paradoxically leaves worse rotational stability of the knee at 12 months than the SBT or, at least, a greater alteration of forces in the pivot-shift gait test. The superiority of the DBT over SBT has been discussed in recent years, while numerous studies show no differences in the results obtained with both techniques, others show that the results obtained with the DBT in the rotational stability of the knee are superior to those obtained with the SBT [23,24]. The observed differences, although statistically significant, are discrete and only in one of the evaluation moments (12 months), so they should be interpreted with caution due to the sample size. However, it could be stated that the DBT has not shown a better result in terms of knee rotational stability compared to the SBT.

In the equilibrium tests, it is necessary to highlight that with both techniques and for the three times evaluated after surgery, the results obtained in all the evaluations (global, Romberg eyes open, Romberg on foam rubber with eyes open, etc.) that were calculated using this group of tests were higher than 90%, indicating that none of the subjects analyzed, both pathological and control, showed symptoms of suffering some type of pathology that affects balance. As in the present series, no other differences were found in the balance tests with bipedal support similar to those used in our work, suggesting that these tests are not sensitive enough to detect possible balance disturbances or of postural control produced by ACL injuries [27].

Both techniques achieved good functional recovery, although the functionality of gait was not fully recovered, and with little or no differences in the results between the two techniques. Therefore, the absence of significant differences in rotational stability in favor of the DBT forces its use to be questioned, since this technique increases complexity and surgical time and, in addition, it is a technique that has a higher cost, since it uses twice as many implants.

The main limitation of the present study is its high dropout rate. A possible explanation for this high dropout rate lies in the special doctor-patient relationship that occurs in the activity of mutual labor companies -all the patients were injured at work and were treated in the mutual labor sphere-, where it is usual that patients stop attending appointments once they are discharged from work, especially in the case of self-employed workers. In contrast to this, there are studies conducted on athletes, with very low or no dropout rates, since athletes who suffer injuries have a very close involvement with their doctor and a high predisposition to collaborate with the therapeutic team and undergo all kinds of tests and assessment tests [28,29]. This high dropout rate decreases the statistical power of the study and may produce a bias that must be taken into account when interpreting the conclusions of this study.

## 5. Conclusions

Reconstruction of the ACL with the DBT offered very similar improvement in functional recovery than the SBT. The two techniques offered similar results regarding the gait pattern, the forces exerted against the ground, the duration of the footsteps, the symmetry between both extremities, the repetitiveness of the gesture during the gait and balance with bipedal support, so that neither technique was superior to the other for these parameters. In the subjects included in this study, ligamentoplasty with the DBT did not result in better rotational stability of the knee at 12 months than the SBT.

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**Institutional Review Board Statement:** The study was approved by the Institutional Ethics Committee of Unión de Mutuas on 13-12-2016.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

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