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Comparison of tunnel expansion and isometric muscle strength after ACL reconstruction with single- or dual-bundle hamstring allograft: a prospective, randomized study

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Objective: The aim of this study was to compare tunnel expansion and isokinetic muscle strength after single- and dual-bundle reconstruction of the anterior cruciate ligament (ACL).

Methods: This study included 34 patients who underwent ACL reconstruction in our clinic between November 2007 and March 2008. Eighteen patients (average age: 27.3 years; range: 19 to 35 years) underwent single-bundle ACL reconstruction and sixteen patients (average age: 30.1 years; range: 20 to 40 years) underwent dual-bundle ACL reconstruction. Method selection was determined by draw. Isokinetic hamstring and quadriceps muscle strength was tested preoperatively using Biodex 3. Three-dimensional computed tomography of the knee joint was taken in the 2nd and 3rd postoperative month. The three-dimensional computed tomography and isokinetic muscle strength tests were repeated at the 6th month follow-up. Each tunnel was divided into six equal parts, and the tunnel width in the sagittal and coronal planes was measured and the same points in the axial plane were measured in the tunnel area.

Results: No significant difference was found between the single- and dual-bundle reconstructions in isokinetic muscle strength values. No statistically significant difference was detected between the tunnel expansions in 2nd, 3rd and 6th month tomographies following single- and dual-bundle ACL reconstruction.

Conclusion: Single- and dual-bundle ACL reconstructions seem to provide similar results in terms of early tunnel enlargement and isokinetic muscle strength.

Key words: ACL reconstruction; dual-bundle; isokinetic; prospective; single-bundle; tunnel expansion.

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It has been claimed that anterior cruciate ligament (ACL) reconstruction using two separate bundles is anatomically superior and ensures greater stability following reports of instability caused by expansion over time in the tunnels created during reconstruction and loss of bone stock in single-bundle reconstruction.[1-4] The clinical significance of this expansion remains controversial.[5-16] In ACL reconstruction, graft selection, tunnel placement, fixation, graft tension and rehabilitation methods have also shown the importance of biomechanics.[17] The dual-bundle method is claimed to result in a more stable knee after surgery. However, no study has been conducted on its effects on muscle strength.

Our prospective, randomized study aimed to compare tunnel enlargement and isokinetic muscle strength between single- and dual-bundle ACL reconstruction.

Patients and methods

ACL rupture was diagnosed in 77 patients through clinical and radiologic findings between November 2007 and March 2008. In these 77 patients, 58 were candidates for ACL reconstruction and 50 accepted to be operated. Two patients who underwent previous arthroscopic surgery and one patient who underwent ACL reconstruction in another clinic were excluded. The remaining 47 patients were informed about the study and 40 patients gave their consent to be included.

Fig. 1. The Biodex 3 device.

Concentric and isokinetic quadriceps and hamstring muscle strengths of both knees were taken at 60°/sec, 180°/sec and 120°/sec the day before surgery using a Biodex 3 (Biodex Biomedical Systems, Inc., Shirley, NY, USA) device (Fig. 1). Peak torque and body weight rates were measured and recorded. Reconstruction method was decided preoperatively by a draw and the patient was not informed. Five patients not followed up regularly and one patient who developed a postoperative infection were removed from the study. Thirty-four patients (33 males, 1 female; average age: 28.6 years; range: 19 to 40 years) were included in the study. Eighteen patients (average age: 30.1 years; range: 20 to 40 years) underwent single-bundle reconstruction and 16 (average age: 27.3 years; range: 19 to 35 years) underwent dual-bundle reconstruction. Average duration between trauma and surgery was approximately 3 months and 10 days (range: 3 months to 2 years). One patient was a professional athlete. Thirty-two patients received combined (spinal and epidural) and 2 patients general anesthesia, as according to their choice.

In the single-bundle method, the ACL was aligned in the middle of the tibial tunnel exit. The femoral tunnel was opened at 1:30 to 2:00 on the left knee lateral femoral condyle. The semitendinosus and gracilis tendons were doubled and their thickness was measured. Femoral fixation was performed using the EndoButton (Smith & Nephew, Inc., Andover, MA, USA) technique. Tibial fixation was performed using a biodegradable poly(L-lactide)-hydroxyapatite screw (BioRCI; Smith & Nephew, Inc., Andover, MA, USA) and staple.

In the dual-bundle method, a 5 cm oblique incision was made 2 cm below and medial to the tibial tuberosity to harvest gracilis and semitendinosus tendons. The thickness of each doubled tendon was separately measured. For the anteromedial band (AMB), the tibial tunnel was placed at 45° in the sagittal plane and tibia tuberosity to keep as close as possible. For the posterolateral band (PLB), placement was at 45° in the sagittal plane. To keep the tunnels from each other, they were replaced closely to the medial collateral bond. Average distance between the tunnels was between 1.5 and 2 cm. The tibial guide wire placed for the AMB was taken out from the tibial attachment of ACL, approximately 13 mm in front of the anterior corner of the posterior cruciate ligament. The PLB guide wire was taken out approximately 7 mm posterior and lateral to the AMB guide wire. The tunnel was opened with a cannulated drill to the same diameter as the graft. After identification of the femoral insertion site of the ligaments, the knees were placed at 120° and in contrast to the transtibial technique, both guide wires were inserted through the anteromedial portal. Other than the classical clock orientation method, insertions were made at the anatomical attachment site of the tendons according to soft tissue remnants and bony landmarks as described by Ferretti et al.[18] By sizing the length of the EndoButton CL, which uses in the total length of the tunnel, the tunnel's length was found where the graft sat on the femur. Grafts were advanced separately through the EndoButton CL ring (Smith & Nephew, Inc., Andover, MA, USA) and doubled. AMB was opened at the lateral femoral condyle at 1:00 to 2:00 on the left and at 3:00 for PLB. First the PLB, then the AMB EndoButtons were stabilized through the tunnel. Poly(L-lactide)-hydroxyapatite biodegradable screw BioRCI and staple were used for tibial fixation.

A compressive bandage was applied following surgery. Patients who underwent meniscal repair were allowed to mobilize with an extension brace and weight-bearing. Passive range of motion (ROM) exercises were started on the first postoperative day. On the second postoperative day, passive ROM was increased and a rehabilitation program of quadriceps strengthening exercises was added. Patients without complication were discharged on the third day. Knees without meniscus lesions or which did not receive meniscectomy at 3 weeks and knees that underwent meniscus repair at 6 weeks were locked in extension. Rehabilitation programs were not different for patients who underwent single- and dual-bundle reconstruction. Stitches were removed on the 15th postoperative day. The physiotherapy program started immediately following surgery and was continued on an outpatient basis starting in the second postoperative week. Patients were allowed to run in the third postoperative month when 60% muscle strength was obtained. In the 6th month, patients were allowed to participate in competitive sport when quadriceps power reached 80%.

Three-dimensional computed tomography (CT) was taken at the 2nd, 3rd and 6th month follow-ups (Figs. 2 and 3). Preoperative muscle strength measurements using the Biodex 3 system were retaken at the 6th postoperative month follow-up. Two-mm sections which were taken intermittently were stored in the digital environment. Measurements were given code numbers rather than names by the same radiologist and planned randomly in sagittal, coronal and axial planes. Tomographic cross-sections of the femur and tibia tunnels in the digital environment were divided into 6 equal parts and labeled L1 at the most proximal point of measurement and L6 at the most distal point. The inside distance of the tunnel on the sagittal and coronal plane, perpendicular to the axis of the tibia, was measured in millimeters. The tunnel dimensions were measured with the axial reconstructions on the same workstation (HP xw8400; Hewlett-Packard Company, Palo Alto, CA, USA).

SPSS for Windows 15.0 software was used for statistical analysis. The Friedman test was used for statistical comparison of the coronal, sagittal and axial plane measurements, and the Mann-Whitney U test was used to evaluate muscle strength. P values of less than 0.05 were considered significant.

Results

Mean operative time for the single-bundle ligament reconstruction was 55 (range: 44 to 72) minutes, and 82 (range: 69 to 132) minutes for the dual-bundle

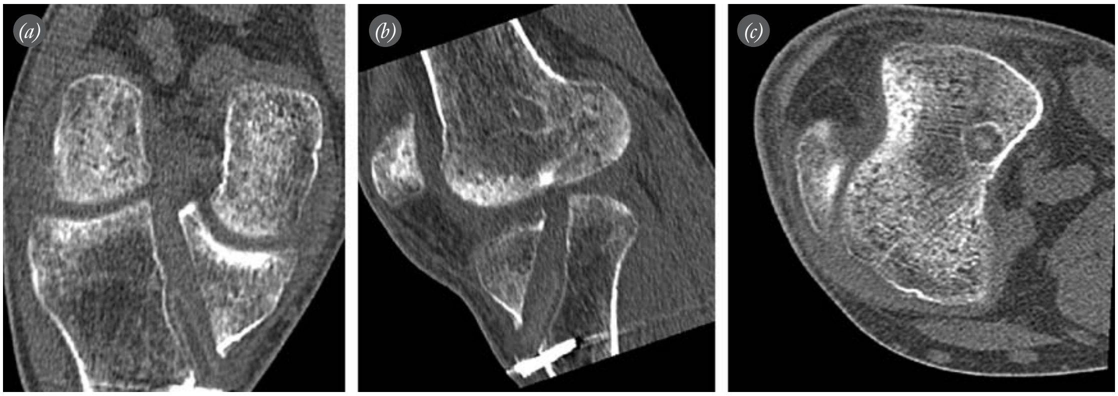

Fig. 2. Postoperative 3rd month CT images of a single-bundle ACL construction patient on the **(a)** coronal, **(b)** sagittal, and **(c)** axial planes.

Fig. 3. Postoperative 2nd month CT image of a dual-bundle ACL construction patient on the coronal plane.

reconstruction. Arthroscopic partial meniscectomy of the medial meniscus was performed in 20 patients, of the lateral meniscus in 6 and of the lateral and medial meniscus in 2, due to a tear. Meniscal repair was performed in four patients. The distribution of meniscal tears is summarized in Table 1.

There was no significant difference between patients who underwent single- and dual-bundle reconstruction in terms of hamstring and quadriceps isokinetic muscle strength at angular velocities of 60°/sec, 120°/sec and 180°/sec pre- and postoperatively ($p>0.05$). There was no significant difference between the pre- and postoperative measurements of both single- and dual-bundle reconstruction patients ($p>0.05$). There was also no significant difference between the measurements of single- and dual-bundle reconstruction patients ($p>0.05$). Average values are reported in Table 2. No significant differences were found between tunnel widths at the 2nd, 3rd or 6th month ($p>0.05$). Of the measurements made at the axial, coronal and sagittal planes, axial plane data are given in Tables 3-5.

Discussion

In the single-bundle reconstruction technique, reconstructions are performed from the posterolateral part of tibia through the anteromedial part of the femur. On the other hand, one of the most important neglected PLB tasks in single-bundle surgery is the stabilization of the rotation of the transverse plan in full extension.[19-22] Although it is claimed that single-bundle reconstruction does not provide patients undergoing knee reconstruction sufficient ability to walk up stairs, change direction suddenly or gain rotational control of the index cases, such as downhill running, other publications have claimed that dual-bundle reconstruction does not result in any difference in rotational stability.[10-16,23-27] Dual-bundle reconstruction of the ACL was then proposed to ensure a more anatomical and stable reconstruction.[28-35]

Studies have shown tunnel enlargement following single-bundle ligament reconstruction.[36,37] A small degree of enlargement begins in the early postoperative period and continues in the following weeks and months.[38] Although well-studied, the clinical effects of this expansion are not yet properly understood. The majority of studies suggest that tunnel enlargement does not affect joint stability.[5-9,19] The most obvious tunnel expansions are seen after revision surgeries. Preoperative preparation, including knowledge of bone loss in revision surgery, is important. Studies suggest that in 80% of patient complaints were resolved following ACL surgery while 20% to 25% indicated

Table 1. Distribution of the patients in terms of meniscal tear and treatment type.

	Single-bundle ACL repair	Dual-bundle ACL repair
Medial meniscus tear: repaired	3	1
Both medial and lateral meniscus tear: meniscectomy performed	1	1 (subtotal meniscectomy performed on the medial meniscus)
Lateral meniscus tear: partial meniscectomy performed	3	3
Medial meniscus tear: partial meniscectomy performed	6	8
Bucket-handle tear of the medial meniscus: subtotal meniscectomy performed	3	3
Total patients with meniscal tear	16	16
Total number of patients	18	16

Table 2. Muscle strength of the patients after single- and dual-bundle ACL reconstruction patients.

Measured value	Muscle group	Single-bundle before surgery	Single-bundle after surgery	Dual-bundle before surgery	Dual-bundle after surgery
60/sec PT	Quadriceps	74.142	95.012	89.063	85.600
60/sec PT	Hamstring	49.108	55.175	46.038	46.433
120/sec PT	Quadriceps	53.417	68.388	63.563	66.417
120/sec PT	Hamstring	31.192	37.713	2.826	28.750
180/sec PT	Quadriceps	43.833	53.562	47.138	55.100
180/sec PT	Hamstring	25.067	29.850	20.013	24.483
60/sec PT/BW	Quadriceps	87.692	111.475	118.025	113.850
60/sec PT/BW	Hamstring	57.550	64.350	60.425	60.600
120/sec PT/VA	Quadriceps	63.308	79.800	84.050	87.467
120/sec PT/VA	Hamstring	36.492	42.350	37.137	37.483
180/sec PT/VA	Quadriceps	51.410	62.813	62.180	72.117
180/sec PT/VA	Hamstring	29.167	33.925	26.300	31.750

PT: peak torque; PT/BW: peak torque/body weight

the continuation of instability and pain.[39,40] These studies provide information about the large number of candidates for revision surgery. Biomechanical and biological factors are responsible for tunnel enlargement.[41] Biomechanical factors (graft choice, fixation method) play a greater role than biological factors.[3,6,42,43] Micro-movement between the graft and tunnel is the primary biomechanical factor.[41] Studies have shown that tunnel expansions are more frequently seen after reconstructions using hamstring autografts than reconstructions using bone-patellar tendon-bone autografts.[3,6,42,43] These studies support the hypothesis that soft tissue remnants inside the tunnel may impair the stability of the graft and ultimately leads to further expansion.[8] It is believed that additional mechanical stress between the tunnel and the graft will lead to further expansion in the tunnel, which in turn will result in complications such as change in tunnel direction and acute tunnel expansion.[4,41] As in similar studies, Fink et al. showed that wear and enlargement of the tunnel is the result of the windshield wiper effect caused by the synovial fluid entering

Table 3. Average area measured on the axial plane after ACL reconstruction with single-bundle (mm²).

Section no.	1. tibia tomography	2. tibia tomography	3. tibia tomography	1. femur tomography	2. femur tomography	3. femur tomography
1	88.58±16.94	85.30±13.11	91.86±16.70	23.95±8.78	22.76±4.28	22.41±3.81
2	92.83±23.29	91.70±16.68	91.58±21.48	29.25±13.17	28.39±5.47	21.03±6.50
3	104.70±18.92	102.64±18.61	101.56±31.93	36.63±18.68	38.14±16.20	39.00±9.98
4	117.63±25.63	115.80±21.32	114.08±26.48	80.37±23.54	80.44±11.89	80.44±19.61
5	130.34±27.80	128.95±15.41	126.65±31.95	116.99±25.20	122.88±16.84	114.44±27.90
6	111.04±22.98	106.45±18.01	108.71±20.60	101.16±19.35	104.81±29.61	109.80±24.12

Table 4. Average anteromedial tunnel measurements on the axial plane after ACL reconstruction with dual-bundle (mm²).

Section no.	1. tibia tomography	2. tibia tomography	3. tibia tomography	1. femur tomography	2. femur tomography	3. femur tomography
1	80.06±32.11	85.60±15.85	86.62±34.28	21.34±4.36	20.45±2.52	20.82±3.86
2	83.47±26.89	91.06±26.80	78.70±27.17	27.20±10.68	26.13±3.47	22.98±5.40
3	83.47±26.89	98.80±29.62	91.26±29.40	31.94±14.29	33.10±8.14	32.22±11.36
4	98.34±25.46	114.15±27.81	104.95±27.71	50.37±7.42	55.20±23.21	59.84±14.69
5	108.15±16.86	117.00±20.86	107.86±22.58	77.05±22.10	85.13±24.43	81.57±25.59
6	96.51±30.72	94.93±29.82	86.37±11.46	74.66±21.02	91.42±18.06	88.51±26.88

Table 5. Average area of the PL tunnel on the axial plane after ACL reconstruction with dual-bundle (mm^2).

Section no.	1. tibia tomography	2. tibia tomography	3. tibia tomography	1. femur tomography	2. femur tomography	3. femur tomography
1	71.47±35.35	65.63±29.05	91.08±16.70	27.84±9.36	23.23±5.68	28.10±8.70
2	48.17±20.62	56.68±24.66	49.01±16.34	33.46±12.58	27.50±9.08	31.97±15.07
3	50.48±28.52	59.51±22.68	47.06±14.83	45.21±15.05	38.91±12.82	33.42±11.03
4	61.17±19.97	68.58±24.04	66.74±18.09	49.21±23.62	45.96±17.89	43.10±11.14
5	74.31±17.75	72.78±14.06	72.24±11.17	58.06±19.53	65.93±25.38	63.11±28.20
6	58.98±13.67	60.05±6.36	61.78±9.84	65.90±20.80	72.18±24.90	69.77±20.32

the dead space between the graft and the tunnel during the first 6 weeks following reconstruction and that this enlargement does not have any clinical meaning.[36,42,44,45] In a study on 22 patients who underwent dual-bundle reconstruction, Siebold[37] measured tunnel width using an MR and analyzed the correlation between tunnel expansion and clinical outcomes using knee outcome scores and a KT-1000 device at the first year follow-up. In nine of his patients (41%), tibial tunnels were completely united although observed femoral and tibial tunnel enlargement did not have any effect.

Several studies have examined the clinical impact of tunnel enlargement following single-bundle ligament reconstruction.[4-8] Consensus is that the tunnel expansion would create stability problems during the revision surgery.[8] During our study, we observed tunnels in close proximity to the insertion point in 2 of our patients.

Studies have shown that tunnels gradually expand in the first 6 weeks in particular.[36] This expansion depends on several factors. Some writers focus on biological factors and others on mechanical factors.[46,47] One of the main mechanical effects is micro-movement caused by the abrasive effect of the windshield wiper effect of the joint fluid and the graft located in the tunnels.[36] Ugutmen et al., in order to limit micromotion, proposed drilling a tunnel with a diameter 1 mm less than that of the graft and then enlarging it using a dilator.[48] Studies have shown that after single-bundle reconstruction, an expansion of 20.9 to 73.9% in the tibial tunnel and 30.1 to 100.4% in the femoral tunnel may be expected.[6,43,48-50] According to our study, there were no differences between the measured widths during the 2nd, 3rd and 6th months. Studies on the single-bundle reconstruction show tunnel expansion before our first period of measurement with no additional expansion shown after.

Some studies have asserted that dual-bundle ACL surgery provides better stability than single-bundle in the anatomical and rotational sense although other publications indicate that there is no difference.[10-16,23-27] No study exists in the literature on the effect of stability on muscle strength. In our study, surgery duration was 154.5% and tourniquet application time was 171% higher in dual-bundle surgeries than single-bundle surgeries. There were no differences in pre- and postoperative isokinetic muscle measurements between single- and dual-bundle surgeries. Similarly, there was no significant difference in tunnel enlargement during tomography taken in the 2nd, 3rd and 6th month. However, greater bone loss occurred in the four tunnels opened in the tibia and femur during dual-bundle reconstruction. This may cause more difficulty in revision surgery. Dual-bundle reconstruction is more difficult for the surgeon with a larger learning curve.

In addition to providing a physiological and anatomical reconstruction, a new surgical technique must also be practical and without major complication. In vitro studies have also reported successful results although the number of publications on long-term results is limited.

In our study, no differences were found between pre- and postoperative isokinetic muscle reviews. We believe that this was because the return to sport activities was not obligatory for the majority of our patients and only one patient was a professional athlete and the others amateurs. In addition, patients were afraid to use the operated knee. The six-month postoperative period may not be long enough for the detection of muscle strength differences.

In the literature, while the rate of tibial tunnel unification in the first year has been reported at 59%,[37] we only encountered one patient with a cross-section at the proximal L1. This ratio is very low compared to those found in the literature. We believe this was due to the suitable placement of the biodegradable screw in the tunnel.[37] However, as patients in our study were only followed-up in the short-term, further studies are necessary.

Although some studies have claimed that dual-bundle reconstruction results in less tunnel enlargement, others assert that it also results in greater bone stock loss due to tunnel coalition.[51,52] Further studies that include a longer study duration, larger patient pool, CT scans taken earlier in the study and additional scoring systems would be beneficial for surgical decision making.

In conclusion, we did not find any significant differences between single- and dual-bundle ACL reconstruction in terms of short-term isokinetic muscle strength and tunnel expansion.

Conflicts of Interest: No conflicts declared.

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