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ORIGINAL ARTICLE

MRI evaluation of the knee post double bundle ACL reconstruction: Association of graft findings and comparison with arthroscopy

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KEYWORDS

MRI;
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Abstract *Purpose:* To determine the association of graft complications after anterior cruciate ligament reconstruction using double bundle graft by magnetic resonance imaging using arthroscopy/surgery as a gold standard.

Patient and methods: A total of 126 patients (130 knees) with complete ACL tears were recruited for this prospective study, and all patients subsequently underwent an MRI examination to evaluate graft integrity and signal intensity.

Results: Out of 130 knees with ACL reconstruction, partial tears of the AM bundle were seen in 25 knees (19.2%) and complete tear of the AM bundle was seen in 26 (20%). Partial tears of the PL bundle were seen in 35 knees (26.9%), and complete tears of the PL bundle in 31 knees (23.8%). These patients' signs of instability were noted in 2 patients with partial tear of PL bundle and in 9 patients with complete tear of PL bundle.

Conclusion: Increased signal intensity within the anteromedial or posterolateral bundles of a double bundle ACL reconstruction is frequently associated with a partial tear. Impingement of the anteromedial graft is frequently associated with partial tear and increased signal intensity which is proved by arthroscopy/surgery. A low incidence of other complications is seen.

1. Introduction

The anterior cruciate ligament (ACL) is the most commonly injured ligament in the knee, resulting in a significant morbidity most pronounced in the resulting sagittal plan instability. Anatomically ACL is divided into two distinct bundles namely

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anteromedial (AM) and posterolateral (PL). This anatomic distinction reflects their anatomic insertions on the tibia. The AM bundle (which is more sagittal oriented) originates more proximally and anteriorly on the lateral femoral condyle than the PL bundle, and inserts anteromedially at the tibial foot print, whereas the PL bundle inserts into the tibia posterolaterally (1–3). When the knee is extended, the PL bundle becomes 15% longer and the AM bundle becomes 30% shortened while on knee flexion the reverse takes place. The PL bundle is also tightened during internal and external rotation of the tibia (4–6). This complex anatomic arrangement of the bundles allows the ACL to withstand axial stresses and tensile forces on the knee, as one component of the ACL is taut and therefore functional in any position of the knee (6).

During the past 3 decades, surgical reconstruction of ACL has become an accepted treatment for symptomatic ACL deficiency (7,8). The goal of surgery is to prevent joint instability with subsequent possible joint degeneration.

A variety of donor sites are available, including Bone-Patellar-Tendon-Bone graft (BPTB), combined semitendinosus and gracilis hamstring tendons, and quadriceps tendon. In addition, the use of allograft (whether chemically treated, irradiated or fresh frozen) or synthetic tapes represents other available options. On the other hand, different methods of fixation of the graft have been applied including interference screws, suspensory devices (Endobutton), and cross pins (8) (Fig. 1).

ACL reconstruction is currently one of the most common surgical procedures in sports medicine and has yielded promising clinical results for patients with ACL injuries. However, a substantial number of postoperative complications may occur after ACL reconstruction, including range of motion (ROM) deficit, quadriceps weakness, and donor-site morbidity, particularly after harvesting BPTB graft (9).

Donor-site morbidity can manifest clinically as anterior knee pain, donor-site tenderness, pain on kneeling, or sensory loss over the anterior knee. Of these, anterior knee pain is a frequent and important complication, with the potential to impede rehabilitation and return to sports activity (10).

Magnetic resonance (MR) imaging is the preferred advanced imaging modality for the evaluation of symptomatic ACL graft reconstructions (1), and can help aid preoperative planning (10,11).

The aim of this study was to determine the association of graft complications after ACL reconstruction using double bundle graft by MRI compared to arthroscopy results.

2. Patients and methods

Following approval by our center human ethical committee, a total of 126 patients (130 knees) who were diagnosed (based on clinical and radiological backgrounds) as having complete ACL tears and either pain or limited extension were recruited for this prospective study between June 2010 and May 2014. The mean age of patients involved in this study was 35 years (range: 22–48). All patients underwent double bundle ACL reconstruction, using a combination of B-PT-B and semitendinosus grafts in 76 patients, and a combination of semitendinosus and gracilis tendons in 50 patients.

2.1. Clinical diagnosis

All patients recruited for this study were clinically assessed for general signs of infection, locking, giving way, history of trauma or recreational activities. Examination was routinely performed including inspection, palpation, ROM and special tests with special emphasis on anterior drawer, lachman, pivot shift, and Mac Murray tests. In addition prearthroscopic evaluation of anterior and side to side translation was performed.

All of these patients underwent double bundle ACL reconstruction surgery either open (33) or arthroscopic (97) elsewhere and were evaluated by diagnostic arthroscopy by two well experienced Knee surgeons (A.F.S. and A.N.S.). The clinical diagnosis of post-reconstruction complications and the treatment results were compared with MRI findings.

3. Diagnostic arthroscopy

The procedure was performed via standard regime including the following.

After spinal anesthesia, the patient lay supine. A pneumatic tourniquet was applied to the mid thigh and after standard scrubbing and draping; it was elevated to 150 mmHG above systolic blood pressure. A standard anterolateral portal was established 1 cm proximal to the joint line and 1 cm lateral to the patellar tendon. A standard screening of the knee joint was performed beginning at the suprapatellar pouch, the patellofemoral joint, the lateral gutter, and the medial gutter during full extension of the knee. On 90 degree flexion the medial joint compartment including the medial capsule, the coronary ligament, and the medial meniscus was inspected. Then the scope was pulled outward slowly to inspect the tibial insertion of the

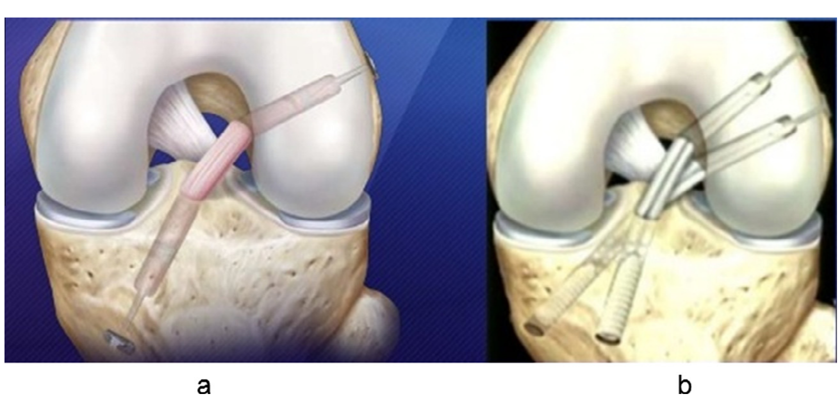

Fig. 1 A diagram shows: single bundle ACL reconstruction (SB ACLR) (a), double bundle ACL reconstruction (DB ACLR).

ACL graft, the femoral insertion, the intercondylar notch, and the degree of synovialization of the graft. The operated limb was then put on figure-of-four position to facilitate inspection of the lateral compartment including the lateral joint capsule, the lateral meniscus, and the popliteus tendon. Any possible complication that was suspected either clinically or radiologically was assessed and managed. Then the knee was irrigated and the wound was sutured. A crepe bandage was applied and then the tourniquet was deflated.

3.1. MRI protocol

A postoperative follow-up MRI scan was obtained on all patients at a mean of 34 months (range: 24–40) (39 patients were presented with knee pain and 36 patients were presented with limited mobility), and MRI was done using a 1.5 T Gyroscan Intera (Philips Medical Systems, Netherlands) and an extremity coil. The knee was imaged at rest in the coil, with approximately 8° of flexion.

Sagittal proton density–weighted fast spin-echo (FSE) with fat saturation, coronal gradient-echo, and axial T2-weighted spin-echo (SE) sequences were acquired with the following parameters: TR/TE 3500–4467/65–70 ms; echo train length (ETL) 8; number of signals acquired NEX 3; receiver bandwidth ±31.25 kHz; acquisition time 5 min 10 s. Coronal STIR (TR/TE 3600–4100/84–88 ms; ETL 10; number of signals acquired 2; acquisition time, 5 min 29 s; receiver bandwidth ±31.25 kHz) and intermediate-weighted (proton density) FSE (2000–2300/14–18 ms; ETL 6; number of signals acquired 2; acquisition time, 5 min 20 s; receiver bandwidth ±41.67 kHz) sequences were performed. All sequences were acquired using a 4-mm slice thickness, 256–512 × 192–256 matrix size, and 14 cm field of view.

3.2. MRI analysis

All MR images were analyzed in consensus by two musculoskeletal radiologists (MA and HA) with both having 15 years of professional experience, and readers were blinded to clinical data. Evaluation concentrated on signal intensity within graft fibers, graft orientation and graft continuity. More specifically, for each MR image plane, images were assessed for the following primary signs: diffuse increased ACL graft signal intensity (SI), and the SI of the intra-articular portion of both grafts was analyzed as described by Howell (12). The intra-articular portion of the grafts was divided into proximal, middle, and distal thirds, and location of focal increased graft signal if present (proximal, middle, or distal) was analyzed. The SI was analyzed on PD-weighted and T2-weighted images and graded on a scale with (I) being a normal SI similar to posterior cruciate ligament (PCL), (II) >50% of the graft having a normal SI, and (III) <50% of the graft having a normal SI. The grade IV by Howell (100% of the graft having an increased SI) was incorporated with grade III. When increased PD-weighted SI and T2-weighted SI were also analyzed (10).

Graft orientation on sagittal images (either taut between femur and tibia, horizontal or lax), complete or partial ACL graft discontinuity (anteromedial or posterolateral). Secondary signs of ACL graft tear included the presence of anterior tibial translation (posterior cortex of mid lateral tibia translated >5 mm anterior to the posterior cortex of the femur on sagittal images) and uncovered posterior horn of lateral meniscus (a line drawn parallel to the posterior cortex of the lateral tibia intersects the posterior horn of lateral meniscus on sagittal images). A graft was considered disrupted when no intact fibers were seen and fluid signal was interposed between the torn ends (10–14). The graft was considered partially torn when there was focal graft thinning compared to any detected segment of normal graft diameter (14).

Images were also assessed for other complications including cystic degeneration of the graft, roof impingement, and arthrofibrosis. Cystic degeneration of the graft was defined as a fluid collection within the graft (13), either within the femoral tunnel, the intra-articular portion, or tibial tunnel. Roof impingement of the graft was defined as contact of the impinged graft with the antero-inferior margin of the intercondylar roof and associated posterior bowing and SI alteration of the graft (13,14). The presence or absence of osteophytes in the femoral intercondylar notch was recorded. Arthrofibrosis was defined as the presence of scar tissue in the knee joint (13). Localized anterior arthrofibrosis, or a cyclops lesion, was defined as a nodular fibrous lesion in the anterior intercondylar notch (12). The integrity of the medial and lateral menisci, posterior cruciate ligament, lateral collateral ligament (LCL), medial collateral ligament (MCL), quadriceps and patellar tendons was also evaluated and graded as normal, degenerated or thickened, partially torn, or torn.

The severity of anterior knee pain (AKP) was classified into 3 stages: (I) pain after activity only; (II) pain during and after activity, but still able to perform at a satisfactory level; and (III) pain during and after activity which is more prolonged and severe to the degree that hinders the patient from performing at a satisfactory level.

3.3. Statistical analysis

The data analysis was carried out using SPSS 14.0 statistical software. The statistical significance of association between MRI findings was calculated using the Fisher Exact Probability Test.

4. Results

Thirty patients were symptomatic and out of 126, 21 were with anterior knee pain and 11 with limited extension of the knee.

The imaging findings are listed in Table 1.

4.1. Graft SI

Graft SI in the AM bundle was normal in 97 of the 130 knees and increased in 33 knees (24.4%), grade II in 19 knees and grade III in 14 knees. SI in the PL bundle was normal in 40 knees and increased in 90 knees, grade II in 47 knees, and grade III in 43 knees (Fig. 1).

4.2. Graft disruption

Regarding prearthroscopic clinical evaluation, positive anterior drawer test was seen in 129 cases (30 cases grade I, 80 cases grade II and 19 cases grade III). Out of 130 knees with ACL reconstruction, partial tears of the AM bundle were seen in

Table 1 MRI findings of ACL graft.

Finding		Graft	
		AM	PL
Graft SI	Normal	97	40
	Grade II	19	47
	Grade III	14	43
Graft Tear	Partial	25	35
	Complete	26	31
Both graft		12	
Impingement		15	
Arthrofibrosis	Focal (cyclops)	8	
	generalized	10	
Displaced interference screws		5	
Ganglion cyst		6	
Infection		1	
Widening of the tunnel		2	

Table 2 Results of MRI and arthroscopy/surgery.

Diagnosis	MRI	Arthroscopy
Partial tear AM	25	22
Partial tear PL	35	31
Complete tear AM	26	23
Complete tear PL	31	29
Both grafts complete tear	12	14
Impingement	15	15
Generalized arthrofibrosis	10	8
Cyclops	8	11
Displaced interference screws	5	–
Ganglion cyst	6	–

Table 3 The diagnostic value of MRI of the knee in evaluation of partial AM bundle tear.

Sensitivity	95.66
Specificity	97.22
NPV	99.09
PPV	88

Table 4 The diagnostic value of MRI of the knee in evaluation of partial PL bundle tear.

Sensitivity	93.99
Specificity	95.83
NPV	95.87
PPV	88.57

25 knees (19.2%) and complete tear was seen in 26 knees (20%). Partial tears of the PL bundle were seen in 35 knees (26.9%), and complete tears in 31 knees (23.8%).

Both AM and PL bundles were completely torn in 12 knees (9.2%) (Fig. 2). These 12 patients had anterior knee pain and limited knee extension; all of these patients have positive secondary signs of incompetent ACL. They denied any history of trauma.

Regarding diagnostic arthroscopy results, partial tears of the AM bundle were seen in 22 knees (16.9%) and complete tear of the AM bundle was seen in 23 knees (17.6%). Partial tears of the PL bundle were seen in 31 knees (23.8%), and complete tears of the PL bundle in 29 knees (22.3%). Both AM and PL bundles were completely torn in 14 knees (10.7%).

Sensitivity, specificity, NPV and PPV are shown in Tables 2–7.

Graft impingement was seen in 15 knees (11.5%). No impingement of the PL bundle was noted (Fig. 3) (Table 1). Generalized arthrofibrosis was seen in 10 knees (7.6%) and 8

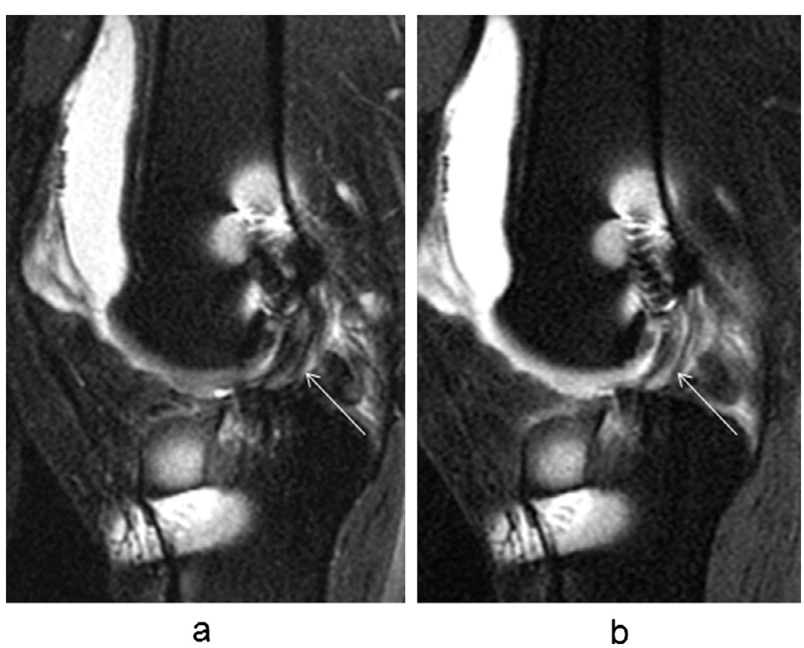

Fig. 2 (a and b) Sagittal PD with fat saturation MR images in a 40-year-old male shows a large amount of increased striated and globular signal intensity within the ACL graft (white arrow in (a and b)) involving more than 50% of the cross-sectional area of the graft.

Table 5 The diagnostic value of MRI of the knee in evaluation of complete AM bundle tear.

Sensitivity	95.83
Specificity	97.12
NPV	99.02
PPV	88.46

Table 6 The diagnostic value of MRI of the knee in evaluation of complete PL bundle tear.

Sensitivity	90.62
Specificity	98
NPV	97.03
PPV	93.55

Table 7 The diagnostic value of MRI of the knee in evaluation of complete tear of both bundles.

Sensitivity	82.35
Specificity	100
NPV	97.46
PPV	100

(6.2%) of them only proved by arthroscopy, while localized cyclops lesion was seen in 8 knees (Fig. 5); 11 lesions were proved by arthroscopy (see Fig. 4 and Table 8).

Ganglion cyst related to the graft in the tibia was seen in 6 knees, closely related to the tibial tunnel (Fig. 6). Displaced interference screws were seen in 5 knees (Fig. 7). Imaging features compatible with septic arthritis were seen in one knee of a known diabetic patient. Widening of the femoral and tibial tunnels was seen in 2 knees, one of them 12 month post-surgery and the other 10 months post-surgery related to cystic or mucoid degeneration of graft.

Lateral collateral ligament sprains were seen in 2 knees (grade 2). Increased signal intensity was seen within the patellar tendon in 3 knees, all of whom had graft harvest from the patellar tendon. Marginal and intercondylar osteophytes were seen in 4 patients. The posterior cruciate ligament and quadriceps tendon were normal in all patients.

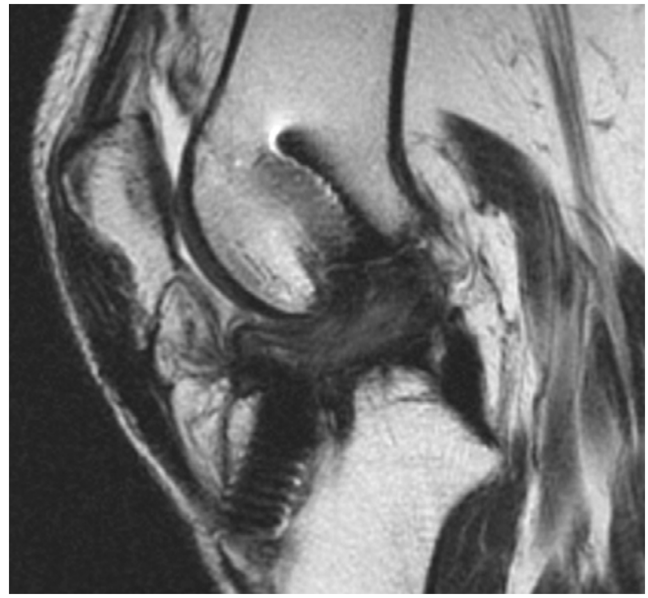

Fig. 4 Sagittal PD MR image in a 32-year-old male shows graft impingement against the roof of the intercondylar region (Blumensaat's line) with increased signal intensity within the graft Grade III.

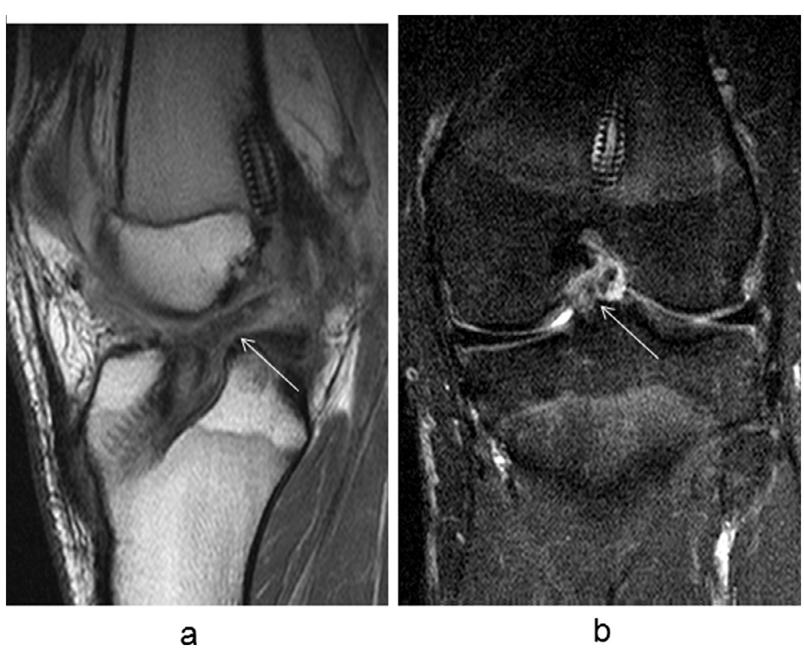

Fig. 3 (a) Sagittal PD and (b) Coronal STIR MR images in a 37-year-old female show disruption of both grafts, white arrow in a shows remnant of AM graft.

Table 8 Incidence of different rupture patterns of anteromedial (AM) and posterolateral (PL) grafts.

AM graft	PL graft			Total
	Normal	Partial Tear	Complete tear	
Normal	81	10	13	104
Partial tear	3	93	2	14
Complete tear	3	3	6	12
Total	87	22	21	130

Fig. 6 Sagittal PD MR image in a 34-year-old male shows a ganglion cyst related to the graft in the tibia with internal septation.

4.3. Associations between MRI graft findings

The SI in intact ACL grafts and partially ruptured AM or PL bundles was evaluated in each knee (Tables 2 and 3). The SI was increased in 12 of the 22 patients (54%) with a partial rupture of the AM bundle and in 28 out of 85 patients (42%) with an intact AM bundle ($p = 0.013$). SI in the PL bundle was increased in 28 of 31 patients with a partial rupture (90%) and 22 of 70 patients with an intact graft (31%) ($p = 0.001$). Of the 15 patients with graft impingement, a partial tear of the AM graft was seen in 7 patients ($p = 0.0165$), and increased SI was seen in the AM bundle in 5 patients and PL bundle in 2 patients.

5. Discussion

The number of double bundle (anatomic) graft ACL reconstructions has increased in recent years because such procedure results in better rotational stability than traditional single bundle graft ACL reconstruction with fewer graft failures (15–18). This was shown in a recent review of 14 randomized controlled trials by Järvelä and Suomalainen (19,20). Controversially, an earlier meta-analysis of four randomized controlled trials showed no difference in reported clinical outcome measures (21).

MRI evaluation of traditional SB ACL graft reconstruction and complications is well established in the literature (10,13,22–25), but there are only a moderate number of publications of DB MRI imaging. According to Casagranda et al. the complications of SB and DB ACL reconstructions are similar (25).

a b

Fig. 5 (a) Sagittal PD and (b) Sag PD with fat sat MR images in a 39-year-old male show a cyclops lesion (white arrow) with intact ACL graft.

Fig. 7 (a) Coronal STIR and (b) Sagittal PD MR images in a 25-year-old male with ACL graft tear and loose femoral screw associated with Hardware malposition.

The evolution of anatomic (double bundle) ACL reconstruction was basically intended to restore as anatomic reconstruction as possible thus mimicking the native ACL in both anatomy and biomechanics (26). It was originally defined as the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites (27,28).

During the first 3 months after ACL reconstruction, graft constructs are typically uniformly low in signal intensity on T1- and T2-weighted images. Thereafter, a progressive vascularization of periligamentous soft tissues with subsequent synovialization and remodeling results in graft ligamentization (25,29). During this postoperative phase (12–18 months), the graft may normally show a degree of intrasubstance increased signal intensity on T1- and T2-weighted images that are reflective of synovial and neovascular proliferation around and within the graft, which is referred to as "*neoligamentization*" of graft tissue (24). However, by 2 years after ACL reconstruction, the literature suggests that a normal graft tendon should resume a uniform normal low-signal-intensity MR imaging appearance (24).

Prior studies (24) have revealed findings of increased intrasubstance graft signal as a sign of graft impingement. Furthermore, partial tears of an ACL graft may appear as areas of increased signal intensity within the graft tissue with some residual intact fibers on T2-weighted images. On the other hand, Recht and Kramer (10) reported that T2-weighted acquisitions may also show regions of increased signal intensity within an intact graft, if such signal was not isointense relative to fluid and not traversing the full thickness of the graft construct.

In this study as MRI scan was obtained on all patients at a mean of 26 months, it revealed increased signal intensity in PLB graft in the majority of patients and in AMB graft in considerable number of patients (25.3%), and these results correlate with Saupe et al. and differ from what was stated previously in the literature.

In this study, as regards diagnostic arthroscopy results, 17.6% of patients had a complete tear of the AMB graft, 22.3% of patients had a complete tear of the PLB graft, and 10.7% of patients had both grafts disrupted. Previously, van eck et al. reported DB graft failure with both grafts disrupted in 8% of patients with surgical confirmation in a 2-year prospective study (27). Recently, van Eck et al. described surgically confirmed patterns of DB reconstruction re-rupture in a cohort of 40 patients presented for revision surgery (27). The most common pattern (35%) was a mid-substance rupture of the AMB graft with a mid-substance rupture of the PLB graft, while in 19% of patients the PLB graft was intact. Also, in a recent study by Kiekara et al. they found that 3% of their patients had both grafts disrupted. In this study, more PLB graft disruptions were noted which were confirmed by arthroscopy (26).

In MRI evaluation, the recognition of graft disruption was based on the discontinuity of graft fibers. This MRI finding was the most reliable (sensitivity 72% and specificity 100%) in a study by Collins et al. (13) of surgically confirmed graft disruption. In their group, the comprehensive assessment of other previously described MRI primary findings of graft disruption such as graft thickness, graft SI, and graft orientation did not further increase sensitivity.

Association between MRI findings was evaluated regarding arthroscopy results. In this study, partial rupture was associated with the increased SI of the graft. Impingement of the AMB graft was associated with a partial tear of the AMB graft and with increased SI of the PLB graft.

Many authors stated that Visualization of intrasubstance ACL graft signal changes at long-term follow-up MR imaging examination, particularly at T2-weighted imaging, has been ascribed as a pathologic finding indicative of possible graft impingement, degeneration, or partial tearing (10).

In this study both grafts were disrupted in small percentage of patients. Clinically, disruption of both grafts is an important finding because it can lead to revision ACL surgery if the patient complains of symptoms of instability in the operated knee. However, long-term follow-up will reveal if the partial tears of the grafts seen in MRI will lead to total disruption of the grafts and instability symptoms of the operated knees with a need for a revision ACL surgery.

Three of the 22 arthroscopically diagnosed partial-thickness AM bundle tears were described as lax at arthroscopy with no evidence of disruption of its fibers. It is possible that although morphologically intact, these grafts were functional failures leading to the false-negative MR imaging interpretations.

To our knowledge, very few studies, compared MRI and arthroscopy results as regarding evaluation of ACL graft, and MRI showed high sensitivity, specificity, NPV and PPV using arthroscopy as a gold standard in diagnosis of partial and complete tear of the AM and PL bundles.

The evolution of anatomic (double bundle) ACL reconstruction was basically intended to restore as anatomic reconstruction as possible thus mimicking the native ACL in both anatomy and biomechanics (32). It was originally defined as the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites (31).

One of the advantages of anatomic (double bundle) ACL reconstruction is the lower femoral tunnel placement in contrary to the single incision (transtibial) arthroscopic approach with less vertical orientation of the graft. Subsequently, there is less need to perform notchplasty to avoid graft attrition or impingement. In addition, this graft orientation allows better control of sagittal translation and rotational stability (33).

Despite the fact that this technique seems more rational to achieve rotational instability, it was confronted with enormous debate regarding graft selection, fixation methods, or the tensioning method for each isolated bundle (34). In addition this specific technique has shown increased complication rate regarding failure of fixation, tunnel dilatation secondary to either lengthened fixation or near tunnel placement or the difficulty to pursue with revision in cases of failures. In the same study done by Kim et al. (26), 28 cases out of 47 patients needed second look arthroscopy where 4 cases exhibited failure of the PL bundle graft with no AM bundle graft failure. In addition, 8 cases showed PLB graft relaxation. These results comply with the results of our study where PLB graft complications (51%) were superior to AMB graft complications (39%). The reasons for more common failures of PLB graft in anatomic ACL reconstruction have been extensively discussed in the literature and they comprise the following: faulty placement (non-anatomic) of the femoral tunnel, fixation under tension or maldirection.

Limitations of this study include, lack of oblique sagittal and coronal sequences along the course of the PLB graft resulting in volume-averaging of PLB graft SI in orthogonal sequences.

Lastly, this study concluded that increased signal intensity within the anteromedial or posterolateral bundles of a double bundle ACL reconstruction is frequently associated with a partial tear. Impingement of the anteromedial graft is frequently associated with partial tear and increased signal intensity which is proved by arthroscopy. A low incidence of other complications is seen.

Conflict of interest

All authors state that there are no conflict of interests in the manuscript, including financial, consultant, institutional and other relationships that might lead to bias or a conflict of interest.

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