



The relationship between graft intensity on MRI and tibial tunnel placement in anatomical double-bundle ACL reconstruction

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Received: 12 April 2019 / Accepted: 22 July 2019 / Published online: 31 July 2019
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Abstract

Purpose To determine whether the graft signal intensity of the anteromedial bundle (AMB) on MRI was related to the tibial tunnel placement, anterior–posterior (A–P) stability, and/or cyclops lesion formation following double-bundle (DB) anterior cruciate ligament (ACL) reconstruction.

Methods Between January 2010 and August 2016, 65 patients underwent arthroscopic DB-ACL reconstruction and were followed up for a minimum of 2 years. Follow-up included 1-week postoperative CT evaluation, 1-year postoperative MRI evaluation, and 2-year postoperative measurement of A–P instability using a KT-2000 arthrometer. Tibial tunnel placement and the location of Parson’s knob were expressed as percentages. Patients were divided into two groups according to the graft signal intensity of the AMB on MRI: the high group (grades 2, 3; group H) and the low group (grade 1; group L).

Results There were 23 knees in group H and 42 knees in group L. There was no difference between the two groups regarding the position of Parson’s knob. The AMB placement in the tibial tunnel in group H was more anterior than that in group L. The incidence of a cyclops lesion was significantly greater in group H [13 cases (56.5%)] compared with group L [7 cases (16.7%); $P = .05$]. The arthrometric side-to-side difference was significantly greater in group H (1.67 mm) than in group L (0.90 mm; $P = .019$).

Conclusion Group H had a more anterior tunnel location and significantly greater incidence of cyclops lesions than group L. An increased signal intensity of the AMB on MRI indicates A–P instability.

Level of evidence Level III retrospective cohort study.

Keywords Arthroscopy · Anterior cruciate ligament (ACL) · Double-bundle reconstruction · Magnetic resonance imaging (MRI) · Tunnel placement · Graft signal intensity

Introduction

Magnetic resonance imaging (MRI) has been widely used in the past to evaluate graft integrity following anterior cruciate ligament (ACL) reconstruction. MRI at over 12 months after

an ACL reconstruction sometimes shows an increased signal intensity of the graft [12]. Howell et al. [15] reported that high-intensity signals on MRI of the graft are regionalized and do not occur throughout the entire length of the graft. They suggested the causes of these high-intensity signals to

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be graft elongation, graft impingement by the intercondylar roof, and unknown nutrition factors, and attributable to impingement were also demonstrated to produce significant correlation with greater anterior laxity in the ACL-reconstructed knee. In addition, they were reported an indication of graft impingement because of tibial tunnel placed too far anteriorly [17].

In ACL reconstruction, the femoral tunnel placement in ACL reconstruction is one of the most important factors influencing the clinical outcome [9, 35, 42, 45]. The positioning and placement of the tunnel and graft can be improved by the knowledge of the anatomical position of the ACL insertion [10].

The tunnel placement on the tibial side is also important [37]. A posteriorly positioned tibial tunnel could avoid graft impingement, but also causes residual instability following ACL reconstruction [17]. It is considered that impingement of the graft by the intercondylar roof is caused by placement of the tibial tunnel. The tibial tunnel placed too far anteriorly allows the graft to contact the intercondylar roof during knee extension and clinically causes effusion, extension loss, cyclops lesion formation that is formed as causing an ACL graft placed too far anteriorly on the tibial plateau might result in impingement on to the top of the notch, graft damage [21], or residual instability [19, 20]. Although a cadaveric study showed the optimal position of the tibial tunnel to avoid graft impingement during single-bundle ACL reconstruction [32], there is no similar clinical research evaluating double-bundle (DB) ACL reconstruction.

Although methods for measuring the placement of the femoral and tibial tunnels have been recently reported by many authors using three-dimensional (3D) computed tomography (CT) [11, 33, 34, 39, 40, 42–44], there are few studies investigating the relationship between the graft signal intensity, detection of a cyclops lesion on MRI, and the tibial tunnel placement on 3D CT.

The purpose of this study was to determine whether the graft signal intensity of the anteromedial bundle (AMB) is related to the tibial tunnel placement, the anterior–posterior (A–P) stability, and/or the formation of a cyclops lesion following DB-ACL reconstruction. We hypothesized that an anteriorly positioned tibial tunnel would increase the risk of graft impingement which showed high intensity of the graft in MRI imaging, had a significantly greater occurrence of a cyclops lesion, and leads to residual laxity.

Methods

This study was approved by the hospital ethics committee and the internal review board of our institution. Between January 2010 and August 2016, 183 patients underwent primary arthroscopic ACL reconstruction carried out by three

surgeons. We excluded nine patients who underwent ACL reconstruction using a patellar tendon, 11 patients who had other ligament injuries, two patients who underwent single-bundle ACL reconstruction, one patient who underwent augmentation, and one patient who simultaneously underwent high tibial osteotomy. Of the 159 patients who underwent arthroscopic DB-ACL reconstruction using a hamstring tendon autograft, there were 65 patients who were followed up for a minimum of 2 years for whom the medical records and CT and MRI findings could be retrospectively reviewed. Of the 65 included patients, 18 were males and 47 were females. The mean age at the time of surgery was 25.6 years (range 15–61 years).

All operations were performed by three surgeons under the supervision of Y.H. The diagnosis of ACL tear was based on presenting symptoms, such as knee pain or knee collapse, and physical examination findings, such as effusion, instability (Lachman test, Pivot shift test), extension or flexion loss, MRI findings, and side-to-side differences detected during testing with the KT-2000 knee ligament arthrometer (MEDmetric Corp., San Diego, CA) at manual maximum force. The diagnosis of meniscal injury was based on the presence of knee pain, extension or flexion loss, positive McMurray test, and MRI findings. Surgery was indicated for patients with the above-mentioned symptoms and imaging findings.

Clinical evaluation of the function and stability of the affected knee was performed preoperatively and at 2 years postoperatively. Patient satisfaction and function were determined by assessing the patients' responses to the International Knee Documentation Committee (IKDC) scoring system subjective score [21] and the Lysholm knee score at 2 years postoperatively [28]. Instability was determined using the KT-2000 arthrometer and was expressed as the side-to-side difference in mm between the reconstructed and normal knees [7]. Included patients received CT evaluation at 1 week postoperatively, MRI evaluation at 1 year postoperatively, and had their A–P instability measured using the KT-2000 at 2 years postoperatively.

Surgical techniques and rehabilitation

All patients underwent DB-ACL reconstruction using a hamstring autograft. All operations were performed using the transportal technique in the lithotomy position. After conventional arthroscopic evaluation and hamstring graft harvesting, the locations of the femoral and tibial insertions of the ACL were confirmed, and the ACL remnant was preserved as much as possible. On the femoral side, the anteromedial (AM) and posterolateral (PL) tunnels were placed using an inside-out technique through the far AM portal. The far AM portal was created medial to the AM portal and just above the medial meniscus. The position was confirmed using a spinal needle to avoid cartilage and meniscus

damage during femoral tunnel creation. A guidewire was inserted at the center of the insertion site of the PL bundle (PLB) through the far AM portal. The knee was hyperflexed, and the guidewire was advanced before the acorn drill bit was passed over the guidewire. The femoral tunnel for the AMB was created using the same technique as for the PLB. The tibial tunnel was made using an ACL tip guide (Acufex; Smith and Nephew Inc., Andover, MA). After the graft was passed through the tunnels, femoral fixation was performed with a titanium button (EndoButton CL; Smith and Nephew Inc.). Tibial fixation of the graft was accomplished at 20° knee flexion by applying 20 N of initial tension and was finally fixed using the Double Spike Plate (Meira Co., Ltd.; Nagoya, Japan) with a 6.5-mm screw. Meniscal instability, if present, was addressed with surgical stabilization of the meniscus to the capsule. All cases of longitudinal tear at the posterior portion were treated with an inside-out arthroscopic repair technique with Henning retractors (Stryker Inc., Kalamazoo, MI) or the all-inside arthroscopic repair technique with a meniscal repair system (FAST-FIX; Smith and Nephew Inc.).

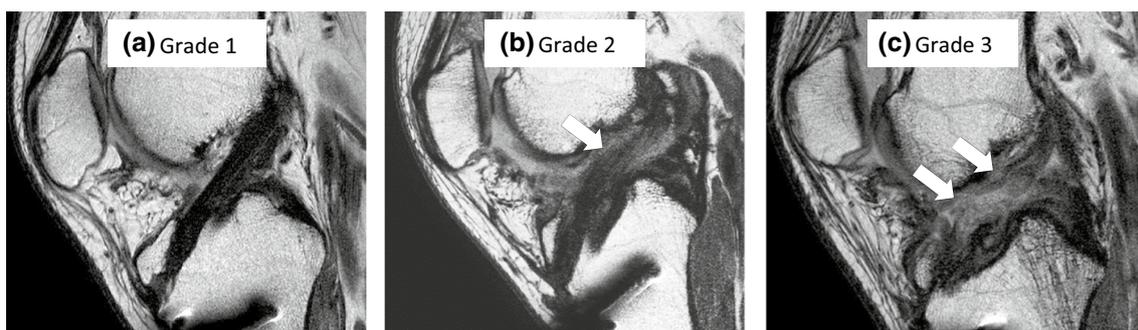
Rehabilitation was scheduled according to the type of surgical procedure performed. Patients who underwent ACL reconstruction alone were allowed to begin partial weightbearing on postoperative day 1, and were immobilized with a brace for 1 week, followed by protected weightbearing for 5 weeks. Patients who underwent ACL reconstruction and meniscal repair were allowed to start weightbearing from 2 weeks postoperatively, followed by protected weightbearing for 6 weeks. The treated knee was functionally supported with modified adjustable braces for

3 months postoperatively. Patients were allowed to jog at 3 months postoperatively and to return to previous sports at 10 months postoperatively. Of 54 patients, 34 patients (63%) underwent second-look arthroscopy or synovectomy at a mean of 15.6 months after DB-ACL reconstruction; hence, we evaluated the graft signal intensity on MRI at 1 year postoperatively.

Magnetic resonance imaging analysis

MRI was performed using a 3.0-Tesla MR imager (Achieva 3 T X series; Philips Healthcare, Best, the Netherlands) using a TR 1800 TE 50 instrument for the proton density-weighted oblique sagittal image, a 16-cm field of view, a number of excitation of 2, a 1.50-mm slice thickness, and a 1.65-mm slice spacing. This technique permitted visualization of almost the entire graft from tibial and femoral tunnel outlets. The signal intensity of the intra-articular portion of the AMB was analyzed as described by Howell et al. [9] and Sonoda et al. [40]. We classified the subjects into three grades based on the MRI findings: grade 1, low-intensity signal; grade 2, high-intensity signal within 50%; and grade 3, high-intensity signal greater than 50% [40] (Fig. 1).

A cyclops lesion was defined as a nodular fibrous lesion in the anterior intercondylar notch. Cyclops lesions were identified if the following were detected: (1) soft tissue fullness in the intercondylar notch, (2) intermediate signal intensity material protruding beyond the intercondylar notch line on the sagittal images with a (3) nodular shape and convex anterior border [3, 5, 8] (Fig. 2).



Representative magnetic resonance imaging 1 year after surgery presenting anteromedial bundle. The MR signals were divided into 3 grades:

- (a) grade 1, low-intensity signal; (2) grade 2, high-intensity signal within 50%; and (c) grade 3, high-intensity signal greater than 50%.

Fig. 1 Representative magnetic resonance imaging of the anteromedial bundle 1 year after surgery. The magnetic resonance signals were divided into three grades: **a** grade 1, low-intensity signal; **b** grade 2,

high-intensity signal within 50%; and **c** grade 3, high-intensity signal greater than 50% compared with the posterior cruciate ligament

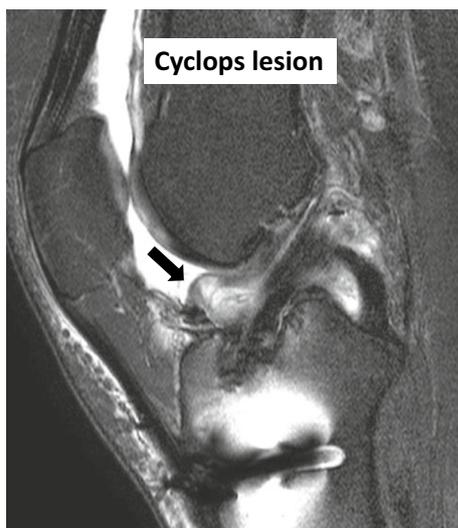


Fig. 2 A cyclops lesion was defined as the presence of soft tissue in the intercondylar notch, with a nodular shape and convex anterior border

Computed tomographic measurement of the tibial tunnel of the anteromedial bundle and Parson's knob

A CT scanner (Philips Brilliance 6; Philips Medical Systems, Cleveland, OH) was used for all patients. Each affected knee was scanned in extension at 1 week postoperatively. The CT slice thickness was 1 mm. 3D and 2D images were simultaneously created using CT software (AZE Virtual Place Lexus; AZE Co., Ltd., Tokyo, Japan).

The positions of the tibial tunnel apertures of the AMB and the PLB were measured using a rectangular frame on 3D CT images obtained at 1 week postoperatively. The bone tunnel position was assessed on 3D CT performed at 1 week postoperatively. We measured the tibial tunnel position and Parson's knob using the method described by Lertwanich et al. and Nishimori et al. [27, 31]. From a top view of the proximal tibia, a rectangular measurement frame was drawn with the posterior border tangential to the most posterior articular margins of both the medial and lateral tibial condyles. The anterior border of the rectangle was a line tangential to the most anterior articular margin of the medial tibial condyle. The position of the tibial tunnel was measured using this reference frame, with the distance from the anterior border defined as the anteroposterior depth and that from the medial border as the mediolateral width; these measurements were expressed as the distance from the center and the anterior border of the AMB in percentages. Regarding the anatomical particularities of the tibial plateau, Parsons et al. [36] reported the existence of a small bony prominence located anterior to the medial tibial

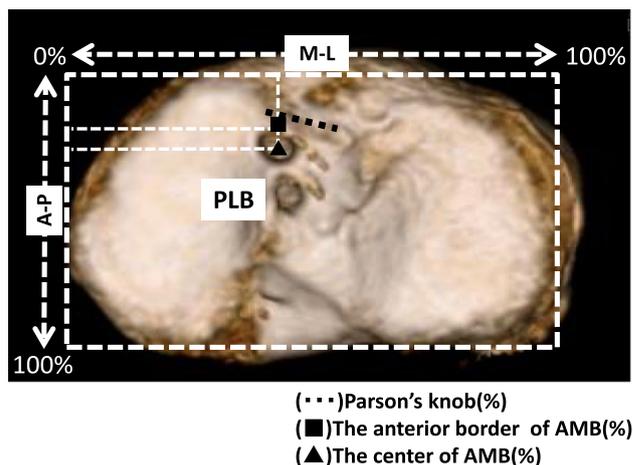


Fig. 3 Tibial articular surface on three-dimensional computed tomography was viewed from straight above to obtain a true proximal-to-distal view of the tibial plateau. Parson's knob was defined as the existence of a small bony prominence located anterior to the medial tibial prominence. Example of the results of radiologic measurement according to the technique of Bernard and Hertel

prominence and medial to the anterior horn of the medial meniscus; this formation was named Parsons' knob [24]. The location of Parsons' knob was measured from the anterior border as the anteroposterior depth and was expressed as a percentage (Fig. 3).

Computed tomographic measurement of the femoral tunnel

Femoral tunnel measurement was performed using the quadrant method described by Bernard et al. [4]. The femoral tunnel position was measured on a true medial view with the medial femoral condyle removed at the middle of the intercondylar notch. The total sagittal diameter of the lateral condyle along Blumensaat's line and the maximum lateral intercondylar notch height were measured on 3D CT images. The distances from the centers of the AM and the PL tunnels to the most dorsal subchondral contour of the lateral femoral condyle and the distances from the center of each tunnel to Blumensaat's line were expressed as percentages.

Statistical analysis

For all parameters and clinical outcomes, the Chi-squared and Kruskal–Wallis tests were used to determine whether significant differences existed between groups. Differences were considered significant if *P* values were < .05.

Results

Patient demographic data and clinical result

According to the operative records, there were no significant differences between the three groups regarding age, sex, height, weight, duration from injury to operation, diameters of the bone tunnels of both the AMB and the PLB, location of Parson's knob, morphology of the tibia, and meniscal treatments (Table 1). According to the MRI findings, patients were divided into two groups: group L (grade 1) and group H (grades 2 and 3). Reliability of the measurements was assessed by examining the interobserver and intraobserver reliabilities with the intraclass correlation coefficient (ICC). A measurement was considered reliable if the ICC was >0.80. The interobserver and intraobserver reliabilities were satisfactory, and the mean values were 0.805 and 0.917, respectively.

Correlation between graft signal intensity on magnetic resonance imaging and computed tomography findings

The relationship between graft signal intensity on CT findings and MRI is shown in Table 2. There were no significant

differences between the two groups regarding the femoral tunnel placement.

In group H, the center of the AMB on the tibial side was located at 28.5% in an A–P direction and at 44.7% in an M–L direction; the anterior border was located at 21.4% in an A–P direction. In group L, the center of the AMB on the tibial side was located at 30.3% in an A–P direction and at 44.5% in an M–L direction; the anterior border was located at 22.9% in an A–P direction. There was a significant difference between the two groups regarding the center of the AMB in an A–P direction ($P = .038$), and the anterior border of the AMB in group H tended to be more anterior than in group L in an A–P direction ($P = .09$).

Correlation between graft signal intensity on magnetic resonance imaging and clinical assessment

The relationship between the graft signal intensity on MRI and the clinical assessment is shown in Table 3. The mean Lysholm knee score and IKDC score were significantly improved from 63.1 and 56.8, respectively, preoperatively, to 94.2 and 86.0, respectively, at 2 years after DB-ACL reconstruction ($P < .001$). There were no significant differences

Table 1 Patients' demographic data

	Grade 1 ($n=42$)	Grade 2 ($n=17$)	Grade 3 ($n=6$)	Grade 4 ($n=65$)	<i>P</i>
<i>Patients' demographic data and clinical outcomes (n = 65)</i>					
Age (range), years	26.3 ± 11.4	25 ± 12.0	22.8 ± 11.5	25.4 ± 11.6	0.49
Sex male/female, <i>n</i>	11/31	5/12	2/4	18/47	
Height, mean (cm)	163.7 ± 9.5	163.6 ± 7.8	165.4 ± 6.9	163.9 ± 8.9	0.55
Weight, mean (kg)	62.4 ± 13.3	64 ± 11.3	62.0 ± 6.0	62.8 ± 12.3	0.91
BMI, mean (kg/m ²)	23.1 ± 3.5	23.8 ± 3.2	22.6 ± 1.6	23.3 ± 3.3	0.55
Duration from injury to operation, mean (month)	46.9 ± 83.5	13.1 ± 128.6	53.1 ± 88.1	37.8 ± 75.2	0.47
<i>Patients' history</i>					
Smoke	3/42	1/17	0/6		0.85
Alcohol intake	21/42	8/17	2/4		0.98
Patients' histories	1 hypertension	1 ureteral calculus			
<i>Diameter of tunnel, mean (mm)</i>					
AMB, tibia	5.6 ± 0.43	5.8 ± 0.4	6.0 ± 0.4	5.7 ± 0.44	0.2
PLB, tibia	5.4 ± 0.46	5.5 ± 0.4	5.5	5.5 ± 0.43	0.89
Parson's knob A–P (%)	20.1 ± 2.5	20.2 ± 2.7	20.8 ± 1.2	20.3 ± 2.4	0.89
A–P measurements of tibia, mean (mm)	46.9 ± 8.0	43.8 ± 3.4	45.3 ± 2.3	46.2 ± 7.0	0.29
M–L measurements of tibia, mean (mm)	71.7 ± 12.6	67 ± 4.5	67 ± 4.5	70.4 ± 11.0	0.4
<i>Meniscal treatment</i>					
None, <i>n</i>	12	11	2	25	
Partial meniscectomy, <i>n</i>	7	1	1	9	
Repair, <i>n</i>	23	5	3	31	

AMB anteromedial bundle, PLB posterolateral bundle, A–P anterior–posterior, M–L medial–lateral, IKDC international knee documentation committee

Data expressed as *P* values (Kruskal–Wallis tests) with significance at < .05

Table 2 Correlation between CT findings and graft signal intensity of MRI

	Group L (Grade 1) (n=42)	Group H (Grade 2, 3) (n=23)	Total (n=65)	P
Tibial tunnel placement of AMB				
Center A–P (%)	30.3	28.5	29.7	0.038
M–L (%)	44.5	44.7	44.6	0.89
Anterior border A–P (%)	22.9	21.4	22.5	0.09
Femoral tunnel placement of AMB				
Deep (%)	20.32	19.4	20.1	0.28
Height (%)	20.17	21.93	21.08	0.12

AMB anteromedial bundle, A–P anterior–posterior, M–L medial–lateral

Data expressed as P values (Kruskal–Wallis tests) with significance at < .05

Table 3 Correlation between clinical outcomes and graft signal intensity of MRI

	Group L (Grade 1) (n=42)	Group H (Grade 2, 3) (n=23)	Total (n=65)	P
<i>Correlation between clinical assessment and graft signal intensity of MRI</i>				
Lysholm score preoperative, mean	61.8 ± 19.6	65.4 ± 14.7	63.1 ± 18.1	0.43
Lysholm score postoperative, mean	93.3 ± 7.8	95.7 ± 4.3	94.2 ± 6.9	0.71
IKDC score preoperative, mean	55.9 ± 15.7	58.3 ± 12.6	56.8 ± 14.8	0.98
IKDC score postoperative, mean	85.2 ± 11.1	87.4 ± 8.9	86.0 ± 10.4	0.56
KT-2000 side-to-side differences, mean (mm)	0.90 ± 0.78	1.67 ± 1.18	1.17 ± 0.99	0.019
Pivot shift test postoperative, n				0.38
3	0	0	0	
2	1	3	4	
1	5	4	9	
0	36	15	51	
Cyclops lesion (%), n	7 (16.7)	13 (55.5)	20 (30.1)	0.05

Data expressed as P values (Kruskal–Wallis tests) with significance at < .05

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between the two groups regarding the clinical score, other treatment, and the instability as assessed by the Pivot shift test.

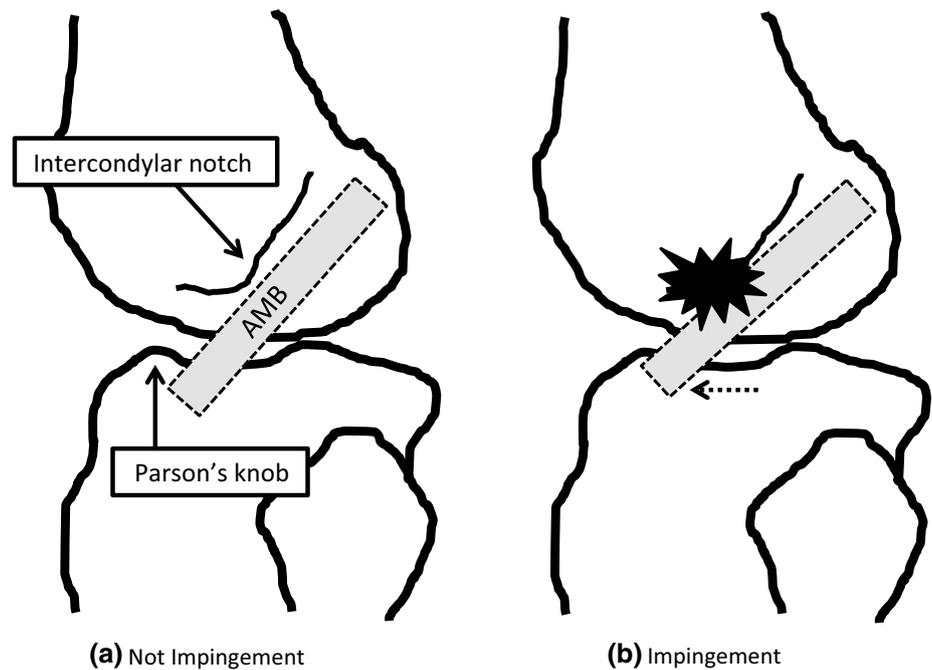
The KT-2000 side-to-side difference was significantly greater in group H (1.67 mm) compared with group L (0.90 mm; $P = .019$), and the incidence of a cyclops lesion was significantly greater in group H (13/23, 56.5%) than in group L (7/42, 16.7%; $P = .05$).

Discussion

The most important findings of the present study were that there was a relationship between the graft signal intensity on MRI, the tunnel position of the tibial side, and the clinical outcomes. When the tibial tunnel was placed less than 30% in an A–P direction, the signal intensity was increased, a cyclops lesion occurred, and there was residual instability following DB-ACL reconstruction. Regarding to this study,

adequate tibial tunnel location of AM bundle is 30.3% to avoid a impingement and obtain a good stability after ACL reconstruction. According to a report on the relationship between the anterior border of the ACL insertion and the bone tunnel, the risk of graft impingement increases if the anterior border of the bone tunnel is located within 2 mm behind the anterior border of the ACL insertion [48]; moreover, it was concluded that there is a real risk of femoral notch impingement, even with a perfect centrally positioned tibial tunnel [48]. Graft impingement at the intercondylar roof is thought to be caused by placement of the tibial tunnel too anterior on the tibial plateau, allowing the graft to contact the intercondylar roof during knee extension (Fig. 4) and cause clinical residual instability [15, 30]. Compared with previous research into the ACL insertion [34, 46], the placement of the AMB in the present study was a little anterior, so it is important to know how far back from the anterior border of the ACL insertion we are when creating the bone tunnel on the tibial side.

Fig. 4 **a** Graft impingement does not occur because the tibial tunnel was created in an appropriate position; **b** the graft impingement occurs because the tibial tunnel was created too anteriorly on the tibial plateau



Parson's knob is reportedly useful as a landmark on the tibial side in ACL reconstruction [35]. In the present study, the anterior border of the AMB was quite close to Parson's knob on the tibial side. In particular, in group H, there was a possibility that the anterior border of the AMB was more anterior than Parson's knob and that the tunnel damaged Parson's knob. Regarding a residual high-intensity signals on MRI following ACL reconstruction, the intra-articular graft undergoes maturation and remodeling process that consists of four steps: initial avascular necrosis, revascularization, cellular proliferation, and final remodeling [24]. This process could be indirectly monitored through MRI, as poor biomechanical properties and incomplete graft maturation are reportedly related to an increased graft signal intensity on MRI [1, 6, 22, 25, 29]. Despite the normal maturation process, it is important to know that an increase in the signal intensity of the graft, especially in the distal two-thirds, may also be due to graft impingement. This complication occurs when the graft contacts the intercondylar notch during the extension of the knee. This has been implicated in the pathogenesis of the cyclops lesion, which consists of a fibrous injury to the anterior side of the graft. Howell et al. [17] reported that a significant increase in graft signal intensity remained on MRI at 1 year after ACL reconstruction in those with graft impingement, and that KT-1000 side-to-side differences were greater in those without graft impingement than in those with graft impingement. Similar results were obtained in the present study, suggesting a relationship between postoperative graft MRI signal intensity and graft impingement; however, it should be noted that there is

a difference between single-bundle reconstruction and DB reconstruction.

Regarding the relationship between tibial tunnel position and clinical instability [2], it showed that the tibial tunnel position in the anterior aspect of the footprint results in significantly less anterior tibial translation than posterior tibial footprint positioning in a cadaveric study, and Hatayama et al. [13] showed similar results in a clinical study. They suggested that anterior placement of the tibial tunnel results in improved control of anterior tibial translation after ACL reconstruction. Hatayama et al. [13] also reported that the anterior border of the tibial tunnel was located at $26.0 \pm 4.1\%$ in lateral radiographic assessment, but in our study the anterior border of the AMB was located at 22.9% in group L on CT measurements. Furthermore, the KT-2000 side-to-side difference was 0.90 mm in group L. On the other hand, the anterior border of the AMB in group H was located at 21.4% and KT-2000 side-to-side difference in group H was 1.67 mm. This result indicates that positioning the tibial tunnel too anteriorly may cause residual instability, even if the tibial tunnel placement of the AMB is almost in the ACL footprint. Moreover, the distances from Parson's knob to the anterior border of the AMB in five patients in group H were negative values; hence, even if the guide pin was inserted in the footprint, there was a possibility that Parson's knob might be ruptured at the time of creating the bone tunnel of the AMB. Our result confirmed the previous report that the risk of graft impingement increases if the anterior border of the bone tunnel is located within

2 mm behind the anterior border of the ACL insertion [48]. To obtain an appropriate tunnel position and satisfactory clinical results, we should consider how far from the anterior edge of the ACL footprint the tibial tunnel of AMB should be created.

There are previous reports about the factors of cyclops lesion. The formation of cyclops lesion tends to occur with a smaller intercondylar notch size [30] or a partially torn graft following ACL reconstruction with fibers lying in the anterior intercondylar notch, which may mimic a cyclops lesion on MRI [6]. They reported that the size of the femoral condyles [12] was a preoperative factor, the tibial tunnel of AMB placed too far anteriorly was an intra-operative factor, and the graft impingement [10, 17] was a postoperative factor. Moreover, a cyclops lesion is also in association with and partial damage of the AMB detected on MRI [41]. Moreover, the definition of the size of the cyclops lesion in these previous studies was ambiguous, and partial damage of the AMB was included as a cyclops lesion or cyclopid scar [47].

Limitations

There are some limitations to this study. First, we had a relatively small sample size and short duration of follow-up. Although it is generally considered that the MRI graft signal intensity will settle in the first year after surgery, previous studies have reported that it can last for 2–3 years [16, 18, 23, 26, 38]. Hence, it is important to continue monitoring the graft signal intensity following ACL reconstruction. Second, this study was a retrospective cohort study, not a prospective study. Intraoperatively, we thought that we created the tibial tunnel of the AMB in the proper position using radiography, but this caused variations. There is a need for the development of a method that can be used to confirm accurate tunnel positioning intraoperatively. Third, we did not evaluate the relationship between second-look arthroscopic findings at the time of hardware removal and the MRI findings. Fourth, the graft signal intensity and CT measurement of the PLB were not evaluated. We evaluated only the AMB, as graft impingements are thought to occur when the anterior portion of the graft touches the intercondylar notch [14, 48, 49]. Finally, the evaluation of the AMB was qualitative, so further quantitative study will be needed.

Future direction

MRI is an important tool for the post-ACL reconstruction evaluation, due to its abilities to identify, in a non-invasive manner, a number of aspects and situations that

could suggest potential problems to us. However, this tool must not be used in isolation when assessing the post-ACL reconstruction status. It should always be integrated with a careful clinical and medical history evaluation, as only an integrated approach to graft status and functionality is most effective in reducing potential diagnostic mistakes. Through the results of this study, creating the tibial tunnel of AMB that does not cause an impingement may help to prevent postoperative instability and other complications.

Conclusion

Group H had a more anterior tunnel location and significantly greater incidence of cyclops lesions than group L. An increased signal intensity of the AMB on MRI indicates A–P instability.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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