Remnant-preserving tibial tunnel positioning using anatomical landmarks in double-bundle anterior cruciate ligament reconstruction

Abstract

Purpose: To assess (1) if six anatomical landmarks (AL) could be arthroscopically confirmed with remnant preservation, and (2) if creating tibial tunnels using these landmarks reduces individual variation and improves reproducibility in double-bundle anterior cruciate ligament (ACL) reconstruction.

Methods: We retrospectively reviewed data of patients who chronologically underwent double-bundle ACL reconstruction by either referencing the footprint after remnant dissection (non-AL group) or subsequently with the AL (AL group). Using operative videos, three independent observers judged whether they could confirm six AL (medial intercondylar ridge, medial and lateral intercondylar tubercles, anterior horn of lateral meniscus, Parsons' knob, and L-shaped ridge) in 20 patients randomly selected from the AL group. We then compared tunnel positions between the two groups, measured from the anterior and medial borders of the proximal tibia and expressed as percentage of the total depth and width of the proximal tibia using 3D computed tomography.

Results: One hundred and four patients (non-AL group, n=54; AL group, n=50) were included. All six AL were arthroscopically confirmed in most cases (89.7-100%). The mean percentages of the anteroposterior (AP) depth for anteromedial (AM) tunnel, mediolateral (ML) width for AM tunnel, AP depth for posterolateral (PL) tunnel, and ML width for PL tunnel were 27.8 ± 6.6%, 46.7 ± 2.8%, 41.4 ± 7.3%, and 46.1 ± 2.6% for the non-AL group, respectively, and 30.7 ± 4.5%, 45.7 ± 2.2%, 45.2 ± 4.5%, 46.9 ± 2.1% for the AL group, respectively, demonstrating significantly less variation in the AL group compared to the non-AL group excluding the ML width of the PL tunnel (p=0.007, 0.046, 0.002, 0.209, respectively).

Conclusions: Six landmarks could be reliably confirmed in cases with remnant preservation, and creating tibial tunnels using these landmarks were reproducible and resulted in less individual variation.

Level of Evidence: Level III, retrospective comparative study.

Introduction

In ACL reconstruction, the femoral and tibial tunnel positions are important factors affecting postoperative knee stability. Recent studies have shown that creating tunnels in anatomically defined positions lead to anteroposterior as well as rotational stability and produces acceptable clinical results.[1–3] Therefore, it is necessary to establish anatomical landmarks that can be confirmed under arthroscopy to reproducibly create tunnels in the desired position.

There is no universally accepted landmark that has been established for creating the tibial tunnel. However, some reports have determined tibial tunnel positions based on distance from tibial landmarks such as the anterior margin of the posterior cruciate ligament (PCL), the over-the-back ridge, and transverse ligament.[4–10] The reproducibility and accuracy of these methods is unclear because there are variations in shape and size of the tibial footprint and concerns about the distance between the respective landmarks and tunnel. Furthermore, the tibial attachment of the ACL remnant is present in many cases even long after the injury, and ACL reconstruction with the preserved remnant has been reported recently.[11–13] Therefore, it is ideal for future applications to create tibial tunnels using landmarks that can be confirmed even with remnant preservation.

A previous report described a detailed assessment of bony/anatomical landmarks around the tibial footprint (Fig 1).[14] The authors found that the tibial attachment of the ACL was confined within a narrow area surrounded by five landmarks (anterior side–Parsons' knob,[15] medial side–medial intercondylar ridge, lateral side–anterior horn of the lateral meniscus, and posterior side–anterior borders of the medial and lateral tubercles) regardless of size and shape. They determined that by considering the ACL footprint as a quadrilateral formed by these five landmarks and creating one or two tunnels within the quadrilateral, tibial tunnels could be reproducibly created in anatomically defined positions. Moreover, they proposed that the joint formed by the medial intercondylar ridge and Parsons' knob at the anteromedial edge, which forms an anteromedial boundary of the ACL tibial footprint termed the "L-shaped ridge," might be a useful sixth landmark to determine the anteromedial edge of the tibial tunnel (Fig 2). However, the degree to which these landmarks can be confirmed by arthroscopy, their accuracy and reproducibility for the creation of tunnels, and whether such a method is possible in remnant-preserving surgery have not been evaluated.

The purpose of this study was to assess (1) if six anatomical landmarks (AL) could be arthroscopically confirmed with remnant preservation, and (2) if creating tibial tunnels using these landmarks reduces individual variation and improves reproducibility in double-bundle ACL reconstruction. We hypothesized that these landmarks are capable of being adequately confirmed arthroscopically and their use would result in good reproducibility and less variation of the tibial tunnels.

Methods

This study was approved by our ethics committee. We retrospectively reviewed data of patients who underwent double-bundle ACL reconstructions using autogenous hamstring tendons performed by the co-author (K.T.) between December 2009 and February 2014. Patients undergoing reoperations after ACL reconstruction or with preoperative knee injuries such as prior trauma affecting the osseous structures of the tibial articular surface were excluded. Until March 2012, we removed the ACL remnant around the tibial area and created two tibial tunnels using the footprint of the ACL remnant as a landmark (non-AL group). Since April 2012, we preserved the ACL remnant and created tibial tunnels using the six aforementioned anatomical landmarks (AL group).

Surgical Technique

Creating tibial tunnels in the non-AL group

We dissected the ACL remnant, preserving only the marginal fiber of the remnant with a shaver or knife to confirm the boundary of the footprint of ACL attachment to the tibia, and inserted guide pins using an Acufex Director Drill Guide (Smith & Nephew Endoscopy) so that two tibial tunnels were created within the footprint. We used the footprint as the sole guide for tunnel placement, and we created the AM tunnel in the anteromedial area and the PL tunnel in the posterolateral area within the footprint. After confirming the placement of guide pins, we created tibial tunnels using a drill with a diameter equal to the graft size. Intraoperative fluoroscopy and X-ray were not used owing to the creation of tibial tunnels.

Creating tibial tunnels in the AL group

First, we identified four landmarks: medial intercondylar ridge, medial and lateral intercondylar tubercles, and anterior horn of the lateral meniscus. Then, to identify anterior landmarks, we split the anteromedial edge of the ACL remnant sharply to check for the presence of the Parsons' knob at the anterior border of the ACL remnant with a probe. Finally, we probed the medial intercondylar eminence and Parsons' knob carefully in order to image the L-shaped ridge. Thereafter, we inserted guide pins using the Acufex Director Drill Guide within a quadrilateral that was surrounded by the six landmarks. First, for the PL tunnel, the tip of the drill guide was positioned at a point anterior to the midpoint of both intercondylar tubercles by the radius of the PL graft (Fig 3A). We checked the position of the guide pin so that the tip was arthroscopically confirmed behind the ACL remnant and at a slightly anterior position from the medial and lateral intercondylar tubercles. Second, for the AM tunnel, the tip of the drill guide was positioned at the point separated by the radius of the AM graft from the corner of the L-shaped ridge (Fig 3B). The guide pins were inserted from the anterior edge of the medial collateral ligament for the PL tunnel and the medial edge of the tibial tuberosity for the AM tunnel. To avoid communication of the two insertion tunnels, pins were placed carefully at a sufficient divergence angle. After confirming the placement of guide pins, we created tibial tunnels in the same manner for the non-AL group. Intraoperative fluoroscopy and X-ray were not used as with the non-AL group.

Arthroscopic Evaluation of Tibial Landmarks

In the first section of thie study, we evaluated the identification of tibial anatomical landmarks with operative videos. Twenty patients randomly selected from the AL group were included in this study, including 7 men and 13 women whose mean age at surgery was 27.4 years (range, 14–52). We recorded a video of the tibial intercondylar area using a 560 Series High Definition Camera System (Smith & Nephew Endoscopy, Andover, MA, USA) to arthroscopically investigate the presence of the aforementioned bony landmarks in the presence of fully preserved ACL remnants. The video of this series of identifications was 40 to 60 seconds long. After the operation, three independent and blinded observers (Y.A., S.T., and H.S.), who were orthopedic surgeons with 9, 7, and 2 years experience, respectively, observed the video on two separate occasions with no information regarding patient data and judged whether or not what the operator was showing in arthroscopy could be recognized as our proposed landmarks.

Radiologic Evaluation of Tibial Tunnels

In the second section of this study, we evaluated tibial tunnels two weeks postoperatively using computed tomography (CT) (SOMATOM Sensation 16; Siemens Medical Solutions, Erlangen, Germany) at a 1-mm slice thickness. Using image analysis software (Osiri X version 5.8; Apple Inc., Cupertino, CA, USA), 3D images of the tibial articular surface were reconstructed from CT data. Tibial tunnels were evaluated in the axial plane. Each AM and PL tunnel position was measured from the anterior and medial border of the proximal tibia and expressed as a percentage of the total depth and total width of the proximal tibia according to the tibial quadrant method described by Tsukada et al.[16] (Fig 4). It was ideal for the margin of the tunnel to not protrude outside the intercondylar area beyond the landmarks that we proposed. We defined “tunnel perforation to the articular surface” as the point when the margin of the tunnel extended to the medial or lateral articular surface (Fig 5A), and “tunnel perforation to anterior” as the point when the margin of the tunnel extended to the anterior beyond the Parsons’ knob (Fig 5B). Furthermore, we defined “tunnel communication” as the communication between the AM and PL tunnels (Fig 5C). In regards to the evaluation, an orthopedic surgeon (H.S.) conducted evaluations in the absence of patients and their medical records related to surgery.

Statistical Analysis

For the identification of tibial landmarks, three observers evaluated whether or not they could identify our proposed landmarks, and we calculated Cohen’s kappa statistics to evaluate inter- and intra-observer reproducibility based on their results. We used Welch’s *t*-test to compare the mean tibial tunnel position and F test to compare the variation in tibial tunnel position between the non-AL and AL groups. For the clinical difference of the tunnel position, a mediolateral deviation of 2mm can increase the risk of perforation to the the articular surface and anterior meniscal root injuries, and could subsequently influence clinical results because the mediolateral width of ACL tibial attachment is known to be quite narrow.[14,17-19] Hence, we regard the clinical difference as 2mm, and the 3% clinical difference effect size was calculated from the mean size of mediolateral tibial condylar width (73.1mm) in this study. Based on a post hoc power analysis to determine the number of patients required to compare the mean tibial tunnel position, a minimum sample size of 45 patients in each group was required for an α value of 0.05 and β value of 0.8, while considering a clinical difference of 3%. Therefore, we selected 104 patients (non-AL group [n=54], AL group [n=50]). We used Fisher’s exact test to compare the rates of tunnel coalition, perforation to the articular surface, and anterior perforation beyond the Parsons’ knob. Statistical analysis was performed with SPSS 21.0 (IBM Corp., Armonk, NY, USA), and P values < 0.05 were considered significant.

Results

During the study period, 104 patients (88% concordance) were included in this study (non-AL group, n=54; AL group, n=50). Within the AL group, 7 patients were classified as group 1, 17 as group 2, four as group 3, and 22 as group 4 according to the ACL remnant patterns described by Crain et al.[20] Regardless of ACL remnant pattern, tibial remnants were present in all cases. Age at operation, sex, height, body weight, and graft size did not significantly differ between the AL and non-AL groups (Table 1).

Arthroscopic evaluation of tibial landmarks

The medial intercondylar tubercle was confirmed in 95% of cases, and the Parsons' knob and L-shaped ridge were confirmed in 89.7% of cases. These three landmarks were identified with substantial intra-observer reproducibility (kappa = 0.654, 0.745, and 0.745, respectively) and substantial inter-observer reproducibility (kappa = 0.656, 0.743, and 0.743, respectively). The other landmarks (medial intercondylar ridge, lateral intercondylar tubercle, anterior horn of lateral meniscus) were confirmed in all cases.

Radiologic evaluation of tibial tunnels

The mean percentages of total anteroposterior (AP) depth and mediolateral (ML) width for AM and PL tunnel positions were similar between the non-AL and AL groups, while the variation in tunnel position was significantly lower in the AL group than the non-AL group excluding the ML width of the PL tunnel (Table 2, Fig 6). The rate of AM/PL tunnel perforation to either the medial or lateral articular surface was lower, but not significantly so, in the AL group, while the rate of anterior AM/PL tunnel perforation beyond the Parsons' knob was significantly lower in the AL group. The rate of AM and PL tunnel communication did not significantly differ between the two groups (Table 3).

Discussion

Our study found that the medial intercondylar ridge, medial and lateral intercondylar tubercle, anterior horn of lateral meniscus, Parsons' knob, and L-shaped ridge could be confirmed reliably in cases with ACL remnant preservation. Additionally, a method of creating tibial tunnels using these landmarks resulted in less individual variation, with tunnels created at a nearly constant position. Although the variation of the ML width of the PL tunnel between the two groups was not significant, there was significant difference in the AP depth between the groups, and we believe that there is less variation in the AL group when considering the planar graph (Fig 6). No previous reports have described a systematic procedure using anatomical landmarks for the creation of tibial tunnels.

Various landmarks for creating tibial tunnels in anatomically defined positions have been proposed to date. Several reports have determined tunnel position based on the distance from the anterior margin of the PCL or over-the-back ridge (also called the transverse interspinous ridge) as a landmark.[4,5,7,9] However, the distances from these landmarks have some individual differences, and these landmarks are difficult to confirm arthroscopically in cases with ACL remnant preservation. Using the anterior horn of the lateral meniscus as a landmark, which is easily detected arthroscopically, Zantop et al.[10] reported that good orientation was achieved for tibial tunnel placement. However, Ferretti et al.[6] stated that, due to variations in the positional relationship between the anterior horn of the lateral meniscus and ACL attachment, this structure is unsuitable for use as a landmark to determine the arrangement of AM and PL tunnels. Kongcharoensombat et al.[8] reported that the transverse ligament, which was aligned with the anterior margin of the ACL tibial insertion, served as a useful landmark. However, the transverse ligament had some anatomical variations[21] and was found in 64% to 71% of samples in cadaveric studies;[22,23] therefore, it cannot be adopted as a landmark in all cases.

It has been described that tibial attachment of the ACL occurred within a narrow area surrounded by characteristic anatomical landmarks by comparing macroscopic and microscopic evaluations with 3D-CT evaluations.[14] On arthroscopy in the present study, six landmarks were reproducibly confirmed in the presence of an ACL remnant. Additionally, the method of creating AM and PL tunnels within the quadrilateral formed by the six landmarks did not depend on distance from the landmarks, as other authors have proposed, but rather on the positional relationship between these landmarks. Moreover, higher reproducibility with less anterior perforation beyond the footprint was confirmed when referencing the six anatomical landmarks than referencing the remnant (Table 2, 3), because the borders of bony landmarks are more distinct than that of the ACL remnant. The removal of remnants may better visualize bony landmarks, possibly resulting in accurate bone tunnel placement. In our study, however, we were able to confirm landmarks while preserving the remnants. By using these landmarks as reference, we believe accurate bone tunnel placement may be achieved while still leaving the remnants intact.

Furthermore, AM tunnels that we created were positioned anteromedially within the ACL attachment, as compared to the center of a normal ACL footprint[16,24] and the tunnel position of other ACL reconstructions (Table 4).[25,26] The most important reason for this result is the use of the "L-shaped ridge" to create the tunnel anteromedially. This landmark could be easily identified by meticulously palpating the position of the medial intercondylar ridge and Parsons' knob with a probe. In regard to tibial tunnel positions, Siebold et al.[27] recommended anteromedial tibial tunnel creation because the direct "C"-shaped tibial insertion exists along the medial tibial spine to the anterior aspect of the lateral meniscus (i.e., mainly equal to our proposal "L-shaped ridge"), and several studies have recently reported that graft obliquity to achieve anteromedial tibial tunnel positioning is important for postoperative knee stability.[28–32] Additionally, some recent studies have reported the proximity of the ACL tibial footprint and anterolateral meniscal root attachment.[33,34] For example, LaPrade et al.[35] demonstrated in a biomechanical cadaveric study that creating a tibial tunnel in the anatomical center of the ACL footprint weakened the ultimate failure strength of anterolateral meniscal root attachment. In light of this finding, we believe that our tunnel positioning procedure using the L-shaped ridge within the ACL attachment is ideal for obtaining more graft obliquity in both the sagittal and coronal planes and decreases the risk of injury to the anterolateral meniscal root attachment.

Reports on the usefulness of preserving the ACL remnant have increased in recent years. Lee et al.[12] compared clinical results between patients with an ACL remnant of more than 20% and those with a remnant of less than 20% and found that, although there was no significant difference in mechanical stability, functional outcome and proprioception were significantly better in patients with a larger remaining remnant. Kim et al.[11] reported that, on second-look arthroscopy after ACL reconstruction, remnants of more than 50% had a positive effect on graft hypertrophy and synovialization, and were associated with better clinical outcomes compared with remnants of less than 50%. Because most ACL ruptures occur in the proximal half and most mechanoreceptors are thought to be located in the sub-synovial layer near the tibial insertion of the ACL, preserving the tibial side of the remnant is an important aspect of this procedure. In the present study, tibial tunnels were accurately created within the ACL attachment even with preservation of the tibial side of the remnant as well, and we believe the method presented here will be valuable in performing ACL reconstruction with remnant preservation.

Limitations

Several limitations to this study must be noted. First, this study was retrospective and not randomized. In addition, the groups were segregated into two time periods, and this change could have introduced performance bias. However, establishing a control group with regard to identifying the presence of these landmarks during the same time frame would raise practical difficulties as well as ethical concerns. Second, the fact that the non-AL group was not a true remnant preserving technique may have weakened the study. If a comparison of tibial tunnel construction that references the tibial footprint and our six proposed anatomical landmarks were both made under a remnant preserving technique, the study design would have been made stronger. However, we think that there is a limit in this study, as dissecting the remnant to a certain extent is unavoidable when referencing the footprint as a landmark. Third, the surgeon's learning curve may have contributed to the results. However, we consider the surgeon's learning curve to have a minimal influence on results, because the surgeon had performed a large number of ACL reconstructions prior to this study. Forth, in arthroscopic evaluation of tibial landmarks, observers judged by watching the video, not by actually performing the arthroscopy themselves, and the intra- and inter-observer reproducibility of the medial intercondylar tubercle, Parsons' knob and L-shaped ridge was relatively low. However, the landmarks we have proposed are easily seen in general arthroscopic surgery, and the method of identification of these landmarks is very simple, so we think that judging by video is roughly equivalent to performing the arthroscopy. Moreover, these three aforementioned landmarks can generally be confirmed by observers regardless of their experience; thus, as reflected in our results minor intra- and inter-observer disagreements may result in lower kappa values in cases where landmarks cannot be recognized. Fifth, we were unable to add the inter- and intra-observer reliability for radiologic evaluation of tibial tunnels. However, Lertwanich et al.[36] reports that the inter- and intra-observer reliability was 0.98-0.99 using an identical method for tibial tunnel measurement as our study. Other studies also utilize the same method for radiologic evaluation with a single orthopedic surgeon.[16,24-26,37] Thus, we consider that our method for radiologic evaluation is appropriate and that our results are reliable. Sixth, we could not demonstrate landmarks to determine the arrangement of AM and PL tunnels. However, the area surrounded by these landmarks is very narrow, and in general the creation of two tunnels covers most of the included area. Finally, we did not evaluate clinical outcomes. Further studies will be needed to show whether the differences between the two groups are clinically important.

Conclusions

Six landmarks could be reliably confirmed in cases with remnant preservation, and creating tibial tunnels using these landmarks were reproducible and resulted in less individual variation.

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Figure Legends

Fig 1. Three-dimensional CT image of left knee tibial plateau (a, medial intercondylar tubercle; b, lateral intercondylar tubercle; c, medial intercondylar ridge; d, Parsons' knob; e, anterior horn of lateral meniscus; A, ACL footprint).

Fig 2. Three-dimensional CT image and arthroscopic image of left knee tibial plateau. (A) Medial intercondylar ridge and Parsons' knob are jointed at their anteromedial edge and form the "L-shaped ridge." (B) After remnant removal, an arthroscopic bird's-eye view of the tibial footprint clearly shows the L-shaped ridge (*arrows*, medial intercondylar ridge; *arrowheads*, Parsons' knob; *dotted line*, L-shaped ridge).

Fig 3. Methods of creating PL and AM tunnels.

(A) The center of the PL tunnel position was defined as the point anterior to the midpoint of both intercondylar tubercles by half of the PL graft diameter (*white arrowheads*, medial intercondylar tubercle; *black arrowheads*, lateral intercondylar tubercle). (B) The center of the AM tunnel position was defined as the point separated by half of the AM graft diameter from the corner of the L-shaped ridge (*red dotted line*, L-shaped ridge; *blue circle*, AM graft size).

Fig 4. Top view of the proximal tibia. Each AM and PL tunnel position was measured from the anterior and medial borders of the proximal tibia and expressed as a percentage of the total depth and total width of the proximal tibia.

Fig 5. Top view of the proximal tibia. (A) Tunnel perforation to the medial/lateral articular surface. (B) Anterior tunnel perforation beyond Parsons' knob (*red arrows*: Parsons' knob). (C) Coalition of two tunnels.

Fig 6. Evaluation of tibial tunnel position. (A) AM tunnel position and (B) PL tunnel position. The AL group had a lower deviation than the non-AL group.

Table 1. Patient data

	AL group (n=50)	Non-AL group (n=54)	*P*
Age at surgery (range, y)	26.0 ± 10.3 (14–52)	24.9 ± 10.1 (12–55)	0.60
Male/Female	17/33	24/30	0.36
Right/Left	19/31	25/29	0.52
Height (range, cm)	164.1±7.1 (151–177)	164.7±9.1 (149–189)	0.68
Weight (range, kg)	64.0±17.4 (43–145)	63.9±14.3 (40–114)	0.97
Graft size, AM bundle (range) (mm)	7.0 (5.5–9)	6.9 (5.5–8)	0.06
Graft size, PL bundle (range) (mm)	6.4 (5–8)	6.4 (4.5–7.5)	0.82

AL, anatomical landmark; AM, anteromedial; PL, posterolateral

Table 2. Comparison of tunnel position between the AL and non-AL groups

	AL group (n = 50)	Non-AL group (n = 54)	*P*
AM tunnel AP depth (%)	30.7 ± 4.5	27.8 ± 6.6	0.011
Range	17.7–40.9	13.9–47.8	0.007
AM tunnel ML width (%)	45.7 ± 2.2	46.7 ± 2.8	0.040
Range	39.9–50.4	39.4–52.2	0.046
PL tunnel AP depth (%)	45.2 ± 4.5	41.4 ± 7.3	0.002
Range	34.1–55.0	20.2–53.3	0.002
PL tunnel ML width (%)	46.9 ± 2.1	46.1 ± 2.6	0.066
Range	42.7–52.2	40.6–52.9	0.209

AL, anatomical landmark; AP depth, anteroposterior depth; ML width, mediolateral width

Table 3. Comparison of tunnel communication and perforation between the AL and non-AL groups

	AL group (n = 50)	Non-AL group (n = 54)	*P*
Tunnel perforation to the medial/ lateral articular joint	4 (6%)	8 (14.8%)	0.27
Tunnel perforation to anterior beyond Parsons' knob	1 (2%)	7 (12.9%)	0.03
Tunnel communication	27 (54%)	34 (62%)	0.35

AL, anatomical landmark

Table 4. Summary of studies on the tibial position of AM and PL bundles and tibial tunnels

Study	Study design	Anteroposterior depth (%)		Mediolateral width (%)	
		AM	PL	AM	PL
Tsukada et al.[16]	Normal ACL	37.6 ± 3.6	50.1 ± 5.0	46.5 ± 3.2	51.2 ± 2.4
Lorenz et al.[24]	Normal ACL	37 ± 3	48 ± 3	48 ± 2	50 ± 2
Tsuda et al.[25]	Reconstructive ACL	36.5 ± 4.9	51.6 ± 5.0	46.1 ± 2.6	47.5 ± 3.1
Yang et al.[26]	Reconstructive ACL	33.7 ± 7.8	53.1 ± 3.7	45.5 ± 2.7	46.0 ± 2.4
Current study	Reconstructive ACL	30.7 ± 4.5	45.2 ± 4.5	45.7 ± 2.2	46.9 ± 2.1

AM, anteromedial; PL, posterolateral

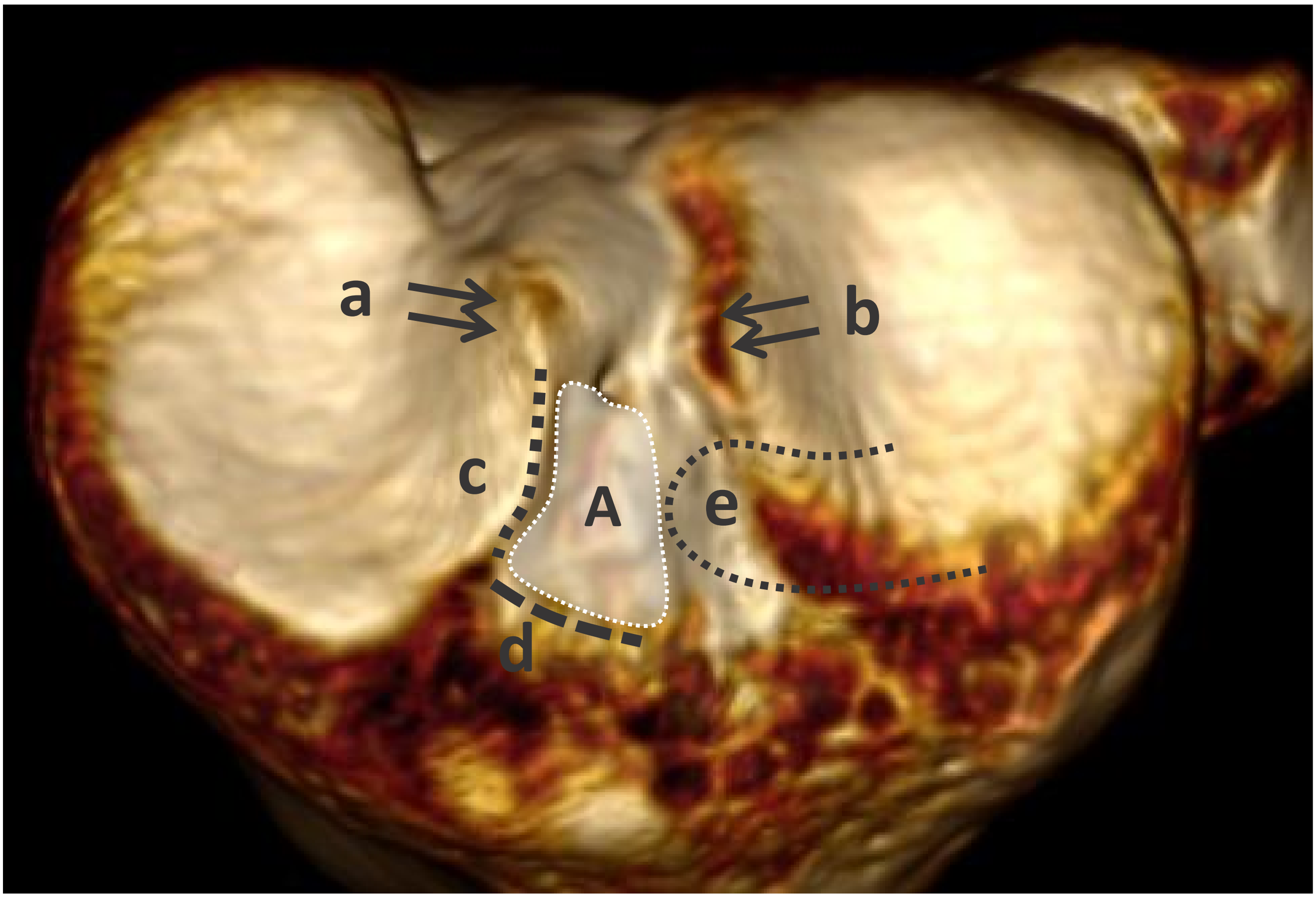


Figure 1

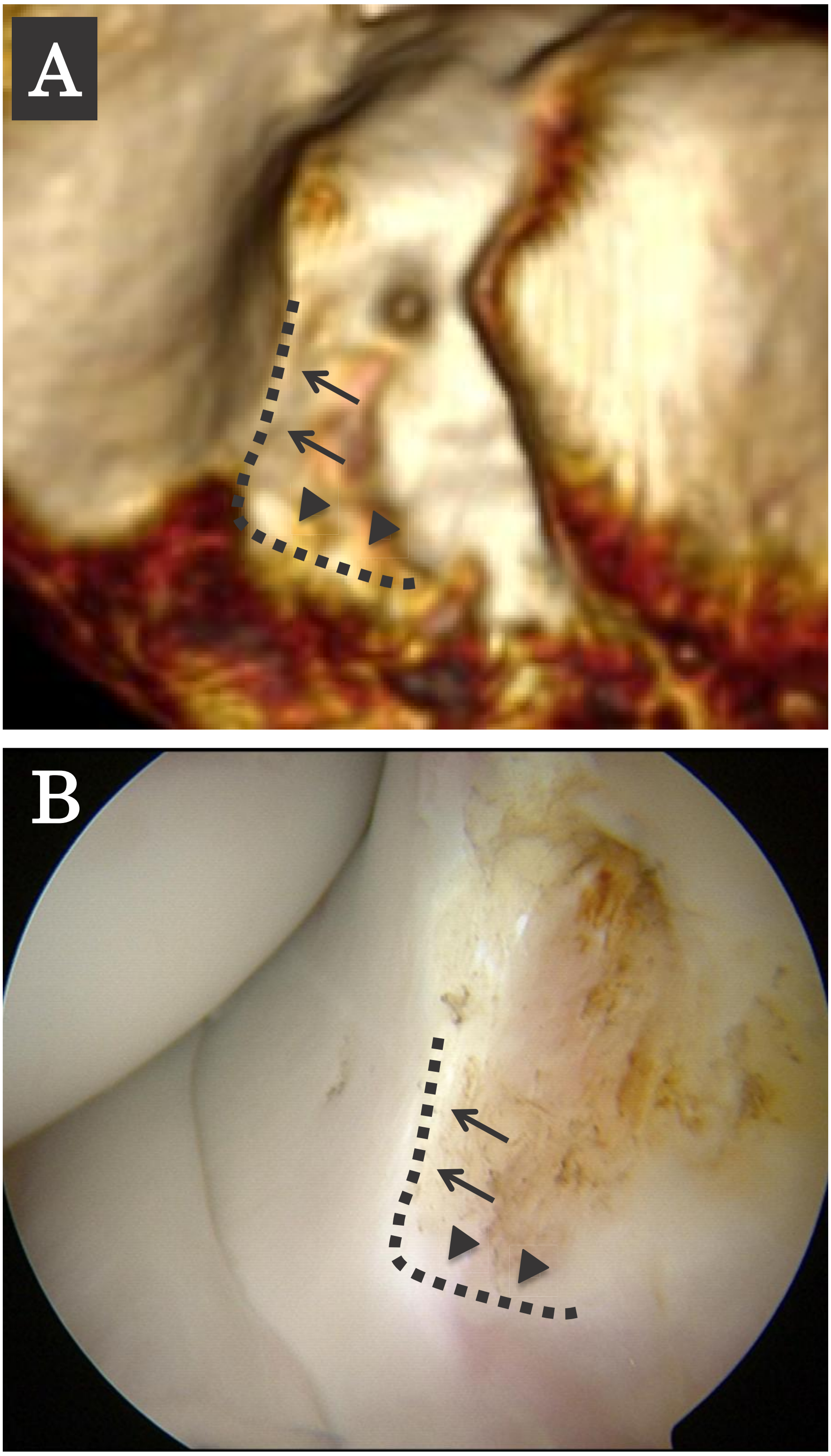


Figure 2

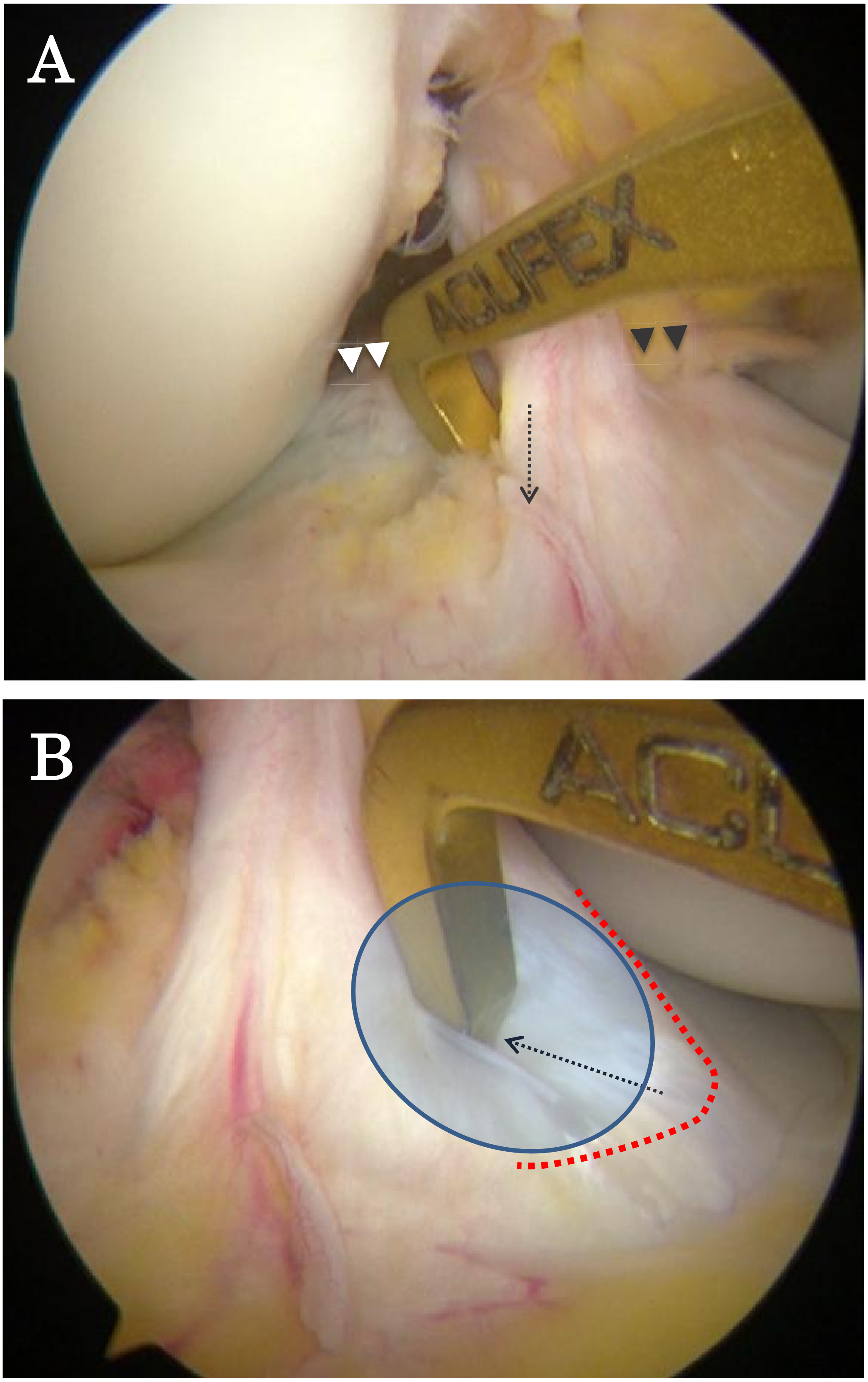


Figure 3

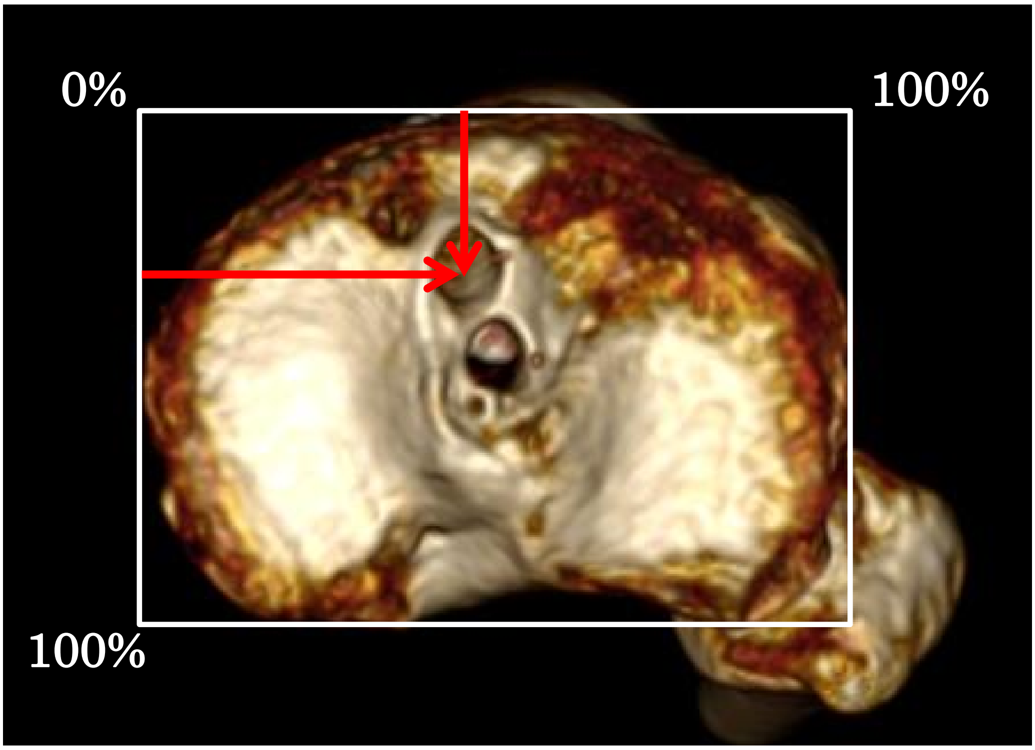


Figure 4

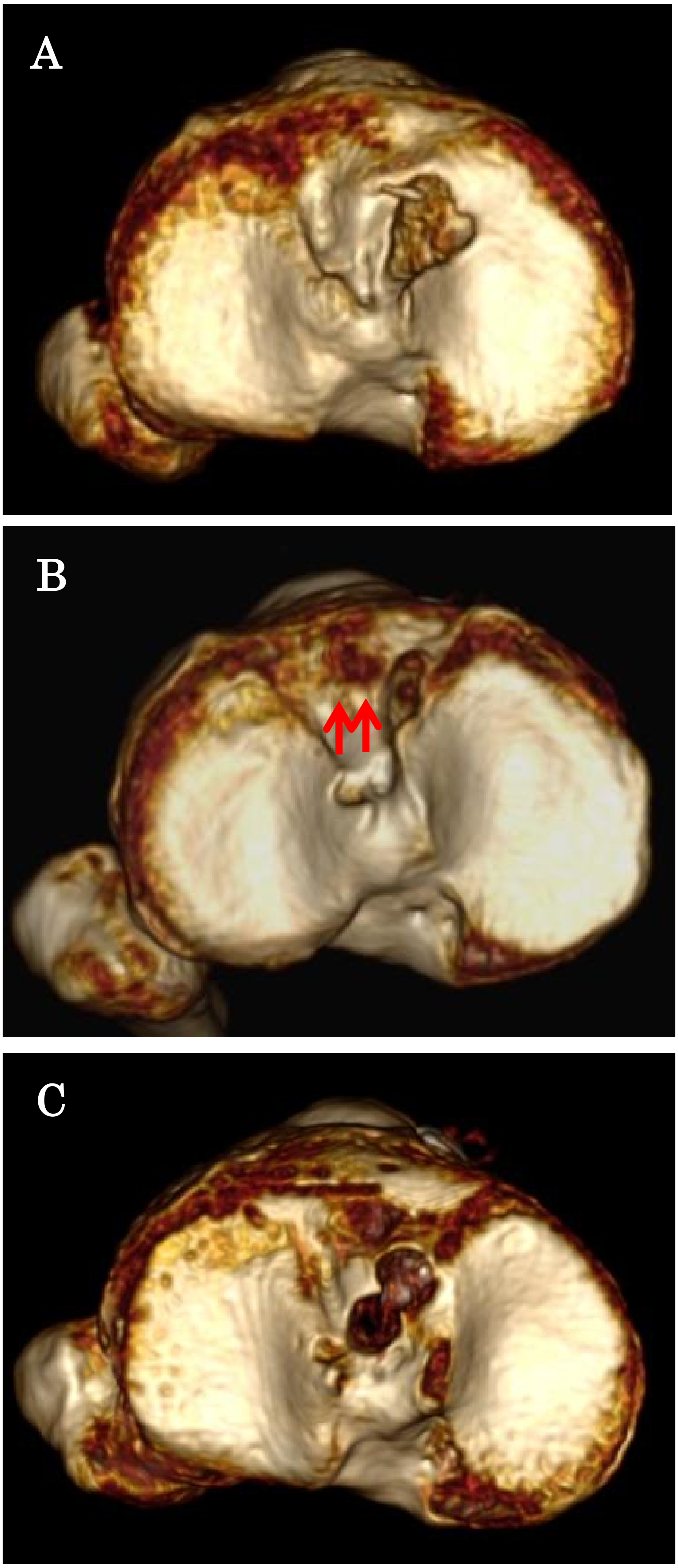
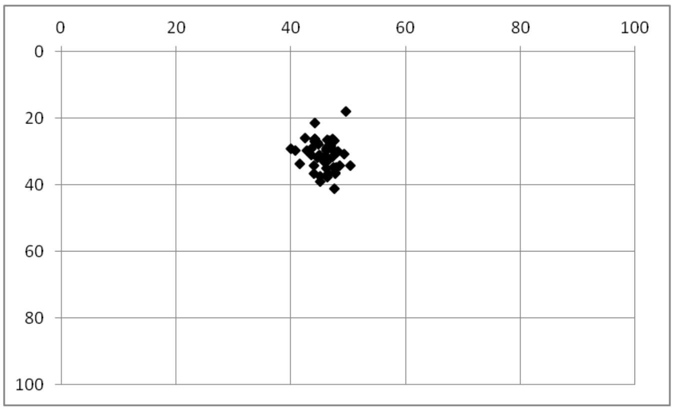
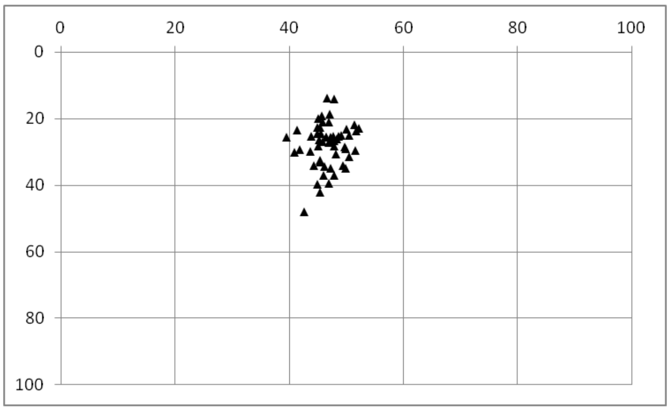


Figure 5

(A) AM tunnel position

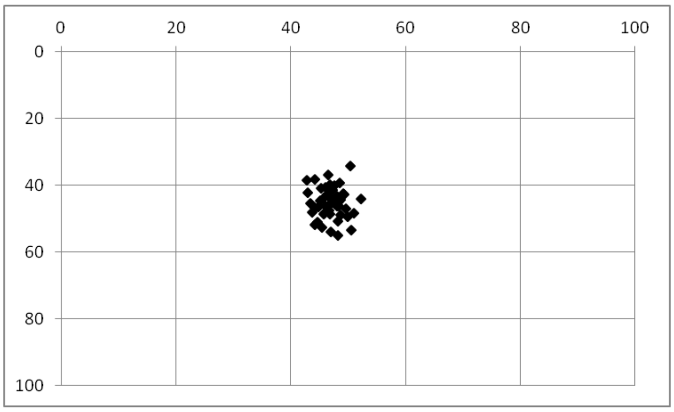


AL group

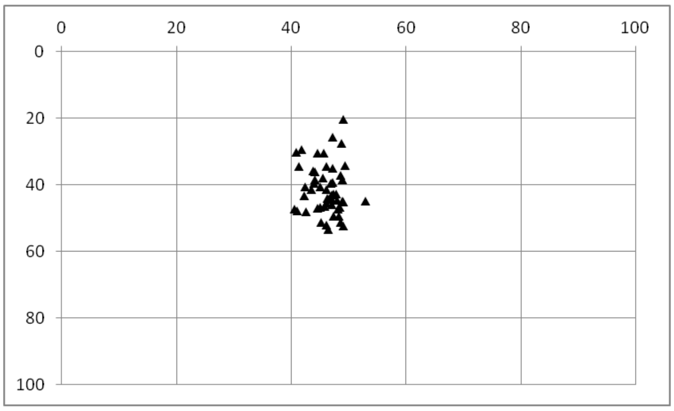


Non-AL group

(B) PL tunnel position



AL group



Non-AL group

Figure 6