The usefulness of the oblique coronal plane of three-dimensional isotropic T2-weighted fast spin-echo (VISTA) knee MRI in the evaluation of posterior cruciate ligament reconstruction with allograft: Comparison with the oblique coronal plane of two-dimensional fast spin-echo T2-weighted sequences

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ABSTRACT

Purpose: We compared two imaging techniques to assess whether 3D VISTA imaging could replace 2D FSE in diagnosing PCL reconstruction complications.
Materials and methods: This retrospective study included 40 patients who underwent surgery of PCL reconstruction and follow-up knee MRI (3D VISTA and 2D FSE) for evaluation of PCL graft integrity. Each image was interpreted independently by two radiologists without knowledge of radiologic reports or clinical history. The diagnostic performance of the 2D FSE PCL view, 3D VISTA PCL view, orthogonal 2D FSE image, and combined sequences were evaluated in terms of sensitivity, specificity, and accuracy for diagnosing complications of PCL graft. The reference diagnoses were made arthroscopically or clinically.
Results: The sensitivities of the 3D VISTA PCL view were similar to those of the 2D PCL view. The sensitivities of the combination of the orthogonal view and the 3D VISTA PCL view were also similar to those of the combination of the orthogonal view and the 2D PCL view. The specificities and accuracies of each image exhibited similar results. There was no statistically significant difference in diagnostic performance between the 3D VISTA PCL view and the 2D PCL view (solitary or combined with the orthogonal view).
Conclusions: The diagnostic performance of the PCL views on 3D VISTA images is comparable to that of 2D FSE images in the diagnosis of PCL graft complications.

1. Introduction

A posterior cruciate ligament (PCL) tear results in posterior subluxation of the tibia on the distal femur [1,2]. In patients with severe PCL injury or chronic instability, PCL reconstruction is preferred [1,3,4]. Common postsurgical complications of the PCL reconstruction are graft failure and graft impingement [5]. Magnetic resonance imaging (MRI) is a good method for evaluating the integrity of the PCL graft as well as diagnosing postsurgical complications [6]. Recently, Park et al. [7] reported that, in addition to the orthogonal imaging plane, the oblique coronal plane (PCL view) provides good anatomic evaluation of the PCL and provides improved diagnostic performance. However, additional oblique views require extra scan time. A three-dimensional (3D) image can be an alternative choice. 3D isotropic MRI using multi-planar reformatted images may reduce scan time by eliminating the need to use the same sequences in different anatomic planes [8]. Generally, 3D imaging methods show insufficient soft tissue contrast, which leads to limitations in the evaluation of the ligament of the knee [9,10]. Three-dimensional isotropic fast spin-echo T2-weighted MRI (volume isotropic turbo spin-echo acquisition [VISTA]), which was developed by Philips Medical Systems, permits the acquisition of thin-section data without an inter-slice gap and multi-planar image

Table 1
Parameters according to MRI sequences.

Imaging parameter	Coronal T1 FSE	Coronal FS T2 FSE	Sagittal FS PD FSE	Sagittal T2 FSE	Axial FS T2 FSE	PCL view T2 FSE	VISTA
TR (msec)	700-800	4000-5000	3000-4000	3500-4000	4500-5000	2000-3000	1500
TE (msec)	10	70-90	30	50-100	60-80	50-80	100-300
Flip angle (°)	90	90	90	90	90	90	90
Matrix size (pixel)	350 × 350	350 × 300	320 × 230	360 × 280	320 × 230	450 × 350	280 × 280
Field of view (cm)	16	16	16	16	16	14	16
Slice thickness (mm)	3	3	3	3	3	3	0.5
Inter-slice gap (mm)	0.3	0.3	0.3	0.3	0.3	0	0
Bandwidth (kHz)	285	260	240	250	280	220	510
Echo train length	6	16	12	15	16	16	85
Signal average	1	1	1	1	1	1	1
Scan time (min:sec)	3:00	3:00	2:30	2:30	2:30	2:00	3:20

Notes: FS = fat saturation, PD = proton density, FSE = fast spin-echo, PCL = posterior cruciate ligament, VISTA = volume isotropic turbo spin-echo acquisition. FS = fat saturation, FSE = fast spin-echo, PD = proton density.
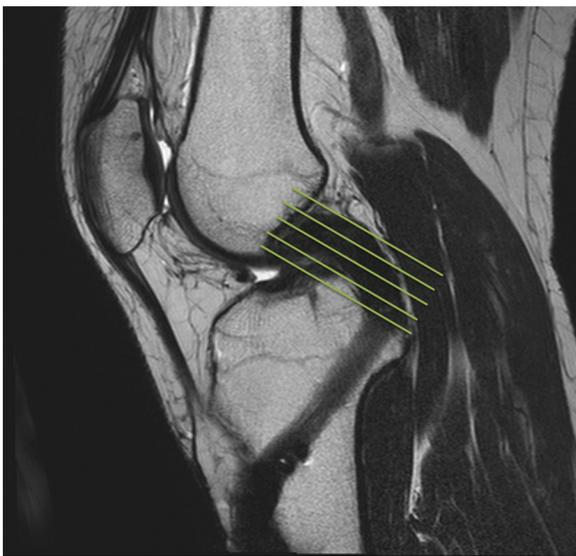

Fig. 1. Posterior cruciate ligament (PCL) views are acquired using a slice thickness of 3 mm, which is parallel to the line connecting the PCL insertion sites on the femur and tibia based on the routine sagittal T2-weighted image (TR/TE, 3500/100).

Fig. 2. Normal posterior cruciate ligament graft on the oblique coronal image (PCL view). A: PCL view of FSE T2-weighted MRI (TR/TE, 2500/76) reveals normal graft (arrow). B: PCL view reformatted from 3D VISTA MRI shows normal graft (arrow).
C: Arthroscopic image shows intact PCL graft (arrow).

reformatting; it is useful for the analysis of complex ligament structures [8]. Similar techniques are the CUBE technique from GE Health Care (Milwaukee, WI, US) and the SPACE sequence from Siemens Medical Solution (Erlangen, Germany). VISTA imaging uses a fast spin-echo (FSE) non-selective 3D method, which takes slow shorter echo spacing to decrease chemical shift artifact [11]. Many studies reported that the diagnostic accuracy of 3D FSE MRI is not inferior to that of two-dimensional (2D) FSE MRI in the evaluation of the internal derangement of the knee [9,10].

However, no prior studies have compared the diagnostic performance of the PCL view in 3D VISTA images with 2D FSE T2-weighted MRI (2D FSE) for the diagnosis of complications of PCL reconstruction. Because previous study reported that the diagnostic performance of the 3D VISTA imaging is comparable to that on 2D FSE in the diagnosis of complications of anterior cruciate ligament (ACL) reconstruction, 3D VISTA imaging can be used as a routine imaging protocol for post-operative screening assessments of surgical complications, regardless of the type knee joint surgery, if we demonstrate similar results in diagnosing PCL reconstruction complications [12].

Our hypothesis was that 3D VISTA image quality is comparable to 2D FSE image quality for the evaluation of the complication of the PCL reconstruction. Thus we compared the diagnostic performance of PCL views on 3D VISTA images with those of the 2D FSE in the diagnosis of complications of PCL reconstruction.
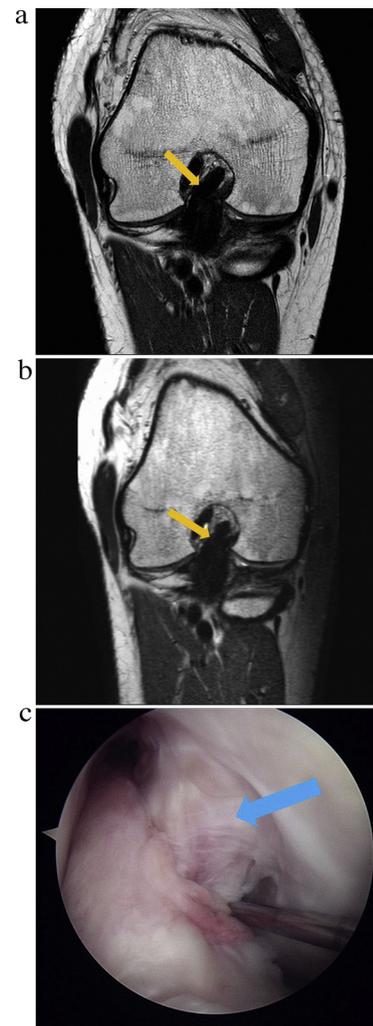
2. Materials and methods

2.1. Case selection and clinical diagnosis

This study was approved by our hospital Institutional Ethics Review Board and the requirement for informed consent of the patients was
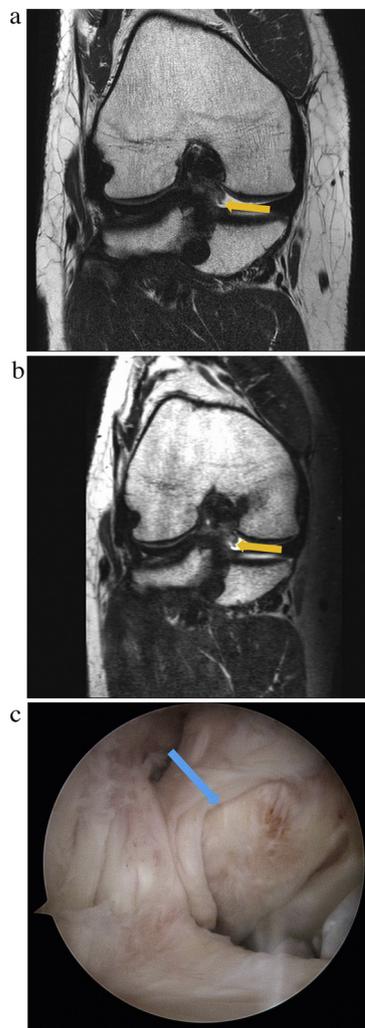
Fig. 3. False positive case of graft failure. A 22-year-old man with knee pain after moving heavy objects six months after PCL reconstruction. A: PCL view of FSE T2-weighted MRI (TR/TE, 2500/76) showing disruption of the graft bundle (arrow).
B: PCL view reformatted from 3D VISTA MRI also showing disruption of the graft bundle (arrow).C: An arthroscopic image shows impingement of the PCL graft (arrow).

waived. We retrospectively evaluated 50 consecutive patients who underwent surgery for PCL reconstruction and follow-up knee MRI for evaluation of PCL graft integrity. We do not perform routine follow-up MRI for PCL reconstruction immediately after surgery to exclude the possibility of misinterpretation of the physiologic change of the graft as graft failure or impingement. The included patients who undergoing PCL reconstruction and follow up knee MRI with both 2D FSE and 3D VISTA MR between August 2014 and April 2016. Ten patients who had undergone combined ACL reconstruction were excluded, so the study included 40 patients. All patients underwent a single bundle reconstruction of the PCL with an allograft of the tibialis anterior tendon. The same orthopedic surgeon performed all PCL reconstruction surgeries. He had fellowship training in knee joint surgery and 30 years of experience in cruciate ligament reconstruction surgery. The mean interval between PCL reconstruction and follow-up MRI was 301 (± 273) days. Second-look operations were performed in 15 cases (38%) and the mean interval between MRI and second-look operation was 155 (± 140) days. Surgically intact graft was defined as an intact continuity, good tensions and abundant synovialization [1]. Surgical graft failure was defined as complete disruption of the graft and impingement was defined as the graft show partial laceration with poor

synovial coverage [13]. Clinical diagnoses of impingement were made based on physical examination, including a positive posterior drawer test, and swelling and pain on knee flexion with gait disturbance [7,14,15]. The positive posterior drawer test was defined if the posterior subluxation of the tibia from the femur could be elicited when the patient flexed the knee joint [16]. A positive result on the Telos stress view was also included in the reference diagnosis of non-surgical patients [7,14]. Telos stress view for PCL reconstruction is applied for the evaluation of the graft. Posterior contour of the proximal tibia and femur should be closely located on locking of the Telos device. If posterior drawer values over than 10 mm implies abnormality of the graft.

2.2. MRI parameters

MRI hardware included a 3.0-T MRI scanner (Achieva, Philips, Best, The Netherlands) and an eight-channel knee-dedicated coil. The parameters and sequences of the MRI are summarized in Table 1. The PCL view was obtained in the plane parallel to the line between the femoral and tibial insertion site of the PCL based on the sagittal T2-weighted image (Fig. 1) [7,14]. For 3D VISTA MRI, we obtained sagittal 3D T2-weighted FSE source images with a reconstruction voxel size of $0.5 \times 0.5 \times 0.5$ mm [12]. A 3D FSE non-selective method, which used short and non-volume selective FSE-refocusing pulses, was adopted to acquire an isotropic 3D image [12,17]. Technologists of the radiologic department reformatted the source image in the PCL view with extended MRI workspace software (Philips), and they performed reformatting with the same angle and same slice thickness as the 2D FSE PCL view without an inter-slice gap [12].

2.3. Image analysis

Both PCL views from the 2D FSE and the 3D VISTA images were interpreted independently by two fellowship-trained musculoskeletal radiologists who were unaware of the radiologic reports and the arthroscopic findings of the patients. Radiologists 1 and 2 had 14 and 8 years of experience, respectively. First, the readers made diagnoses based on only the 2D FSE PCL views. At the next session, after three weeks, they made diagnoses based on 3D VISTA PCL views only. After another three-week period, the readers made diagnoses based on orthogonal images (sagittal and coronal T2 weighted images). After more than three weeks later they made diagnoses based on orthogonal views and 2D FSE PCL views. Finally, more than three weeks later, they diagnosed based on orthogonal views and 3D VISTA PCL views.

An intact PCL graft was defined as a uniform bundle of low signal intensity on MRI (Fig. 2). Graft failure was diagnosed when a discontinuation of graft fibers or a fluid-filled defect (absence of graft and replaced by the joint fluid) on either 2D FSE PCL views or 3D VISTA PCL views was seen [14]. Impingement of PCL graft was considered when a focal area of increased signal intensity was seen in the not-totally-torn graft fibers (Figs. 3 and 4) [14]. We tried our best to exclude the misinterpretation of the physiologic change of the graft as impingement or failure.

2.4. Statistical analysis

Agreements between the two radiologists for diagnostic performance were analyzed using kappa statistics. Interpretation of the each kappa value was as follows: poor ($k \leq 0.1$), slight ($0.1 < k \leq 0.2$), fair ($0.2 < k \leq 0.4$), moderate ($0.4 < k \leq 0.6$), substantial ($0.6 < k \leq 0.8$), and almost perfect ($0.8 < k \leq 1$) [18]. The diagnostic performance of the 2D FSE PCL view, the 3D VISTA PCL view, the orthogonal 2D FSE image, and the combined sequences were evaluated in terms of sensitivity, specificity, and accuracy for diagnosing complications of the PCL graft. The reference diagnoses were made arthroscopically or clinically. McNemar statistics were used to analyze each value of diagnostic performance. PASW software, version 18.0 (IBM, Armonk, NY,
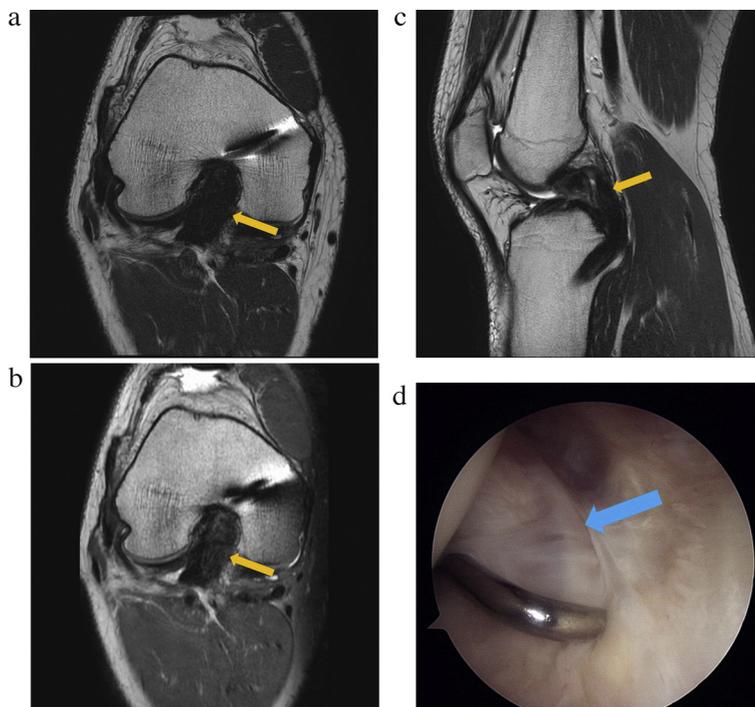
Fig. 4. A 41-year-old man who was admitted to remove hardware and for a second-look arthroscopic exam after PCL reconstruction. A: The PCL view of an FSE T2-weighted MRI (TR/TE, 2700/60) shows an intact PCL graft (arrow). B: PCL view reformatted from 3D VISTA MRI demonstrates a bright signal in the graft and some contour irregularities (arrow). The interpretation of this image was an impingement of the graft.C: An orthogonal sagittal FSE T2-weighted MRI (TR/TE, 4000/100) reveals an intact graft bundle (arrow). D: An arthroscopic image shows an intact PCL graft (arrow).

Table 2

Case selection and clinical diagnosis of posterior cruciate ligament graft complications.

Diagnostic method	Graft impingement	Intact graft	Total
Surgical	6 (15%)	9 (23%)	15 (38%)
Non-surgical	8 (20%)	17 (42%)	25 (62%)
Total	14 (35%)	26 (65%)	40 (100%)

Table 3

Agreement between radiologists on diagnostic performance.

Views	Kappa value	95% confidence interval	P-value
[a]PCL view	0.890	0.743 – 1.000	< 0.001
[b]VPCL view	0.842	0.671 – 1.000	< 0.001
Orthogonal view	0.733	0.488 – 0.979	< 0.001
Orthogonal + PCL	0.725	0.509 – 0.942	< 0.001
Orthogonal + VPCL	0.687	0.469 – 0.906	< 0.001

Kappa values are presented with the 95% confidence interval.
Note: poor (k < 0.1), slight (0.1 ≤ k ≤ 0.2), fair (0.2 < k ≤ 0.4), moderate (0.4 < k ≤ 0.6), substantial (0.6 < k ≤ 0.8), and almost perfect (0.8 < k ≤ 1).
  [a] PCL view = 2D FSE PCL view.
  [b] VPCL view = 3D VISTA PCL view.

USA) were used in the statistical analyses. A p-value ≤ 0.05 was considered to be statistically significant.

3. Results

The study participants were composed of 33 men and 7 women (mean age: 33.0 ± 12.6 years, range: 19–61 years). Fourteen cases were ultimately diagnosed with graft impingement (33% [14/40], Table 2). The arthroscopic surgeries confirmed six cases of graft impingement and nine cases of an intact graft (Table 2). Eight cases of graft impingement were diagnosed non-surgically. A case of graft failure was not seen. The agreement for diagnostic performance between the two radiologists was almost perfect for the 2D PCL view and 3D VISTA PCL view, (k values, 0.89 and 0.84, respectively, Table 3) and substantial on the orthogonal view and combined images (k values, 0.69 – 0.73). When MRI was classified as normal or impingement of the graft, the sensitivities and accuracies of the 2D FSE PCL view and 3D VISTA PCL view were significantly higher than those of the orthogonal view in radiologist 1(p values, 0.016, 0.039 in sensitivities and 0.012, 0.022 in accuracy, Table 4 and 5). However, the specificities of the 2D FSE PCL view and 3D VISTA PCL view were not significantly higher than those of the orthogonal view in both radiologists. The diagnostic performances of 3D VISTA PCL view and 3D VISTA PCL view with the

Table 4

Sensitivity, specificity, and accuracy of the 2D FSE PCL view, the 3D VISTA PCL view and the orthogonal views in the differentiation of normal and abnormal findings in the diagnosis of PCL graft complications.

Views	Sensitivity (%)		Specificity (%)		Accuracy (%)	
	Radiologist 1	Radiologist 2	Radiologist 1	Radiologist 2	Radiologist 1	Radiologist 2
[a]**PCL view**	92.9 (13/14)	78.6 (11/14)	92.3 (24/26)	92.3 (24/26)	92.5 (37/40)	87.5 (35/40)
[b]**VPCL view**	92.9 (13/14)	85.7 (12/14)	92.3 (24/26)	84.6 (22/26)	92.5 (37/40)	85.0 (34/40)
Orthogonal view	42.9 (6/14)	57.1 (8/14)	84.6 (22/26)	92.3 (24/26)	70.0 (28/40)	80.0 (32/40)
Orthogonal + PCLview	92.9 (13/14)	71.4 (10/14)	88.5 (23/26)	96.2 (25/26)	90.0 (36/40)	87.5 (35/40)
Orthogonal + VPCLview	100 (14/14)	71.4 (10/14)	84.6 (22/26)	92.3 (24/26)	90.0 (36/40)	85.0 (34/40)

Note: Numbers in parentheses represent the number of patients used to calculate the percentage.
  [a] PCL view = 2D FSE PCL view.
  [b] VPCL view = 3D VISTA PCL view.

Table 5

McNemar test for the sensitivity, specificity, and accuracy of the 2D FSE PCL view, the 3D VISTA PCL view, and the orthogonal views in the differentiation of normal and abnormal findings in the diagnosis of PCL graft complications.

Views	Sensitivity		Specificity		Accuracy	
	Radiologist 1	Radiologist 2	Radiologist 1	Radiologist 2	Radiologist 1	Radiologist 2
PCL view[a] vs. VPCL view[b]	1.000	1.000	1.000	0.687	1.000	1.000
Orthogonal view vs. PCL view	**0.016**	0.250	0.625	1.000	**0.012**	0.375
Orthogonal view vs. VPCL view	**0.039**	0.219	0.625	0.687	**0.022**	0.774
Orthogonal view vs. orthogonal + PCL view	**0.016**	0.500	1.000	1.000	**0.021**	0.250
Orthogonal view vs. orthogonal + VPCL view	**0.0078**	0.500	1.000	1.000	0.057	0.687
Orthogonal + PCL view vs. orthogonal + VPCL view	1.000	1.000	1.000	1.000	1.000	1.000

Note: Numbers represent *p* values.

Bold values are stastistically significant values.

[a] PCL view = 2D FSE PCL view.

[b] VPCL view = 3D VISTA PCL view.

combination of the orthogonal view were similar to those of the 2D FSE PCL view and 2D FSE PCL view with combination of the orthogonal view (Table 5). The radiologist 1 showed higher sensitivities when we combined 2D FSE PCL view or 3D VISTA PCL view with the orthogonal view and the radiologist 1 showed higher accuracies when we combined 2D FSE PCL view to orthogonal view (*p* values, 0.016, 0.008 in sensitivities and 0.021 in accuracy, Table 5). However, the radiologist 2 did not show significant differences of diagnostic performance. (Table 5). There was not a statistically significant difference in diagnostic performance between the 3D VISTA PCL view and the 2D PCL view (solitary or combined with the orthogonal view).

4. Discussion

Contrary to previous studies that concluded that the PCL graft is easier to evaluate using an orthogonal sagittal MRI, Park et al. reported that the PCL view can provide better anatomic evaluation of the PCL graft [14,19,20]. Like native PCL, the oblique and curvilinear contour of the PCL graft make it difficult to sufficiently evaluate the entire course of the PCL graft. Therefore, the PCL view, which follows a parallel line connecting the tibial and femoral insertion site of the graft, can decrease the partial volume averaging artifact and provide good visualization of the entire contour of the graft [14]. Park et al. suggested that the superiority of the PCL view results from its ability to visualize the entire width of the graft, which can be difficult with a sagittal image [7]. Previously, we reported that the 3D VISTA isotropic image has the same diagnostic ability for ACL and PCL injuries and in the evaluation of the complication of the ACL graft and therefore can replace 2D FSE images [12,21,22]. Generally, 3D MRI sequences based on gradient-echo imaging, which produce T2* contrast by using small flip angles and long TEs, have poor SNR and CNR; however, 3D isotropic spin-echo MRI techniques have good tissue contrast [17,22,23]. The agreement in diagnosis of the PCL graft complications between radiologists ranged from substantial to almost perfect (Table 3), and the agreement between the two PCL views (2D PCL view and 3D VISTA PCL view) were higher than those of the orthogonal view and the combined images. 3D reformatted MRI is helpful when we evaluate anatomic details in an arbitrary chosen angle and 3D isotropic images provide high spatial resolution and good T2 contrast with an acceptable scan time [12,23]. Therefore, 3D VISTA MRI is regarded as comparable to 2D FSE MRI for the evaluation of soft tissues and bony structures [12]. In this study, statistically significant differences between 3D VISTA PCL view and 2D PCL view in the evaluation of the graft such as the discrimination between impingement and normal findings did not exist (*p* > 0.05). When combination images of the orthogonal view and each PCL view were applied, a significant difference in the diagnostic performance was not seen (*p* > 0.05). Reformatted 3D MRI has inferior margin distinctiveness of the anatomic structure and spatial resolution compared to 2D MRI [12,21,22,24]. We also observed this

problem. However, this handicap did not affect the diagnostic ability of 3D MRI, especially in the evaluation of the graft complication. Park et al. also reported that inferior image quality did not affect diagnostic performance in the evaluation of PCL pathology, and explained this phenomenon from the fact that diagnosis of PCL injury is mainly based on whether the ligament has its own continuity or not [22]. That is to say, whether the MRI has a distinct margin or not does not matter significantly in the evaluation of the PCL injury. We think this suggestion can also be applied in the evaluation of graft complications.

There were some limitations of this study. First, we made only a small number of surgical diagnoses and thus our cases might not accurately represent the pool of all surgical diagnoses. Approximately 38% of all of our cases underwent arthroscopic surgery. As every mild impingement of the PCL graft does not always need surgical revision we could not enroll entirely surgically confirmed cases. The other cases were confirmed clinically without surgery. Although not surgically confirmed, the diagnoses of the other cases were made based on as many as possible independent clinical findings and physical examination. We took great cares to correctly diagnose these cases by many other diagnostic methods such as Telos view which seems to be very sensitive PCL injury. Nevertheless, we acknowledge this inevitably limits the reliability of our study. Second, we did not have a case of complete disruption of the graft. Third, the mean intervals of first surgery and MRI and the interval between MRI and second look surgery were variable. This variability can be a potential source of bias. And last, the clinical usefulness of 3D VISTA of the knee joint is dependent on whether the 3D VISTA sequences can accurately assess all other anatomic and pathologic components of the knee joint. We should also assess for the existence of hemorrhage or joint effusion, marrow edema, chondral lesions and hidden small bony fractures [12,21]. The suitability of 3D VISTA images for the evaluation of these pathologies should be more explored in following studies. However, 3D VISTA can obviously replace 2D FSE in the evaluation of the graft complication whether the surgery was ACL recon or PCL recon. Replacing much more sequences by 3D isotropic image still remain as a future study.

In conclusion, the diagnostic performace of the PCL views on the 3D VISTA images was comparable to those of the 2D FSE in the diagnosis of PCL graft complications. Therefore, 3D VISTA images can replace 2D FSE in the evaluation of the postsurgical evaluation of the PCL reconstruction.

Conflict of interest

The authors declare that they have no conflict of interest.

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