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FULL PAPER

Usefulness of oblique coronal magnetic resonance images of the knee after posterior cruciate ligament reconstruction

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Objective: To know the usefulness of the oblique coronal view of the posterior cruciate ligament (PCL) in the evaluation of the graft normal anatomy and the diagnostic accuracy of combining the PCL view with orthogonal views for the evaluation of PCL graft failure or impingement after reconstruction procedures.

Methods: This retrospective study included 54 patients who underwent PCL-view MRI after PCL reconstruction surgery. Anatomic identification of graft failure and impingement was scored by two radiologists. The ability to diagnose PCL graft failure with the PCL view, orthogonal view or combined PCL/orthogonal views was evaluated by calculating the sensitivity, specificity and accuracy.

Results: The entire width discrimination scores and margin sharpness scores for the PCL view were significantly higher than those for the orthogonal view for both

readers. The specificities and accuracies for the PCL view and the combined PCL/orthogonal views were higher than those for the orthogonal view alone, but these differences were not statistically significant.

Conclusion: The PCL view provided a better anatomic evaluation than the orthogonal view with regard to the entire width evaluation and margin sharpness evaluation of the PCL graft. The combined view of orthogonal and PCL views was slightly more sensitive and accurate, but not significantly so, in the diagnoses of graft failure and impingement.

Advances in knowledge: The PCL view provided a better anatomic evaluation than the orthogonal view with regard to the entire width evaluation and margin sharpness evaluation of the PCL graft. The PCL view was slightly more sensitive and accurate, but not significantly so, in the diagnoses of graft failure and impingement.

INTRODUCTION

The aim of posterior cruciate ligament (PCL) reconstruction is to restore the stability of the native PCL. PCL reconstruction is preferred for patients with bone fractures, PCL laxity higher than Grade 3 and chronic PCL instability.^{1,2} Disruption of the graft, graft impingement and laxity of the graft are common post-surgical complications.³ Instability rates after PCL reconstruction have been reported between 20 and 33%.⁴ MRI is the method of choice to evaluate the PCL graft. Previous reports on the MR evaluation of PCL grafts were based on the routine orthogonal MR plane of the knee joint.^{1,5} Alcalá-Galiano et al³ reported that the oblique sagittal plane, which follows the course of the graft, can be helpful in evaluating PCL reconstruction. Recently, Park et al⁶ reported that the oblique coronal plane in knee joint MRI provides a better anatomic evaluation of

the PCL and improves the diagnostic specificity and accuracy. We wanted to evaluate whether this unique imaging plane (the PCL view) can be used to evaluate the PCL graft after PCL reconstruction surgery. The purpose of this study was to know the usefulness of the PCL view in the evaluation of the graft normal anatomy and the diagnostic accuracy of combining the PCL view with the orthogonal view for the evaluation of PCL graft failure or impingement after reconstruction procedures.

METHODS AND MATERIALS

Case selection and clinical diagnosis

This study was approved by the institutional ethics review board at our hospital, and informed consent was waived owing to the retrospective study design. We retrospectively

Table 1. Imaging parameters of the MR sequences

Imaging parameter	Coronal FS T_2 FSE	Coronal PD FSE	Sagittal FS PD FSE	Sagittal T_2 FSE	Axial FS T_2 FSE	PCL-view T_2 FSE
TR (ms)	3000–5000	2500–3600	3500–4500	3500–5000	4000–4500	2000–3000
TE (ms)	60–90	30–40	30–40	50–100	60–80	50–80
Flip angle (°)	90	90	90	90	90	90
Matrix size (pixels)	350 × 250	450 × 300	350 × 250	400 × 300	350 × 250	450 × 350
FOV (cm)	16	16	16	16	16	14
Slice thickness (mm)	3	3	3	3	3	3
Interslice gap (mm)	0.3	0.3	0.3	0.3	0.3	0
Bandwidth (kHz)	230	460	250	290	240	420
ETL	15	15	14	17	15	13
Signal average	2	1	1	1	1	1
Scan time (min:s)	3:20	2:20	2:40	2:00	2:40	2:00

ETL, echo train length; FOV, field of view; FS, fat saturation; FSE, fast spin echo; PCL, posterior cruciate ligament; PD, proton density; TE, echo time; TR, repetition time.

evaluated 54 patients who underwent PCL reconstruction surgery and knee MRI approximately 7 months after surgery between March 2012 and September 2015. The study group included 10 females and 44 males (mean age: 34 ± 13 years, range: 16–61 years). All surgical procedures were performed by an

experienced orthopaedic surgeon. The surgical procedure was single-bundle PCL reconstruction with an allotibialis anterior tendon. The mean follow-up time between PCL reconstruction and post-operative MR examination was 182 ± 59 days. 29 (54%) of 54 patients underwent a second-look operation. The surgical

Figure 1. Posterior cruciate ligament (PCL) views are obtained using a slice thickness of 3 mm, which is parallel to the line connecting the PCL insertion sites on the tibia and femur based on the orthogonal sagittal T_2 weighted image (repetition time/echo time, 4000/100 ms).

Figure 2. Post-operative MRI of a 41-year-old male performed 8 months after arthroscopic posterior cruciate ligament (PCL) reconstruction with an allograft from the tibialis anterior tendon. (a) A sagittal T_2 weighted image [repetition time (TR)/echo time (TE), 3800/80 ms] showing the normal reconstructed PCL (arrow). The total score of anatomic identification was 9 (the entire length score 3, entire width score 3 and margin sharpness score 3). (b) PCL view (TR/TE, 2500/80 ms) showing the entire width and sharp margin of the PCL (arrow). The total score of anatomic identification was 8 (the entire length score 2, entire width score 3 and margin sharpness score 3). Second-look arthroscopy revealed an intact PCL graft.

records from the electronic medical records revealed 25 cases with an intact PCL graft, 3 cases with impingement of the PCL graft and 1 case with graft failure of the PCL graft. In clinical examinations, graft impingement was diagnosed in two patients without surgery. Therefore, six patients were ultimately diagnosed with graft failures. In the outpatient department, the same surgeon who performed the PCL reconstruction also evaluated graft failure clinically based on a physical examination, including a positive posterior drawer test, and clinical findings of swelling

and discomfort on knee flexion or a limping gait.⁶⁻⁸ The posterior drawer sign has 85% accuracy in the diagnosis of PCL laxity.⁸ We considered the result of the posterior drawer test as positive if posterior subluxation of the tibia from the distal femur could be elicited with knee joint flexion.⁹ Other radiologic findings, such as a positive Telos stress view and clinical results, such as a response to physical therapy and course of clinical symptoms, were also included in the final diagnosis of non-surgical cases.⁶

Figure 3. Post-operative MRI of a 54-year-old male performed 7 months after arthroscopic posterior cruciate ligament (PCL) reconstruction with an allograft from the tibialis anterior tendon. (a) A sagittal T_2 weighted image [repetition time (TR)/echo time (TE), 3800/100 ms] showing the focally increased signal intensities in the PCL graft (arrow). (b) PCL view (TR/TE, 2700/60 ms) showing increased signal intensities in the mid portion of the graft (arrow). Second-look arthroscopy revealed impingement of the PCL graft.

Figure 4. Post-operative MRI of a 22-year-old male performed 8 months after arthroscopic posterior cruciate ligament (PCL) reconstruction with an allograft from the tibialis anterior tendon. (a) A sagittal T_2 weighted image [repetition time (TR)/echo time (TE), 4000/80 ms] showing a disrupted PCL graft (arrow). (b) PCL view (TR/TE, 2500/80 ms) showing a prominent disruption of the PCL graft (arrow). Second-look arthroscopy revealed PCL graft failure.

MR parameters

We acquired all MR images with a 3.0-T MR scanner (Achieva; Philips Medical Systems, Best, Netherlands) with an eight-channel knee coil. The image parameters and sequences are summarized in Table 1. PCL views were obtained in the plane parallel to the line between the PCL insertion site of the tibia and femur, based on orthogonal sagittal T_2 weighted images (T2WIs) (Figure 1).⁶ The parameters of the PCL views were as follows: repetition time/echo time = 2000–3000/40–80, field of view = 14 cm, echo train length = 13, matrix size = 450×350 pixels and slice thickness = 3 mm.

Image analysis

The PCL view of the MRI was performed at least 5 months (mean interval: 217 ± 60 days) after reconstruction surgery to avoid the period of physiologic ligamentization.¹¹ Orthogonal MR images and PCL views were interpreted independently by two fellowship-trained musculoskeletal radiologists with 15 and 8 years' experience, who were unaware of the medical history and the results of the previous radiologic reports.

First, anatomic identification of PCL graft pathology on the orthogonal MRI sequence (sagittal and coronal T2WIs) and PCL views was evaluated. Anatomic identification was scored for the

entire length of the graft (entire length), entire width of the graft (entire width) and margin sharpness of the graft according to a 4-point scale (0, poor; 1, fair; 2, good; and 3, excellent).^{6,12} The score for the entire length evaluated the extent to which the reader could perform a longitudinal evaluation of the graft from the tibial end to the femoral end. The score for the entire width evaluated the extent to which the reader could perform a transverse evaluation of the graft from the medial to the lateral edges.¹²

Diagnostic ability with the PCL view, orthogonal view and combined PCL/orthogonal views was evaluated. We considered the reconstructed PCL as intact if a bundle of low signal intensity was observed on the T2WI (Figure 2). The PCL graft was considered to have an impingement if there was a focal area of increased signal intensity in the intact graft fibres (Figure 3). The reconstructed PCL was considered to have complete graft failure if the MRI findings included an absence of graft fibres and a fluid-filled defect (Figure 4).¹²

Statistical analysis

Anatomic identification with the orthogonal view and PCL view, as scored by the two musculoskeletal radiologists, was compared. Interreader agreement was analyzed with an intraclass correlation coefficient (ICC). ICC interpretation can range from 0 (no

Table 2. Case selection and clinical diagnosis of posterior cruciate ligament (PCL) graft injury

Method used to confirm PCL graft injury	Graft injury (+)		Graft injury (–)	Total
	Impingement	Graft failure		
Surgery	3	1	25	29
Clinical findings and physical examination	2	0	23	25
Total	5	1	48	54

Table 3. Intraclass correlation coefficients (ICCs) between two readers for scores on anatomic identification

Images	Entire length evaluation ^a (a)	Entire width evaluation ^b (b)	Margin sharpness (c)	Total (a + b + c)
Orthogonal view (sagittal and coronal T2WIs)	0.849 (0.754–0.909)	0.869 (0.782–0.922)	0.921 (0.867–0.953)	0.901 (0.835–0.942)
PCL view	0.814 (0.692–0.890)	0.848 (0.753–0.909)	0.810 (0.693–0.885)	0.774 (0.634–0.864)

PCL, posterior cruciate ligament; T2WIs, T₂ weighted images.

Numbers in parentheses are 95% confidence intervals.

ICCs were characterized as follows: poor, <0.40; fair to good, 0.40 < κ ≤ 0.75; excellent, >0.75.

^aDiscrimination ability through the entire length.

^bDiscrimination ability through the entire width.

agreement) to 1 (perfect agreement): a value <0.40 indicates poor agreement; 0.40–0.74, moderate agreement; and 0.75–1.00, excellent agreement.¹³ We used Wilcoxon signed-rank tests to determine the statistical significance of the anatomic identification scores. We used kappa statistics to analyze the inter-reader agreement of the diagnostic performance. Interpretation of the kappa value was as follows: poor (κ ≤ 0.1), slight (0.1 < κ ≤ 0.2), fair (0.2 < κ ≤ 0.4), moderate (0.4 < κ ≤ 0.6), substantial (0.6 < κ ≤ 0.8) and almost perfect (0.8 < κ ≤ 1).¹⁴ We evaluated the diagnostic performance of the orthogonal view, PCL view and combined PCL/orthogonal views with the sensitivity, specificity and accuracy for diagnosing PCL graft failure. Arthroscopically or clinically confirmed diagnoses of graft failure were used as the reference standard, and the values were analyzed with the McNemar's test. Statistical analyses were performed by using PASW software v. 18.0 (IBM, Armonk, NY), and *p*-values ≤ 0.05 were considered to be statistically significant.

RESULTS

29 (54%) of the 54 patients underwent surgery. 3/29 (10%) patients had graft impingement and 1/29 (3%) patient had graft failure (Table 2). The remaining 25 patients who underwent surgery had an intact PCL graft. 2/25 (8%) patients who did not undergo surgery had impingement.

The ICCs of the anatomic identification scores for the orthogonal view and PCL views ranged between 0.774 and

0.921, indicating excellent interreader agreement (Table 3). The mean scores for the anatomic identification of the reconstructed PCLs, as well as the results of Wilcoxon signed-rank tests comparing the scores between the orthogonal and PCL views, are summarized in Table 4. The entire width discrimination scores and the margin sharpness scores for the PCL view were significantly higher than those for the orthogonal view for both readers. There were no significant differences in the entire length discrimination score between the two imaging methods.

Interreader agreement for the diagnostic performance on the orthogonal view, PCL view and combined PCL/orthogonal views was moderate or substantial (κ -value, 0.589–0.699) (Table 5). 6–9 (11–17%) cases showed a false-positive diagnosis on at least one of the above-mentioned views, which proved to be an intact graft (Figure 5). 2 (4%) cases from Reader 1 and 1 (2%) case from Reader 2 showed false-negative diagnoses on both the orthogonal and PCL views, which proved to be a graft injury (Figure 6). There were no significant differences between the orthogonal view, PCL view and combined PCL/orthogonal views in the sensitivity, specificity and accuracy for diagnosing PCL graft injury (Table 6).

DISCUSSION

The MRI appearance of the PCL graft varies according to the type of graft, fixation technique and time interval between MRI and surgery.^{3,15} Previous studies have reported that the PCL

Table 4. Mean scores for the anatomic identification of the reconstructed posterior cruciate ligament (PCL) on orthogonal and PCL views

Images	Entire length evaluation ^a (a)	Entire width evaluation ^b (b)	Margin sharpness (c)	Total (a + b + c)
Orthogonal view (sagittal and coronal T2WIs)	2.57 ± 0.50/2.61 ± 0.49 (2–3)	2.04 ± 0.70/2.13 ± 0.70 (1–3)	2.19 ± 0.70/2.22 ± 0.66 (1–3)	6.80 ± 1.69/6.96 ± 1.60 (4–9)
PCL view	2.37 ± 0.49/2.46 ± 0.50 (2–3)	2.63 ± 0.56/2.69 ± 0.54 (1–3)	2.48 ± 0.54/2.56 ± 0.54 (1–3)	7.48 ± 1.08/7.70 ± 1.19 (4–9)
<i>p</i> -value	0.034/0.117	<0.001/<0.001	0.006/0.001	0.005/0.001

T2WIs, T₂ weighted images.

Values are mean ± standard deviations and are displayed as Reader 1/Reader 2.

Data in parentheses are ranges of the values.

p-values are between the orthogonal views and PCL views.

^aDiscrimination ability through the entire length.

^bDiscrimination ability through the entire width.

Table 5. Interreader agreement (κ) for diagnostic performance

Sequences	kappa value (κ)	95% confidence interval	<i>p</i> -value
Orthogonal view (sagittal and coronal T2WIs)	0.589	0.335–0.842	<0.001
PCL view	0.621	0.359–0.883	<0.001
Combination of orthogonal view and PCL view	0.699	0.438–0.959	<0.001

PCL, posterior cruciate ligament; T2WIs, T_2 weighted images.

Interreader agreement (κ) was characterized as follows: poor ($\kappa < 0.1$), slight ($0.1 \leq \kappa \leq 0.2$), fair ($0.2 < \kappa \leq 0.4$), moderate ($0.4 < \kappa \leq 0.6$), substantial ($0.6 < \kappa \leq 0.8$) and almost perfect ($0.8 < \kappa \leq 1$).

graft is easier to evaluate on T_2 weighted sagittal images and on the image parallel to the course of the tibial tunnel.^{15,16} However, for the native PCL, we previously found that the PCL view provides a better anatomic evaluation and mild improvement in specificity and accuracy in the diagnosis of PCL injury.⁶ As the curvilinear course of the PCL does not permit sufficient evaluation on the orthogonal plane, the entire course of the PCL is not clearly depicted on routine sagittal images. Therefore, oblique coronal images, which are parallel to the line connecting the femoral and tibial insertion sites of the PCL, can be used to decrease the partial volume-averaging artefact and achieve “full-width” visualization of the PCL.⁶ Nevertheless, whether these results can be applied to the PCL graft is a separate issue because the course and shape of the graft is somewhat different from those of the native PCL. The native PCL is composed of two bundles (anterolateral and posteromedial), but the PCL graft used in this study was a single bundle. Theoretically, double-bundle surgery may be more effective in preventing posterior instability because the double-bundle technique more closely resembles the natural course of the PCL. However, there is no current consensus regarding which surgical procedure is

superior for the rehabilitation of knee function.^{3,16–18} The scoring system for anatomic identification revealed excellent interreader agreement, implying good reproducibility (Table 3). The ICCs for the orthogonal view totalled 0.90 and those for the PCL view totalled 0.77. The ICC values were similar to those for native PCL evaluation (ICCs = 0.88 in the orthogonal view and 0.93 in the PCL view).⁶ Although the absolute value of the ICC of the native PCL in the PCL view was higher than that of the PCL graft, interpretation of the value is the same. Anatomic identification with the PCL view was superior to that of the orthogonal view with regard to entire width evaluation and margin sharpness evaluation; however, it was not superior with regard to entire length evaluation (Table 4). These results are similar to those of a previous study on the native PCL.⁶ The superiority of the PCL view may result from its ability to visualize the entire width of the ligament along a parallel axis, providing accurate information about the attachment site to the distal femur.⁶ We believe that the PCL view could also provide more accurate information than the orthogonal view regarding the tibial and femoral insertion sites of the graft. However, the PCL view may lead to inferior evaluation of the entire length of

Figure 5. Post-operative MRI of a 28-year-old female performed 11 months after arthroscopic posterior cruciate ligament (PCL) reconstruction with an allograft from the tibialis anterior tendon. (a) A sagittal T_2 weighted image [repetition time (TR)/echo time (TE), 3600/80 ms] showing the focally increased signal intensities in the PCL graft (arrow). (b) PCL view (TR/TE, 2500/80 ms) showing an intact PCL graft (arrow). Second-look arthroscopy revealed an intact PCL graft.

Figure 6. Post-operative MRI of a 51-year-old male performed 7 months after arthroscopic posterior cruciate ligament (PCL) reconstruction with an allograft from the tibialis anterior tendon. (a) Sagittal T_2 weighted image [repetition time (TR)/echo time (TE), 4000/100 ms] showing an intact PCL graft (arrow). (b) PCL view (TR/TE, 2700/60 ms) showing an intact PCL graft (arrow). (c) Second-look arthroscopy revealing impingement of the PCL graft (arrow).

the graft because the entire length of the graft is better seen on the orthogonal sagittal image, although this difference between imaging views was not statistically significant in the present study (Table 4). The MR signal intensity of the PCL varies with the age of the graft.³ In general, the PCL graft undergoes a remodelling and resynovialization process, the so-called “ligamentization” process, between 4 and 8 months after surgery, during which the PCL graft transforms into a tissue similar to the native PCL, both morphologically and histologically.^{1,5} During this phase, a high signal intensity of the graft on the T2WI may be mistaken for a tear.³ Therefore, we excluded patients who underwent MRI less than 7 months after surgery to avoid confusion between graft impingement and normal ligamentization.

The κ -values for interreader agreement on the diagnosis (*i.e.* normal, impingement or graft failure) were higher for the PCL view and combined PCL/orthogonal views than for the orthogonal view only. This indicates that the PCL view leads to more reproducible diagnoses than the orthogonal view. The reproducibility of the PCL view for the native PCL is also superior to the orthogonal view; however, the absolute κ -values for

the native PCL are higher than those for the PCL graft (orthogonal view, 0.735; PCL view, 0.927).⁶

The specificities and accuracies of the PCL view and combined PCL/orthogonal views were higher than those of the orthogonal view alone. These results suggest that the PCL view alone or the addition of the PCL view to the orthogonal view can reduce false-negative diagnoses; however, the values for specificity and accuracy did not differ significantly between imaging views. This trend was also found in a study of native PCL injury. The authors reported the same sensitivity but superior specificity and accuracy of the PCL view compared with the orthogonal view.⁶ Therefore, we suggest that the PCL view could potentially help reduce false-negative diagnoses in the evaluation of both native PCL injury and PCL graft injury.

This study had some limitations. First, we included only one case of graft failure. Second, only 54% of patients underwent surgical confirmation. 17 of total 29 cases underwent operation for removal of medical hardware, 8 cases underwent operation for suspicion of retear, 3 cases for treatment of synovitis and

Table 6. Sensitivity, specificity and accuracy of the orthogonal and posterior cruciate ligament (PCL) views in the diagnosis of PCL graft failure

Images	Sensitivity (%)	Specificity (%)	Accuracy (%)
Orthogonal view (sagittal and coronal T2WIs)	66.7 (4/6)/66.7 (4/6)	81.3 (39/48)/87.5 (42/48)	79.6 (43/54)/85.2 (46/54)
PCL view	66.7 (4/6)/66.7 (4/6)	95.8 (46/48)/93.8 (45/48)	92.6 (50/54)/90.7 (49/54)
O + PCL view	83.3 (5/6)/66.7 (4/6)	93.8 (45/48)/95.8 (46/48)	92.6 (50/54)/92.6 (50/54)
<i>p</i> -value			
O vs PCL view	1.000/1.000	0.039/0.375	0.065/0.375
O vs O + PCL view	1.000/1.000	0.070/0.125	0.039/0.125

O, orthogonal view; T2WIs, T_2 weighted images.

Data are displayed as Reader 1/Reader 2.

Numbers in parentheses are the number of patients used to calculate the percentages.

1 case for removal of foreign body in the knee joint. Third, we used a subjective scoring system to evaluate the anatomic identification of the PCL graft. Fourth, we did not use the exact same imaging parameters for the orthogonal and PCL views. For example, we used a different repetition time/echo time, interslice gap (PCL view, 0; orthogonal view, 0.3) and field of view (PCL view, 14 cm; orthogonal view, 16 cm). These differences could have influenced the depiction of the graft.

In conclusion, the PCL view provided a better anatomic evaluation than the orthogonal view with regard to entire width evaluation and margin sharpness evaluation of the PCL graft. The combined view of orthogonal and PCL views was slightly more sensitive and more accurate in identifying graft failure and impingement, but this advantage was not statistically significant. The PCL view can be used as an ancillary tool to distinguish equivocal cases of graft complication.

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