


Analysis of Hemodynamic Changes After Medial Patellofemoral Ligament Reconstruction



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ABSTRACT

The resumption of blood flow is an important factor in the remodeling process of the graft. The purpose of this study is to evaluate hemodynamic changes after medial patellofemoral ligament (MPFL) reconstruction using magnetic resonance angiography (MRA) as the evaluation of graft remodeling. Eleven knees that underwent anatomical MPFL reconstruction with the semitendinosus tendon were studied. We evaluated the blood flow around the bone tunnel wall in the arterial phase using MRA approximate 3 months and 1 year after surgery. Clinical and radiological evaluations were also analyzed. MRA showed an inflow vessel into the bone tunnel wall from the medial superior genicular artery on the femoral side, and from the articular branch of the descending genicular artery and the medial superior genicular artery on the patellar side. This contrast effect was decreased at 12 months after surgery in all cases. The clinical scores improved from baseline one year postoperatively. We revealed the blood flow to the bone tunnel wall after anatomical MPFL reconstruction is detected by MRA. The blood flow started within 2 or 3 months postoperatively and was sustained for 12 months. This study supported remodeling of the graft continues 3 months after surgery when the conformity of the patellofemoral joint stabilizes.

Introduction

The medial patellofemoral ligament (MPFL) is the primary mechanism supporting medial patellofemoral joint stability. When the continuity of the MPFL is disrupted by patellar dislocation, the stability of the PF joint is reduced. Reconstruction by guiding a graft into the bone tunnel is widely used as a treatment to improve stability. In order to obtain good stability, postoperative biosorption of the graft to the bone is important. On the other hand, the resumption of blood flow is an important factor in the reconstruction process of the graft, which can develop into necrosis early after reconstruction [1, 2]. Contrast-enhanced magnetic resonance imaging (MRI) and magnetic resonance angiography (MRA) have been used to evaluate blood flow to the tendon graft [3–5]. Contrast-enhanced MRI images are taken in the venous phase, when the transplanted tendon is well-constructed, making it difficult to assess the blood flow path. However, MRA has revealed blood flow changes associated with graft reconstruction by visualizing blood flow to the bone tunnel wall and graft after anterior cruciate ligament (ACL) 1 bundle reconstruction, using a semitendinosus tendon [6–8]. Therefore, we consider MRA to be a helpful tool to elucidate the remodeling process of the graft.

We hypothesized that inflow vessels to the tendon graft after MPFL reconstruction are revealed applying the technique of MRA. Fujii et al. [9] have reported chronological radiographic evaluation after MPFL reconstruction. If chronological blood flow change to the bone tunnel wall and reconstructed ligament after MPFL reconstruction is clarified in vivo, it will help to elucidate the remodeling process. Against this background, we performed MRA after MPFL reconstruction in order to confirm whether blood flow could be evaluated. We also examined the changes in hemodynamics over time using clinical and radiological evaluations.

Materials and methods

Subjects

Ten cases and 11 knees with recurrent patellar dislocation that underwent MPFL reconstruction using the semitendinosus tendon from July 2013 to September 2016 were included in this study. Habitual patellar dislocations were excluded. The mean age of the patients was 26.4 years with 8 female cases involving 9 knees and 2 male cases involving 2 knees. The mean height and body mass index were 160.5 cm and 21.6 kg/m², respectively. The patients' demographic data are presented in ► **Table 1**.

Ethics approval for this study was obtained from the Ethical Review Board of our hospital (ERB-C-268-3). All procedures were conducted in accordance with the ethical standards of the current ethical regulations for research [10] and the Helsinki Declaration of 1975, as revised in 2000.

MPFL reconstruction

MPFL reconstruction was performed by modifying the method reported by Toritsuka et al. [11] and by Nakagawa et al. [12]. This procedure can reconstruct MPFL anatomically, albeit at the risk of a patellar fracture. All operations were performed by 2 experienced orthopedic surgeons, who worked at same time, under the supervision of the director of Sports Orthopaedics.

The semitendinosus tendon was harvested according to the method of Hara et al. [13]. A femoral tunnel with a depth of 30 mm was created with reference to the osseous landmarks distal to the adductor tubercle (proximally and posteriorly from the centre of the medial femoral epicondyle) toward the lateral femoral bone cortex, as reported by Nomura et al. [14]. Two patellar bone tunnels with a depth of 15 mm each and 4.5-mm in diameter were created with a reamer using 2 K-wires as guidewires inserted 1/2 and 1/3 of the distance from the proximal edge of the patella. The bone tunnel wall and the graft were in close contact with each other, and the fit good in all cases. The tendinous region of the excised and semitendinosus muscle tendon was sutured to both ends of the #2 FiberWire (Arthrex, Naples, FL) to make a double-bundle tendon graft. The FiberWire was passed through the patellar bone tunnel, and both ends of the tendon graft were then drawn into the tunnel and fixed to the lateral cortex of the patella using an EndoButton (Smith & Nephew, London, England). The patella was fixed to the center of the femoral trochlea, while the axial position was confirmed using imaging. For fixation on the femoral side, the Toggle-Loc Fixation Device (Zimmer Biomet, Warsaw, IN) was used, according to the method described by Nakagawa et al. [12]. Lateral retinacular release was not performed.

Postoperative management

From the day after MPFL reconstruction surgery, passive- and active-assisted range of knee motion was initiated. Weight bearing was gradually increased to full at 3 weeks postoperatively. Running was allowed at 3 months, followed by a return to previous sporting activity(ies) at 6 months [9, 15, 16].

Magnetic resonance angiography

Imaging was performed with a 3.0 T magnetic resonance imager (Gyrosan Achieva; Philips Medical Systems, Best, Netherlands) with an 8-channel knee coil [6]. First, we obtained the conventional images. Then, an intravenous infusion line was established on the dorsal side of the patient's hand and the patient was placed in the supine position with the knee fully extended in the neutral position. A fat-suppressed 3D-gradient echo T1-weighted image was used to obtain contrast-enhanced MRA images. Contrast-enhanced MRA was performed after intravenous injection of Gd-DTPA (0.1 mmol/kg body weight). The imaging parameter was as follows: repetition time (T_R) = 7 msec, echo time (T_E) = 4.4 msec, flip angle (FA) = 12, field of view = 150 mm, slice thickness = 2.4 mm, gap between slices = -1.2 mm, with a 256 × 190 matrix. Contrast-enhanced MRA was performed every 27 sec. Imaging was confined to oblique and sagittal sections to align the popliteal artery. Total imaging time was 2 min and 34 sec. Maximum intensity projection images were obtained in each of the sagittal and transverse projections selected to encompass the nutrient blood from the popliteal artery to the tendon graft and bone tunnel wall. MRA was performed after approximately 3 months and 12 months after surgery.

Evaluation

All patients were evaluated before, 3, and 12 months after MPFL reconstruction. Clinical data, including the incidence of recurrent subluxation and dislocation, patellar apprehension, and the Knee Society, Lysholm, and Kujala scores were measured preoperatively

and 12 months after surgery [17]. Plain radiography of the knee, including conventional anteroposterior and lateral views, and the flexed patellar axis was performed 3 and 12 months after reconstruction. Trochlear dysplasia, according to the Dejour classification, was measured on lateral radiographs [18]. Computed tomography or magnetic resonance imaging (MRI) was utilized to measure the tibial tubercle-trochlear groove (TT-TG) distance [19]. The evaluation was performed by the knee surgery specialist.

Statistical analysis

Data are expressed as the mean \pm standard deviation. Clinical scores (Kujala score, Knee Society score, and Lysholm score) and radiographic data (tilting angle, lateral tilt ratio, and congruence angle) were analyzed using the paired *t* test. In all analyses, $p < 0.05$ was considered statistically significant. The 95 % confidence interval (CI) was used to assess the demographic characteristics. Cohen's *d* was used to estimate effect sizes.

Results

The mean time of MRA imaging in the early postoperative period was 2.7 months, and the mean 12-month postoperative timing was 13.4 months (► **Table 1**).

Patient radiographic data are shown in ► **Table 2**. The parameters about patellofemoral joint alignment improved postoperatively.

All of the clinical scores for the full study population improved from baseline to 12 months post-operatively (► **Table 3**). Cohen's *d* of tilting angle, lateral shift ratio, congruence angle, Kujala score, Knee Society score, and Lysholm score are 0.95, 0.74, 0.86, 2.57, 3.70, and 2.29, respectively.

Early postoperative MRA showed an inflow vessel from the medial superior genicular artery into the femoral bone tunnel wall (► **Fig. 1a**). Blood flow to the patellar bone tunnel wall was from the articular branch of the descending genicular artery and the medial superior genicular artery, proximally, and from the medial inferior genicular artery, distally. In addition, a contrast effect was observed around the tendon graft between the bone tunnel (► **Fig. 2a–c**, ► **Fig. 3a–c**). Approximately 1 year after surgery, the contrast effects around the tendon graft and at the bone tunnel wall were diminished (► **Fig. 1b**) In the sagittal section, the bone tunnel wall of both the femur and patella was contrasted as a ring (► **Fig. 2d–f**, ► **Fig. 3d–f**). This contrast effect was seen from the early postoperative period and tended to decrease up to 1 year after surgery. Similar results were obtained in all cases.

Two knees showed no signs of trochlear dysplasia, whereas 6 exhibited type A, one exhibited type B, 2 exhibited type C, and none exhibited type D trochlear dysplasia (► **Table 2**). Before the operation, the tilting angle, the lateral shift ratio, and the congruence angle were $25.4^\circ \pm 11.4^\circ$, $43.5 \pm 25.0\%$, and $22.5^\circ \pm 25.5^\circ$, respectively. On plain radiographs obtained 12 months post-operatively,

► **Table 1** Patients' demographic data.

Case no.	Age (years)	Sex	Laterality	Duration to 1 st MRA (months)	Duration to 2 nd MRA (months)	Follow-up (months)
1	43	Male	R	3.1	11.8	89
2	13	Female	R	3.3	14.4	95
3	45	Female	L	2.6	13.6	89
4	37	Female	L	2.2	11.7	83
5	11	Female	L	3.3	13.9	80
6	24	Female	L	2.7	14.1	73
7	23	Male	L	2.0	15.1	71
8	21	Female	L	2.0	11.6	71
9	22	Female	R	3.0	16.9	59
10	14	Female	L	2.9	13.1	59
11	37	Female	R	2.2	10.7	51
Average	26.4 \pm 12.2	–	–	2.7 \pm 0.5	13.4 \pm 1.8	74.5 \pm 14.2

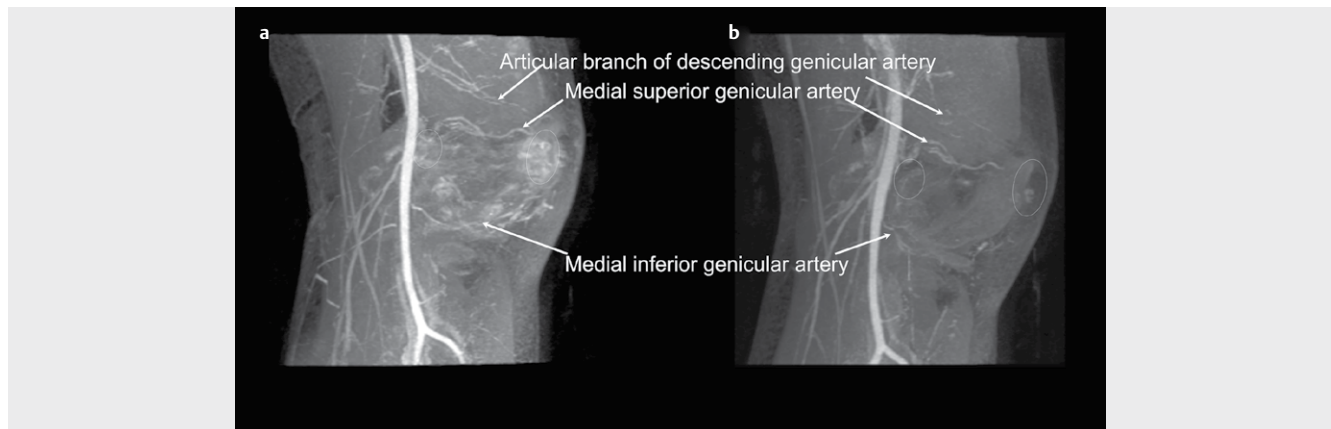
► **Table 2** Radiographic data.

	Pre-operative mean \pm SD, 95 %CI	Post-operative mean \pm SD, 95 %CI	p value, Cohen's <i>d</i>
Femorotibial angle, degrees	175.45 \pm 2.54, 173.75–177.16	–	–
Caton-Deschamps index	1.19 \pm 0.23, 1.03–1.35	–	–
Sulcus angle, degrees	148.27 \pm 9.68, 141.77–154.77	–	–
Dejour classification, number of knees, N/A/B/C/D	2/6/1/2/0	–	–
TT-TG distance, mm	13.97 \pm 4.48, 10.96–16.98	–	–
Tilting angle, degrees	25.36 \pm 11.36, 17.73–33.0,	16.82 \pm 5.60, 13.06–20.58	<0.01, 0.95
Lateral shift ratio, %	43.54 \pm 24.96, 26.78–60.31	28.35 \pm 15.21, 18.14–38.57	<0.01, 0.74
Congruence angle, degrees	22.55 \pm 25.46, 17.73–33.00	2.82 \pm 20.33, –0.84–16.48	<0.01, 0.86
The paired <i>t</i> -test was used for statistical analysis. SD, standard deviation; CI, confidence interval; TT-TG, tibial tubercle-trochlear groove.			

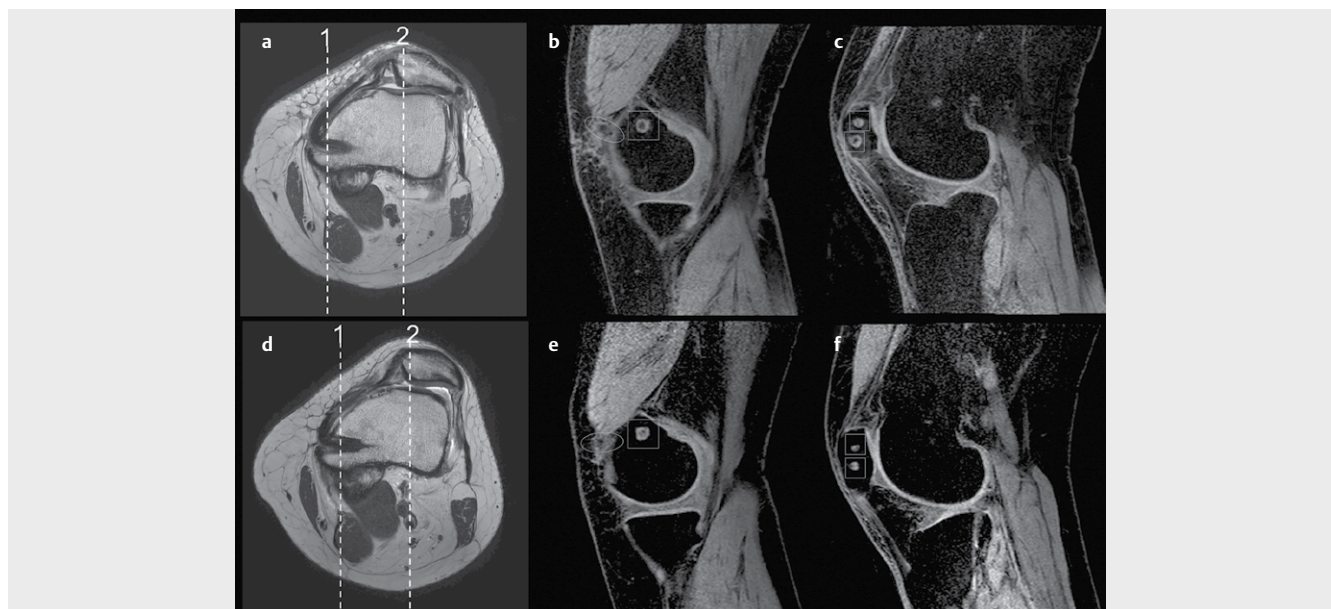
► **Table 3** Pre- and post-operative clinical scores.

	Pre-operative mean \pm SD, 95%CI	Post-operative mean \pm SD, 95%CI	p value, Cohen's d
Kujala score	61.27 \pm 20.05, 47.81–74.74	98.36 \pm 3.88, 95.76–100.97	<0.01, 2.57
Knee Society score	71.82 \pm 9.10, 65.71–77.93	96.82 \pm 2.96, 94.83–98.81	<0.01, 3.70
Lysholm score	77.09 \pm 13.19, 68.23–85.96	99.00 \pm 3.00, 96.99–101.02	<0.01, 2.29

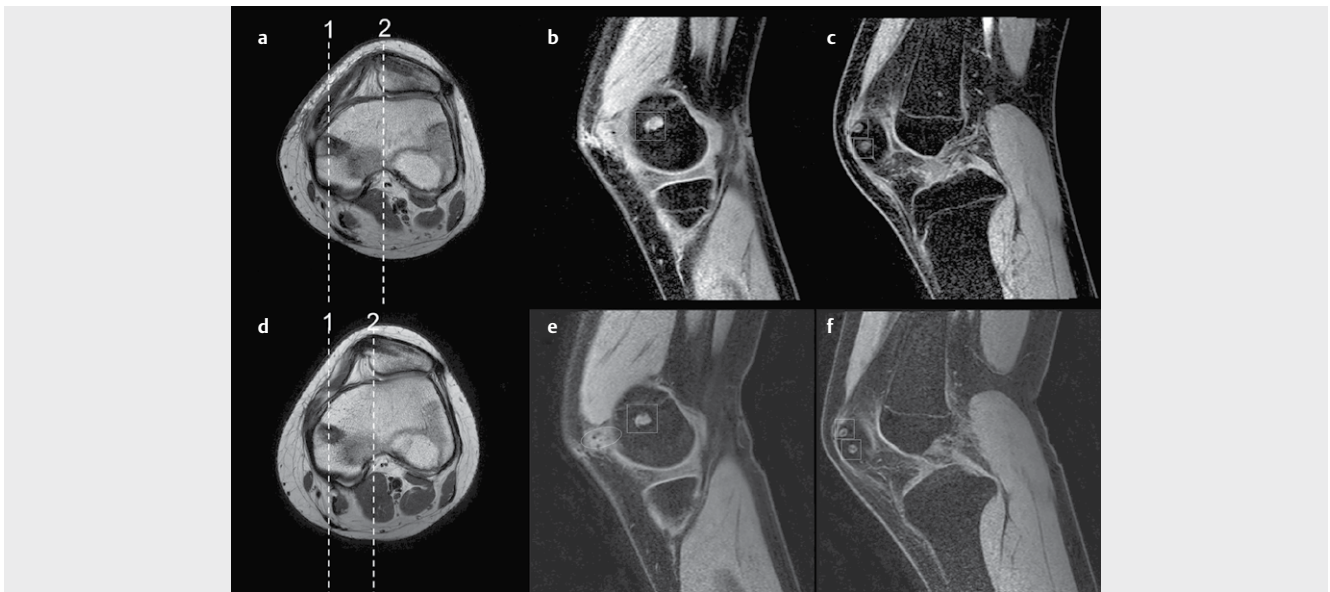
The paired t-test was used for statistical analysis. SD, standard deviation; CI, confidence interval.



► **Fig. 1** (a) An oblique, sagittal magnetic resonance angiography image of the knee taken 2 months after left medial patellofemoral ligament reconstruction. The articular branch of the descending artery and the medial superior genicular artery extended to the proximal patellar bone tunnel in all patients and the medial inferior genicular artery extended to the distal patellar bone tunnel. The medial superior genicular artery also extended to the femoral bone tunnel.; (b) The same slice as in ► **Fig. 1a**, 12 months after MPFL reconstruction is shown.; All of the contrast effects seen at 2 months postoperatively were attenuated.; Dotted line circle: patellar bone tunnels; Solid line circle: femoral bone tunnel



► **Fig. 2** Magnetic resonance imaging of case No. 4; **a–c** 2 months after left MPFL reconstruction.; **d–f** 12 months after left MPFL reconstruction.; **a, d** Axial image of the left knee.; **b, e** Sagittal section of line 1 shows the femoral bone tunnel (square) and the tendon graft (circle).; **c, f** Sagittal section of line 2 shows the patellar bone tunnels (square).



► **Fig. 3** Magnetic resonance imaging of case No.10; **a–c** 3 months after left MPFL reconstruction.; **d–f** 12 months after left MPFL reconstruction.; **a, d** Axial image of the left knee; **b, e** Sagittal section of line 1 shows the femoral bone tunnel (square) and the tendon graft (circle).; **c, f** Sagittal section of line 2 shows the patellar bone tunnels (square).

the tilting angle, the lateral shift ratio, and the congruence angle were $16.8^\circ \pm 5.6^\circ$, $28.4 \pm 15.2\%$, and $2.8^\circ \pm 20.3^\circ$, respectively. The tilting and congruence angles and the lateral shift ratio at 12 months post-operatively significantly increased relative to pre-operatively ($p = 0.01$, $p < 0.01$, $p < 0.01$, respectively).

None of these patients showed recurrence of subluxation or dislocation of the patella. They all returned to their original sports level. The average preoperative Tegner activity score [20] was 3.0 ± 1.5 points.

Discussion

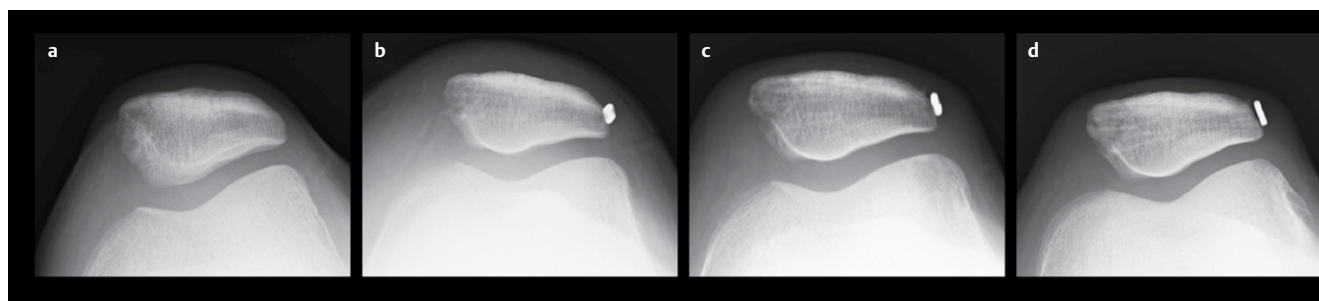
The aim of this study was to evaluate blood flow after MPFL reconstruction applying the technique of MRA. The main findings of this study demonstrate that an inflow vessel from the medial superior genicular artery into the femoral bone tunnel wall and blood flow to the patellar bone tunnel wall was from the articular branch of the descending genicular artery and the medial superior genicular artery, proximally, and from the medial inferior genicular artery, distally. Moreover, contrast effects of bone tunnel walls were seen from the early postoperative period and tended to decrease up to 1 year after surgery.

One of the representative surgeries to place the graft in the bone tunnel is ACL reconstruction using the hamstring tendon. Remodeling of the graft and strong union of the bone-tendon junction are important factors that determine the outcome after ACL reconstruction [21, 22]. It has been reported that the tendon graft undergoes the processes of necrosis, angiogenesis, cell proliferation, and collagen remodeling that histologically approximate the normal ACL [23]. However, the histological changes of the transplanted tendon after MPFL reconstruction remain unknown. On the other hand, the hemodynamics of the surrounding bone tunnel wall and the graft after ACL reconstruction have been analyzed

using MRA; Arai et al. [6, 7] successfully visualized the hemodynamics after ACL reconstruction using MRA, and Kanamura et al. [8] subsequently reported the changes over time. In this study, a similar technique was used after MPFL reconstruction. As a result, contrast effects of the medial superior genicular artery on the femoral bone tunnel and the articular branch of the descending genicular artery and medial superior genicular artery on the proximal patellar bone tunnel were confirmed. In the distal patellar bone tunnel, a contrast effect from the medial inferior genicular artery was observed. The current findings showed that MRA after MPFL reconstruction exhibited a contrast effect around the graft and that blood flow to the bone tunnel wall was observed at about 3 months after surgery. In this study, blood flow to the bone tunnel wall was restored after MPFL reconstruction as well as after ACL reconstruction, suggesting that the biological union between the bone tunnel wall and the graft had progressed.

Also, at 12 months postoperatively, these blood flows were reduced but still visible, suggesting that remodeling is ongoing. Fujii et al. studied the changes in PF joint conformity over time and reported that it changes up to 3 months postoperatively, but stabilizes thereafter [9]. Based on the above, we concluded that this study demonstrated that ligamentization of the graft progressed even if the conformity of the PF joint did not change (► **Fig. 4**).

The rehabilitation protocol after MPFL reconstruction varies in the literature, and systematic reviews show that most patients return to sports 3 to 6 months after surgery [16]. Similarly, our postoperative protocol is to start athletic rehabilitation from 2 to 3 months after surgery and to return to sports at 6 months after surgery. Based upon the findings of this study, we believe that the postoperative period should be limited to linear athletic rehabilitation, avoiding rotational movements that place a heavy load on the graft, as is the case after ACL reconstruction.



► **Fig. 4** Chronological radiographic changes of the patellar axis after MPFL reconstruction; The tilting and congruence angles improved immediately after the operation (b) compared with before the operation (a). The tilting and congruence angles 3 months after the operation (c) were decreased relative to those recorded immediately after the operation (b). The tilting and congruence angles were not different 3 months and one year after the operation (d).

In addition, a contrast effect was seen around the graft between the bone tunnels approximate 3 months after surgery, indicating that the graft was covered with tissue with good blood flow outside the bone tunnel. In ACL reconstruction, the central portion of the graft is located intra-articularly and has no surrounding soft tissue to contact. Thus, the only way to restore blood flow to the central portion of the transplanted tendon is through the tendon-bone junction on the femoral or tibial side. In contrast, the MPFL is located outside the joint cavity, and the central portion of the graft in MPFL reconstruction is surrounded by soft tissue. Therefore, we considered that a good contrast effect around the graft tendon was achieved. The direct influx of blood flow from the soft tissues around the graft may have facilitated remodeling of the graft between the bone tunnels.

The results of the present study indicate that hemodynamics of the graft may change up to 3 months post-operatively. In post-MPFL reconstruction rehabilitation programs, it is important to avoid knee rotation, such as turns and side steps, to prevent excessive lateral stress on the patella up to 3 months postoperatively.

There are several limitations to this study. Firstly, the sample size was too small to evaluate statistically and the gender ratio is also not uniform. Furthermore, the evaluations were qualitative, and the signal values could not be evaluated quantitatively. Finally, we evaluated the subjects only during the early stage (approximate 3 months postoperatively) and 12 months postoperatively, and the changes during these periods are unknown.

In conclusion, we evaluated blood flow to the graft after MPFL reconstruction and demonstrated that MRA can be used to detect blood flow and that contrast effects can be obtained in the bone tunnel wall and around the graft at approximate 3 months postoperatively. We further found that these contrast effects decrease at 12 months postoperatively. The results of this study may be useful in elucidating the reconstruction and maturation process of the graft after MPFL reconstruction.

Conflict of Interest

The authors declare that they have no conflict of interest.

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