Concomitant posterior anchoring further reduces posterior meniscal extrusion during pullout repair of medial meniscus posterior root tears: a retrospective study

Abstract

Purpose: Transtibial pullout repair improves the clinical outcomes of medial meniscus (MM) posterior root tears (PRTs); however, reducing MM extrusion remains challenging. Thus, the purpose of this study was to examine the role of additional posterior anchoring (PA) during pullout repair in reducing the severity of MM extrusion compared to pullout repair alone.

Methods: Patients who underwent pullout repair with two-cinch stitches (TCS) only or TCS combined with PA (TCS-PA)—deployment of an additional suture anchor in the posteromedial corner of MM—were included retrospectively. MM medial and posterior extrusion (MMME and MMPE), MM extrusion and remaining volume (MMEV and MMRV), and corresponding ratios were evaluated preoperatively and 3 months postoperatively using a three-dimensional meniscal model at 10° and 90° of knee flexion and compared within and between groups.

Results: A total of 15 and 16 patients treated with TCS and TCS-PA, respectively, were enrolled. At 90° knee flexion, both techniques significantly reduced MMPE (TCS: 4.2 ± 0.7 mm to 3.5 ± 0.6 mm, $p < 0.05$; TCS-PA: 3.7 ± 0.8 mm to 2.8 ± 0.7 mm, $p < 0.05$) at 3 months postoperatively. TCS-PA reduced MMPE more significantly than TCS alone ($p < 0.05$). Only TCS-PA significantly improved the MMEV and MMRV ratios (39.6 ± 8.9% to 28.1 ± 6.0%, $p < 0.05$ and 60.4 ± 8.9% to 71.9 ± 6.0%, $p < 0.05$, respectively). Significance was not found in all other comparisons.

Conclusions: Both techniques improved MMPE at knee flexion at the 3-month follow up, with TCS-PA providing significantly superior results. Our findings support the evidence that the application of PA may be an effective surgical option for alleviating persistent MMPE.

Keywords: medial meniscus, pullout repair, meniscal extrusion, meniscal root tear, suture anchor, three-dimensional magnetic resonance imaging

INTRODUCTION

There is growing recognition that the posterior root of the medial meniscus (MM) is crucial to stabilize the joint along with the MM [1, 2]. MM posterior root tears (MMPRTs) frequently result in MM extrusion (MME) [3, 4], and disruption of the femorotibial contact mechanism [5]. This impedes the MM from converting axial pressure into hoop stress, leading to functional failure of the meniscus and, ultimately, the development of osteoarthritis [6, 7].

Among the many techniques used in arthroscopic treatment of MMPRTs, transtibial pullout repair has achieved superior survival rates, restoration of normal knee rotation [8], and significantly improved short- to mid-term clinical outcomes [9]. Thus, transtibial pullout repair is considered the principal surgical technique for MMPRT treatment [10, 11]. However, Kaplan et al., demonstrated that although clinical improvement after MMPRT repair was favourable and sustained, MME persisted in the majority of cases [12, 13].

Reduction in postoperative MME is a prerequisite for favourable clinical outcomes. Studies assessing the correlation between MME and clinical outcomes have shown that preventing postoperative MME leads to superior clinical outcomes [14]. However, Asians, a population with a high incidence of MMPRT, have a lifestyle of deep squatting or sitting on the floor, leading to a greater extent of MM posterior extrusion (MMPE) [15]. In a study on the correlation between MMPE and postoperative clinical outcomes, a reduction in MMPE was associated with improved clinical outcomes when the knee was flexed at 90° [16].

Multiple additional techniques, such as pullout sutures [17] or bone tunnelling at the posteromedial corner [18], and a combination with MM centralization [19], have been proposed to be used in conjunction with pullout repair; however, a consensus on the optimum approach to reduce MMPE has not been reached. Recently introduced is a novel configuration that combines additional posterior anchoring (PA) with pullout sutures for a substantial reduction in MMPE [20]. Benefitting from the additional PA, the intraoperatively measured translation of the pullout suture—a proxy for MMPE—was significantly suppressed during knee flexion. However, there remains no direct evaluation of whether the combination of pullout sutures and PA significantly improves MMPE.

Thus, the objective of this study was to examine whether additional PA to the posteromedial corner of the meniscus-tibia complex during transtibial pullout repair of an MMPRT could significantly reduce motion-related MMPE compared to transtibial pullout repair alone. We hypothesized that supplementing the surgery with PA would significantly reduce MMPE at 90° of knee flexion.

MATERIALS AND METHODS

Study participants

Approval from the appropriate institutional review boards was obtained and the study was conducted in line with the ethical standards of the 1964 Declaration of Helsinki and its later amendments. After a detailed explanation of all procedures, written consent was obtained. Thirty-four patients (10 men, 24 women; mean age: 65.8 ± 7.1 years) who had undergone surgical repair of MMPRTs at our institution were evaluated retrospectively. From May 2020 to October 2021, 15 patients were treated with the two-cinch stitches (TCS) technique, and from January to November 2021, 19 patients were treated with the TCS plus PA (TCS-PA). Included patients were required to have characteristic findings of MMPRTs on initial magnetic resonance imaging (MRI) (cleft/ghost/radial tear and giraffe neck signs adjacent to the MM posterior root insertion [21, 22]). Patients with radiographic osteoarthritis of Kellgren-Lawrence grade III or IV and/or historic meniscal injury were excluded. The classification of MMPRTs was determined by arthroscopy as follows: type 1 and 2 tears are partial and complete radial tears within 9 mm of the root insertion, respectively; type 3 tears are bucket-handle tears; type 4 tears are complex oblique meniscal tears that extend to the root insertion; and type 5 tears are avulsion fractures of the meniscal root attachment [23].

Surgical protocol

Treatment of MMPRTs was performed arthroscopically by a well-experienced surgeon. After creating anterolateral and anteromedial portals, routine diagnostic arthroscopy was performed. In patients with a tight medial compartment, a pie-crusting procedure was conducted [24].

Pullout repair of the TCS was conducted by vertically penetrating the inner and outer portion of the posterior horn of MM with two No. 2 Ultrabraid sutures (Smith & Nephew, London, UK) at 10 and 5 mm from the torn area, respectively, using a Knee Scorpion suture passer (Arthrex Inc., Naples, FL, USA) [25]. Subsequently, by placing a custom posterior root aiming guide (MMPRT Guide, Smith & Nephew) at the anatomic footprint of the MM posterior root, a 4.0-mm transtibial tunnel was established [26] (Fig. 1a).

After retrieving the cinch sutures through the transtibial tunnel, an additional PA technique was performed by applying the JuggerStitch™ meniscal repair device (Zimmer Biomet, Warsaw, IN, USA) through the standard anteromedial portal [20]. In the position of knee flexion and external rotation, an additional transosseous tunnel was established medially 15 mm from the anatomical footprint of the MM posterior root, with 1.8mm Q-FIX Flexible Drill (Smith & Nephew), penetrating the posterior tibial cortex inferiorly in the posteromedial direction. With the knee in flexion, the first anchor was advanced through the additional transosseous tunnel (Fig. 1b). Subsequently, with the knee in extension, the second anchor advanced horizontally in the posteromedial direction from the bottom of the posterior meniscal horn and traversed outside the joint capsule (Fig. 1c). Finally, the suture loop holding the two anchors was tightened to firmly deploy anchors on the medial surface of the MM and the posterior horn was secured to the tibial plateau (Fig. 1d). Pullout sutures were fixed to the tibial cortex with a bioabsorbable screw under 30° of knee flexion and 10 N tension [27]. The operation time for the pullout repair alone and combined with the PA procedure was recorded.

Rehabilitation protocol

A uniform postoperative rehabilitation protocol was applied to all patients. First, the knee was kept off weight with a knee immobiliser during the first 2 weeks after surgery. Then, flexion was limited to 90° for the first 4 weeks. After 6 weeks, full weight-bearing and 120° knee flexion were allowed. Finally, deep knee flexion was allowed 3 months postoperatively [28].

MRI examination and three-dimensional meniscus reconstruction

Patients received preoperative and 3-month postoperative open MRI scans (multiplanar images with a continuous slice thickness of 1 mm) on an Oasis 1.2T instrument (Hitachi Medical, Chiba, Japan), without weight bearing, while the knee was in 10° and 90° of flexion. On both the sagittal and coronal planes, a proton density-weighted isotropic resolution fast spin-echo (iso FSE, Hitachi Medical) sequence was applied with the following settings: repetition time/echo time, 600/96 ms; matrix, 224 × 224; field of view, 18 cm; 1 average; echo-train length, 24; bandwidth, ± 98.1 kHz; and scanning time, 4.8 min. The three-dimensional (3D) joint model was constructed semi-automatically with voxel density thresholds for surface identification using the image processing workstation, SYNAPSE

VINCENT® (Fuji Medical System, Tokyo, Japan). Segmentation of the MM was manually conducted by a radiologist and two orthopaedic surgeons using texture-tracking techniques. Following the segmentation procedure, a 3D reconstruction of the meniscus was obtained using volume rendering, as shown previously [29].

Measurement methods

Measurements of the 3D meniscal models were taken from the axial position [30]. After the boundary of the tibia was identified, the portion of the MM lying outside this boundary was defined as the MME area. The measurements of MMPE and MM medial extrusion (MMME) were characterised by measuring the length from the posterior and medial boundary of the tibia (excluding osteophytes) to the most distal point of the medially and posteriorly extruded MM, respectively (Fig. 2). The MM volume (MMV) was determined by the sum of the volumes of all the voxels located inside the boundary of the meniscus. The MM extrusion volume (MMEV) and MM remaining volume (MMRV) were calculated as the sum of all voxel volumes in the extruded and intra-articular portions of the meniscus, respectively. In addition, to adjust for individual differences, the ratios of MMEV (MMEV/MMV) and MMRV (MMRV/MMV) were calculated.

The above parameters were independently evaluated by two orthopaedic surgeons on preoperative and 3-month postoperative 3D MRI images. Radiographs and normal MRI images were also scrutinized to corroborate and complement 3D MRI findings (Fig. 3 and 4) [12]. The intraclass correlation coefficient (ICC) was applied to evaluate inter-observer reliability. Each observer measured the 3D meniscal models repeatedly at 4-week intervals to determine intra-observer reliability.

Statistical evaluation

Statistical evaluations were conducted using SPSS Statistics (Ver. 24.0, IBM Corp., Armonk, NY, USA). Measurements were presented as mean ± standard deviation (SD). *P* values < 0.05 were considered statistically significant. The Mann-Whitney U test was applied for comparison of 3D MRI characteristics between the two groups at 10° and 90º, respectively. The Wilcoxon signed-rank test was applied for comparison of the preoperative and postoperative 3D MRI characteristics within each group. A minimum statistical power of 0.8 and an α value of 0.05 were set to calculate the sample size. To obtain the significance of differences between pre- and postoperative MMPE for each technique and between postoperative MMPE for both techniques, the required sample size ($n_{TCS} = n_{TCS\text{-}PA}$) was at least 15 for each technique.

RESULTS

The patient demographics are presented in Table 1. Three patients were excluded owing to the unavailability of postoperative MRI images, and 15 patients that underwent TCS and 16 that underwent TCS-PA repair were finally included. Based on arthroscopic examination, one case was identified as type 1 MMPRT, and all remaining cases were type 2 MMPRT [23]. The operation time required for patients undergoing pullout repair and PA procedure was not significantly different from that of transtibial pullout repair alone (TCS, 38.1 ± 7.6 minutes; TCS-PA, 43.2 ± 5.6 minutes; p > 0.05). There were no significant differences between the TCS and TCS-PA groups in the remaining parameters.

Postoperative changes in 3D MRI measurements

10° knee flexion

When comparing pre- and postoperative measurements, no significant differences were observed in any of the parameters in neither the TCS (Fig. 5a, b) nor TCS-PA (Fig. 5e, f) group.

When comparing the postoperative measurements of the TCS-PA group with those of the TCS group, the differences were not statistically significant for any of the parameters (Table 2).

90° knee flexion

Both techniques significantly reduced the postoperative MMPE ($p < 0.05$), although the difference in postoperative MMME was not significant (Fig. 4, 5). Regarding volumetric measurements, both techniques led to a non-significant decrease in the MMEV and a non-significant increase in the intra-articular MMRV. However, in patients who underwent the TCS-PA technique, we observed significant reductions in the MMEV ratio ($p < 0.05$) and a significant increase in the intra-articular MMRV ratio ($p < 0.05$) (Table 3).

A comparison of postoperative measurements between the TCS and TCS-PA groups revealed that the addition of a PA procedure more significantly reduced MMPE than the TCS technique alone, and the difference between preoperative and postoperative MMPE values (ΔMMPE) was significantly more pronounced in the TCS-PA group ($p < 0.05$) (Table 3).

Reliability analysis

The ICCs for inter-observer reliability of MMPE and MMME were 0.90 (95% confidence interval [CI]: 0.82–0.98) and 0.92 (95% CI: 0.84–0.96), respectively. The ICCs for inter-observer reliability of MME and MMEV were 0.93 (95% CI: 0.86–0.97) and 0.92 (95% CI: 0.85–0.95), respectively.

The ICCs for intra-observer reliability of MMPE and MMME were 0.95 (95% CI: 0.88–0.98) and 0.92 (95% CI: 0.85–0.96), respectively. The ICCs for intra-observer reliability of MME and MMEV were 0.93 (95% CI: 0.87–0.97) and 0.94 (95% CI: 0.89–0.97), respectively.

DISCUSSION

The most important finding of the present research is that the TCS technique for MMPRTs significantly reduced the MMPE in postoperative knee flexion at 90°. However, the addition of PA further reduced the MMPE, compared to the transtibial pullout repair technique alone. The findings confirmed our hypothesis that PA in conjunction with the pullout repair technique significantly reduces the risk of MMPE at 90° of knee flexion after MMPRT repair.

Restricting the extent of postoperative MMPE facilitates the restoration of the joint contact mechanism and is associated with favourable clinical outcomes [29], although the occurrence of MMPRT is often related to mild-to-moderate knee flexion [31]. Kodama et al. demonstrated that reducing MMPE in the flexed position significantly improved MM translation during knee motion, and the improvement in MM motion was associated with the inhibition of cartilage degeneration of the mid-to-posterior section of medial femoral condyle [32]. Their study performed a FasT-Fix-dependent modified Mason–Allen suture (F-MMA). There was a significant decrease in MMPE at 3 months postoperatively than preoperatively (from 4.60 to 3.21 mm). This finding is consistent with our study. However, the progression in MMPE at 12 months postoperatively (3.49 mm) may suggest that a simple pullout repair is insufficient in restricting MMPE at a longer follow-up. Regarding the PA procedure, it was previously described that perioperative suture translation (a surrogate for MME) would be significantly reduced by anchoring at the appropriate location in the direction of MM extrusion during pullout repair of the

MMPRTs. Okazaki et al. observed that perioperative suture translation was significantly lower in the group undergoing concomitant PA procedure than in the pullout repair group alone (TCS-PA, 1.6 mm; TCS, 2.5 mm; $p < 0.05$), with results similar to those presented here [20].

In the present study, only TCS-PA significantly improved MMEV and MMRV ratios, but failed to significantly improve MMEV or MMRV. One possible explanation is that the restriction on MM radial translation was impaired by MMPRT and the extruded MM underwent degenerative changes such as swelling or bulging [33]. The MMEV/MMRV ratios was designed to eliminate individual differences. Therefore, although the reduced MMEV got offset by degenerative changes, the increase in the MMRV ratio will be beneficial for the restoration of meniscal function and for better clinical outcomes.

Treatment of MMPRTs with pullout sutures has previously shown to improve MME and kinematics [29, 32, 34], however, suture displacement after cyclic loading [35] and prolongation during knee flexion from 0° to 90° [20] remains unavoidable and challenging for the outcome of MMPRTs repairs. A finite element analysis of patients who underwent pullout repair revealed that the postoperative MMPE and tibial contact area in the extended position (e.g., standing, walking) were not significantly different from the tear state during suture loosening [36]. Therefore, as pullout sutures inevitably suffer displacement and loosening, we believe that further establishment of transosseous tunnels, such as PA, would secure the stability of the suture-meniscal complex. By cautiously evaluating the 3-month 3D MRI results, this study was intended to obtain preliminary evidence that the PA technique facilitates the restoration of meniscal root continuity and correction of extrusion before providing further rehabilitation counselling to patients.

The combination of PA with pullout repair was intended to further establish the meniscus-tibial connection, rather than simply reconstruct the root continuity. A study investigating the chronology of

MMPRTs reported that the meniscotibial ligament loses its function before the occurrence of MMPRTs, making the posterior root vulnerable to loss of support during knee motion [37]. Koga et al. proposed combining the MM centralization technique with pullout repair to reduce postoperative MME, enhancing the stability of the repaired tissue [19]. They seek to optimize the position of the MM postoperatively by placing several all-suture knotless anchors at the posterior border of the medial collateral ligament (MCL), which is the most extruded spot. Unlike the centralization technique, PA involves a shorter transosseous tunnel that mitigates suture micromotion during rehabilitation. In addition, owing to the reduced number of suture anchors, no additional portals are required, making PA technically simpler and more cost-effective. Although additional drilling of the transosseous tunnel might be criticized for increasing the operative complexity, this procedure is thought to augment bone marrow migration and promote root tissue healing [38].

This study has several limitations. First, this study retrospectively evaluated the outcomes of the two techniques in a non-randomized manner and with unequal numbers of cases. Second, the 3-month follow-up period was insufficient for the assessment of clinical outcomes; however, a significant reduction in MMPE was observed. Kaplan et al. indicated that MRI at 4–8 months before questionnaire follow-up would provide the earliest evidence of healing and extrusion correction of repaired meniscal roots and recommended early MRI for the above evidence [12]. Third, only the extrusion and translation states of the two techniques in the MM non-weight-bearing condition were measured in this study. Further studies with prospective designs, larger sample sizes, conducted under weight-bearing conditions, and with long-term follow-up comparing the clinical outcomes between two techniques should be performed to corroborate current findings.

Conclusion

The TCS technique was instrumental in reducing MMPE in the knee-flexion position after MMPRT treatment. Moreover, application of PA further improved the reduction in MMPE. Our findings suggest that PA might be a potential option for reducing persistent MMPE when postoperative extrusion of the repaired MMPRT needs to be reduced in a practical way.

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Figure captions

Fig. 1 Medial meniscus posterior root tear repaired with the two-cinch stitch (TCS) technique (**a**), TCS combined with posterior anchoring (TCS-PA) technique (**b** and **c**), and a schematic diagram of TCS-PA (**d**). The red and blue arrowheads indicate the outer and inner stitches of the TCS, respectively. The yellow arrow shows the first stitch of the meniscal suture anchor, and the green arrow shows the second stitch of the meniscal suture anchor. PCL, posterior cruciate ligament; MFC, medial femoral condyle; MTP, medial tibial plateau

Fig. 2 Three-dimensional medial meniscus (MM) model and measurements of MM medial extrusion (MMME) and MM posterior extrusion (MMPE) at 10° (**a**) and 90° knee (**b**) flexion. The cyan area indicates the intra-tibial plateau portion; the purple area indicates the extruded portion of the MM. A horizontal reference line (red line) crossing the inter-condylar eminence of the tibia is created. The length between the medial edge of the tibia (blue dashed line) and the medial-most extrusion point of the MM (blue line) represents the MMME (blue arrow). The length between the posterior edge of the tibia (green dashed line) and the posterior-most extrusion point of the MM (green line) represents the MMPE (green arrow)

Fig. 3 Radiographs of the right knee of a 63-year-old woman in the two-cinch-stitch with concomitant posterior anchoring (PA) group

(a) Rosenberg view radiographs showing preoperative (left) KL grade 2, and 3-month postoperatively (right) without progression in KL grade and joint space width. **b**, Three-dimensional computed tomography (CT) showing the superior view of the tibial plateau. Red and yellow arrows, the upper and lower portions of the PA transosseous tunnel, respectively. Blue and green lines, the coronal (**c**) and sagittal (**d**) sections passing the PA tunnel, respectively. **c**, Coronal image showing the PA tunnel (red arrow). **d**, Sagittal image showing the PA tunnel (red arrow).

KL grade, Kellgren and Lawrence grade; LFC, lateral femoral condyle; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau

Fig. 4 Preoperative and 3-month postoperative changes in medial meniscus posterior extrusion (MMPE) in representative cases of the two-cinch-stitch (TCS) group (**a**, **b**) and the TCS with concomitant posterior anchoring (TCS-PA) (**c**, **d**) group at 90° of knee flexion

(a) Preoperative image showing an MMPE of 3.9 mm in the patient who underwent TCS. **(b)** Three-month postoperative image showing a decrease in MMPE (3.4 mm) compared to preoperative. **c**, Preoperative image showing an MMPE of 4.2 mm in the patient who underwent TCS-PA. **d**, Three-month postoperative image showing a decrease in MMPE (2.2 mm) compared to preoperative. The solid line indicates posterior border of the tibial plateau, while the broken line for the posterior border of the medial meniscus.

Fig. 5 Preoperative and 3-month postoperative changes in extrusion of the medial meniscus (MM) in representative cases of the two-cinch stitches (TCS) group (**a** to **d**) and the TCS with concomitant posterior anchoring (TCS-PA) (**e** to **h**) groups at 10° and 90° of knee flexion. No significant decrease of MM extrusion (MME: purple area) was observed 3 months postoperatively in the TSC case at 10° (**a**, **b**) and 90° (**c**, **d**) knee flexion compared to the preoperative period, respectively. No significant decrease of the MME area was observed 3 months postoperatively in the TCS-PA case at 10° knee flexion compared to the preoperative period (**e**, **f**). A significant decrease in the MME area was observed 3 months postoperatively in the TCS-PA case at 90° knee flexion compared to the preoperative period (**g**, **h**). Red dots indicate the centre of the transtibial tunnel for the retrieval of the TCS sutures. Yellow dots indicate the centre of the transosseous tunnel for the insertion of the PA stitch.

Table 1 Patient demographics

	TCS	TCS-PA	*p*
Number of cases	15	16	
Gender, male/female	5/10	5/11	n.s.
Age, years	65.6±8.3	66.4±6.2	n.s.
Height, m	1.6±0.1	1.5±0.1	n.s.
Body weight, kg	64.6±10.7	65.2±14.3	n.s.
Body mass index, kg/m^2	25.8±3.8	28.4±5.1	n.s.
Preoperative KL grade (0/1/2)	0/3/12	0/5/11	n.s.
Duration from injury to surgery, days	59.3±43.5	58.3±35.9	n.s.
Root tear classification (type 1/2/3/4/5)	1/14/0/0/0	0/16/0/0/0	

Values are presented in mean ± standard deviation; n.s. not statistically significant; Significance between groups was determined with use of the Mann–Whitney U test. $p < 0.05$; TCS, two-cinch stitches; TCS-PA, TCS combined with posterior anchoring; KL grade, Kellgren and Lawrence grade

Table 2 Postoperative changes in 3D MRI measurements at knee flexion angle of 10°

	Preoperative			Postoperative 3-month		
	TCS	TCS-PA	*p*	TCS	TCS-PA	*p*
MMME (mm)	3.5±0.9	3.4±0.8	n.s.	3.3±0.7	3.2±0.8	n.s.
MMPE (mm)	-2.4±1.3	-2.3±1.1	n.s.	-2.6±1.0	-2.5±0.8	n.s.
MMV (cm^3)	3.0±0.5	3.0±0.6	n.s.	3.2±0.5	3.1±0.6	n.s.
MMEV (cm^3)	0.9±0.4	1.0±0.3	n.s.	0.9±0.4	0.9±0.3	n.s.
MMEV ratio (%)	29.5±10.0	33.4±9.2	n.s.	28.7±11.7	30.1±8.0	n.s.
MMRV (cm^3)	2.1±0.4	2.0±0.5	n.s.	2.3±0.5	2.2±0.4	n.s.
MMRV ratio (%)	70.5±10.0	66.6±9.2	n.s.	71.3±11.7	70.9±8.0	n.s.

Values are presented in mean ± standard deviation; n.s. not statistically significant; *Significance between measurements before and after operation was determined with use of the Wilcoxon signed-rank. $p < 0.05$; Significance between groups was determined with use of the Mann–Whitney U test. $p < 0.05$; TCS, two-cinch stitches; TCS-PA, TCS combined with posterior anchoring

Table 3 Postoperative changes in 3D MRI measurements at knee flexion angle of 90°

	Preoperative			Postoperative 3-month		
	TCS	TCS-PA	*p*	TCS	TCS-PA	*p*
MMME (mm)	2.8±0.8	2.9±0.7	n.s.	2.6±0.8	2.4±0.5	n.s.
MMPE (mm)	4.2±0.7	3.7±0.8	n.s.	3.5±0.6*	2.8±0.7*	*p*<0.001
ΔMMPE (mm)				-0.5±0.4	-0.9±0.5	*p*<0.001
MMV (cm^3)	3.0±0.5	3.0±0.5	n.s.	3.1±0.5	3.2±0.6	n.s.
MMEV (cm^3)	1.1±0.5	1.2±0.3	n.s.	0.9±0.3	0.9±0.2	n.s.
MMEV ratio (%)	36.7±11.4	39.6±8.9	n.s.	30.2±8.4	28.1±6.0*	n.s.
MMRV (cm^3)	1.9±0.5	1.8±0.5	n.s.	2.2±0.4	2.3±0.4	n.s.
MMRV ratio (%)	63.3±11.4	60.4±8.9	n.s.	69.8±8.4	71.9±6.0*	n.s.

Values are presented as mean ± standard deviation; n.s. not statistically significant; *Significance between measurements before and after operation was determined with use of the Wilcoxon signed-rank. $p < 0.05$; Significance between groups was determined with use of the Mann–Whitney U test. $p < 0.05$; TCS, two-cinch stitches; TCS-PA, TCS combined with posterior anchoring

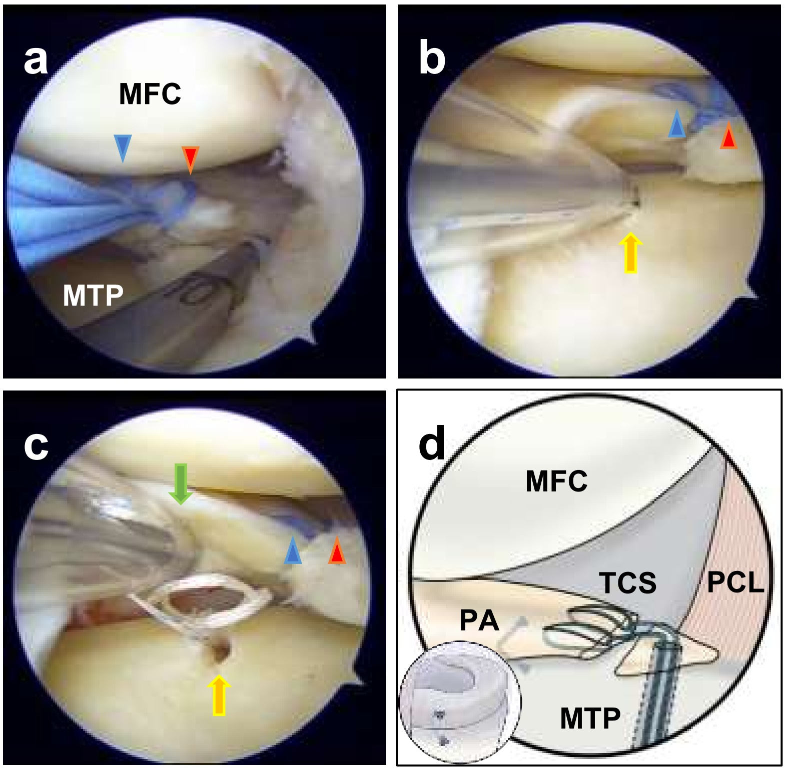

Figure 1

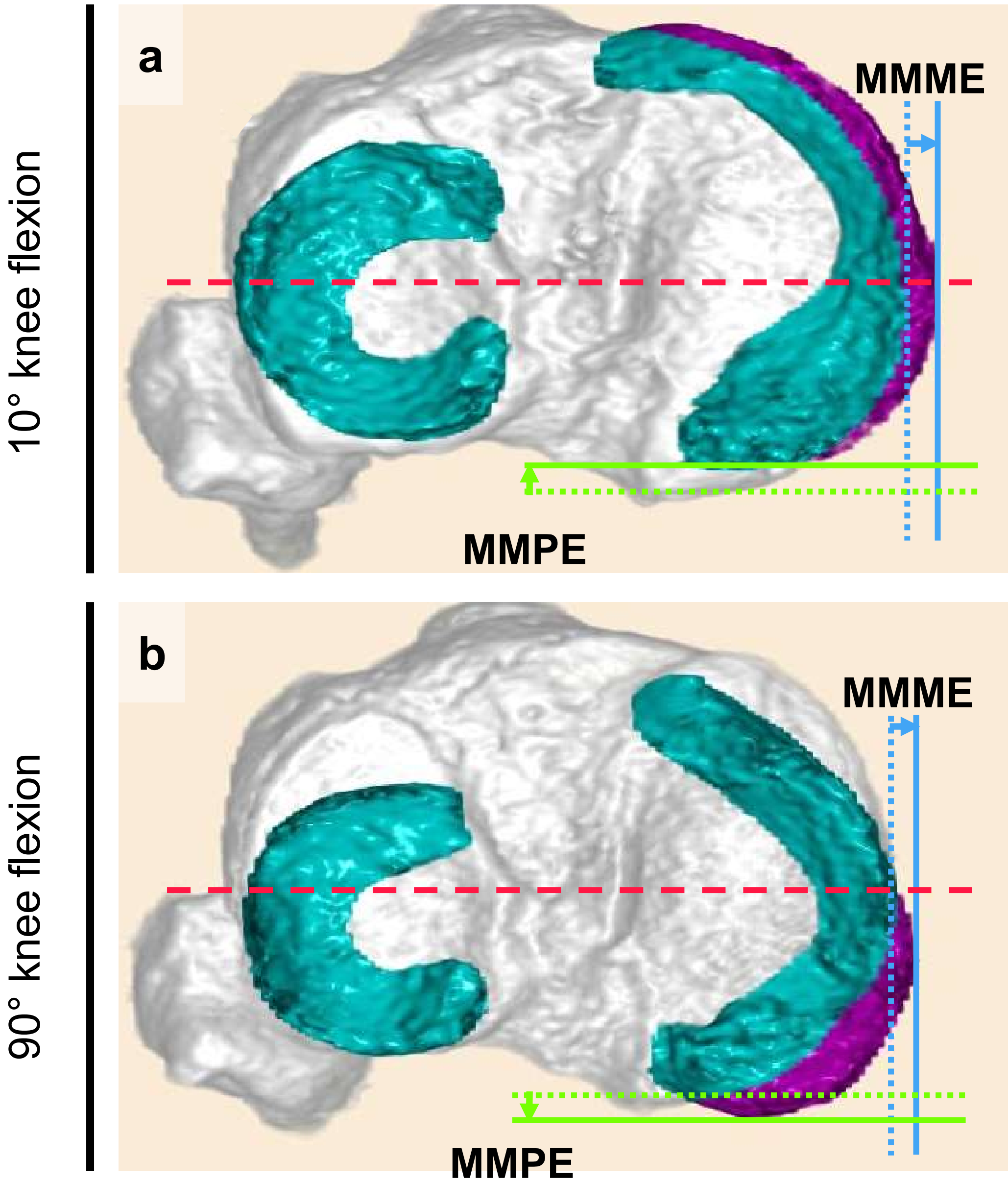

Figure 2

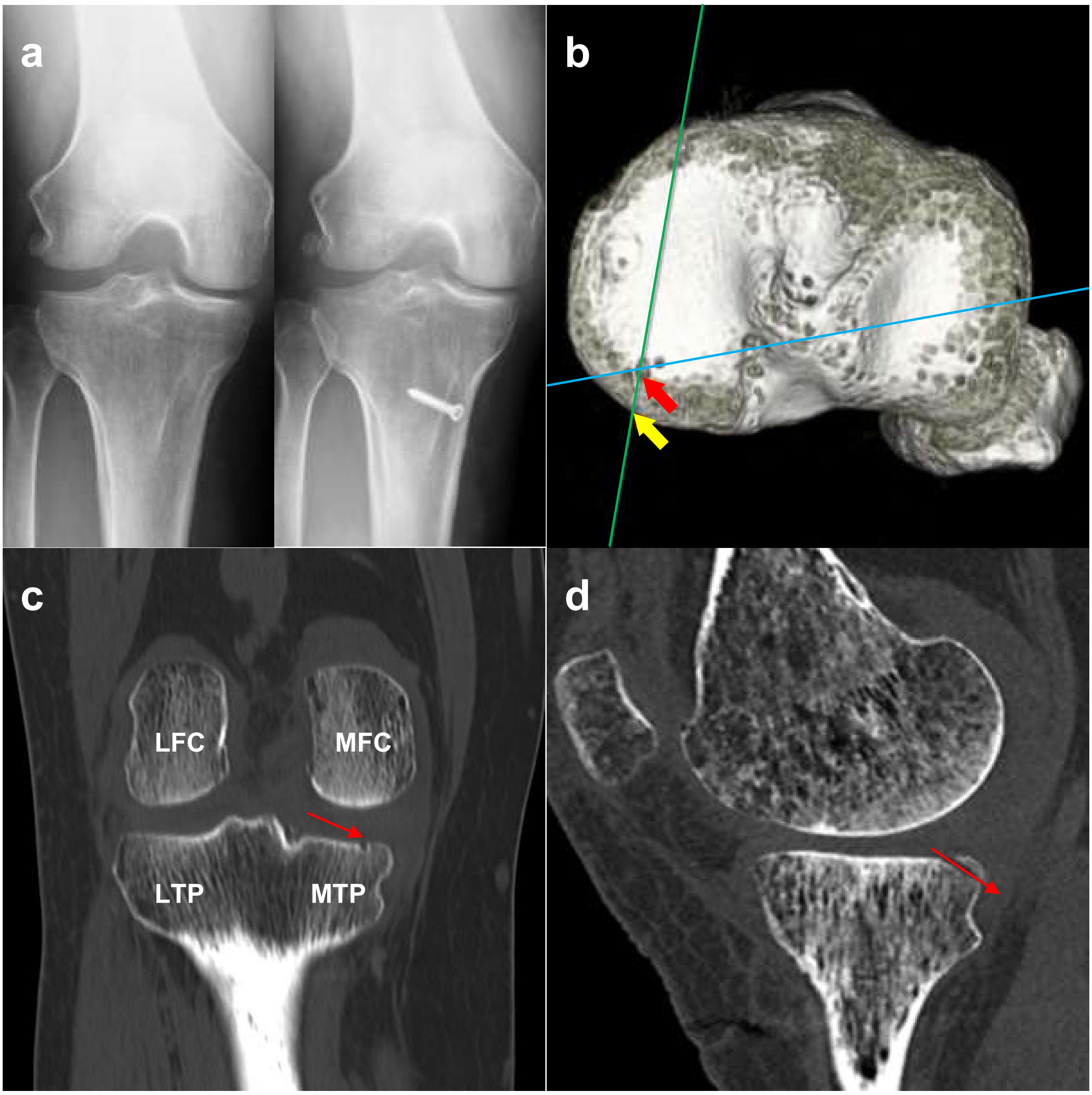

Fig. 3

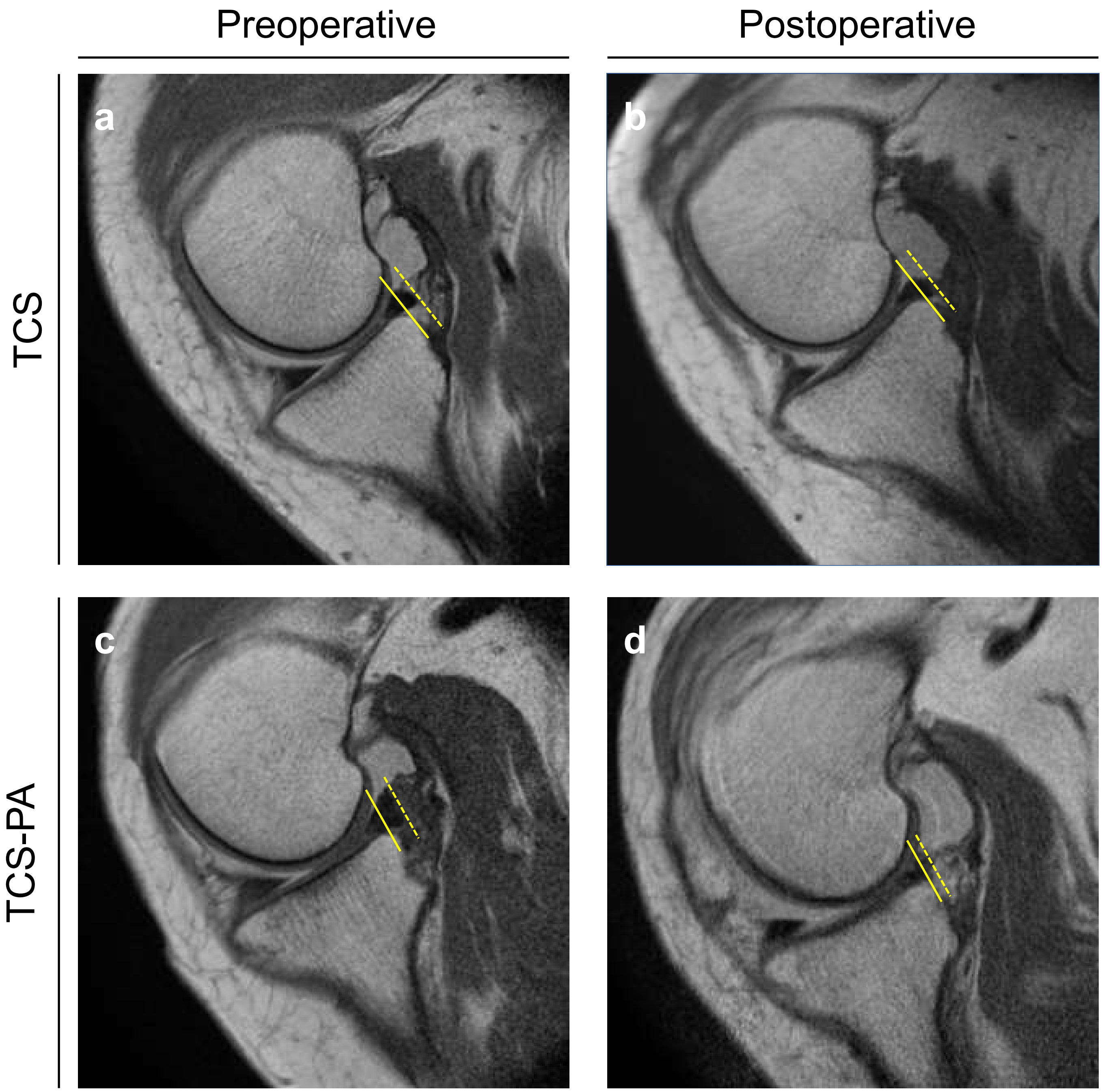

Fig. 4

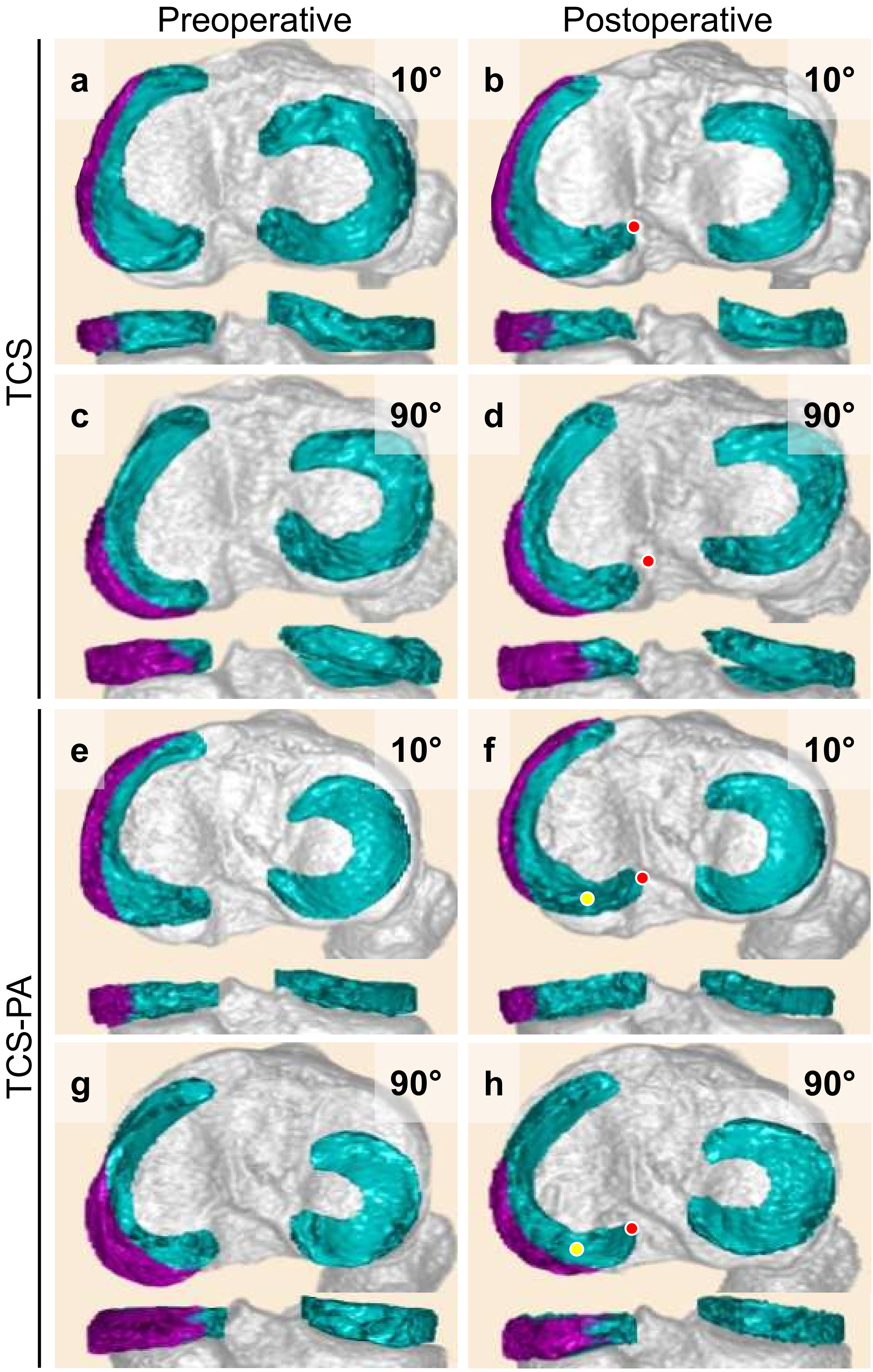
Preoperative
Postoperative
TCS
TCS-PA
a
10°
b
10°
c
90°
d
90°
e
10°
f
10°
g
90°
h
90°

Figure 5