Arch Orthop Trauma Surg (2017) 137:1087–1095
DOI 10.1007/s00402-017-2705-z

ARTHROSCOPY AND SPORTS MEDICINE

Surgical treatment of patellar instability: clinical and radiological outcome after medial patellofemoral ligament reconstruction and tibial tuberosity medialisation

Stefan Lobner[1,3] · Christine Krauss[2,3] · Frank Reichwein[3] · Thilo Patzer[4] · Wolfgang Nebelung[3] · Arne J. Venjakob[3]

Received: 28 November 2016 / Published online: 16 May 2017

Abstract
Introduction The aim of this retrospective study was to analyse clinical and radiological outcome after medial patellofemoral ligament reconstruction (MPFLR) and tibial tuberosity medialisation (TTM) in patients with recurrent patellar instability.
Materials and methods Thirty-five patients were included between 2008 and 2012. According to defined criteria such as tibial tuberosity-trochlear groove (TTTG) distance, hyperpression on the lateral patella facet and lateral retropatellar cartilage damage either MPFLR (group A) or TTM (group B) was performed: 18 patients underwent TTM, the other 17 patients underwent MPFLR. At a mean of 25.4 ± 9.7 (group A) and 35.2 ± 17.6 months (group B) patients were clinically and radiologically reviewed. Validated knee scores such as Kujala, Lysholm and Tegner score were evaluated.
Results In both groups one patient reported of a non-traumatic patellar redislocation. Patients who underwent MPFLR (group A) had less pain postoperatively during activity according to the Visual Analogue Scale (group A: 2.0 ± 2.1 points, group B: 3.9 ± 2.3 points). Retropatellar cartilage damage increased in group B from grade 1 (range: 1–3) preoperatively to grade 2 (range 1–3) postoperatively ($p > 0.05$). All other clinically evaluated items, as well as the applied knee scoring systems, indicated no significant difference ($p > 0.05$) and displayed good to excellent results.
Conclusions MPFLR and TTM leed to good clinical results despite its own indications. For this reason—in selected cases—TTM may still be a suitable procedure for surgical treatment of patellar instability. However, patients treated by TTM (group B) revealed an increased retropatellar cartilage damage as well as significantly more pain during activity.

Keywords Patellar instability · Recurrent patellar dislocation · MPFL reconstruction · Tibial tuberosity transfer

Introduction

Acute primary patellar dislocation remains a common problem in the young and active patient [1, 2]. The estimated incidence is ranged between 5.8 and 7.0 per 100,000, whereas it may increase to up to 31.0 per 100,000 in adolescents [1, 3]. In addition, 30–60% of patients with primary patellar dislocation may experience further episodes of patellar instability as well as anterior knee pain [4, 5]. The reported recurrence rate of patellar instability after non operative treatment varies from 15 to 49% [3, 5, 6].

A complex interaction of static (bone morphology), passive (capsule and ligaments) and active stabilizing factors (muscles) [7, 8] mainly determine patellofemoral joint stability. This results in the following main risk factors for patellar instability: trochlear dysplasia, patella alta,

✉ Stefan Lobner
stefan.lobner@hhu.de

1 Department of Orthopaedics, Trauma Surgery and Sports Medicine, Johanna-Etienne Hospital Neuss, Neuss, Germany

2 Sports Clinic of Stuttgart, Stuttgart, Germany

3 Department of Rheumatology and Arthroscopy, Marienkrankenhaus Duesseldorf-Kaiserswerth, Duesseldorf, Germany

4 Department of Orthopaedics, University Hospital of Duesseldorf, Duesseldorf, Germany

an increased tibial tuberosity-trochlear groove (TTTG) distance as well as malalignment [9–12].

Surgical treatment of patellar instability can basically be divided into soft tissue and bony procedures. While reconstruction of the medial patellofemoral ligament (MPFLR) may be a successful treatment for patients with medial soft tissue injury or insufficiency [12, 13], patients with distal bony malalignment may require tibial tuberosity medialisation (TTM) [13, 14]. The efficiency of both operative techniques as well as its indication is controversially discussed, because both MPFLR and TTM have their own limitations and indication. However, comparative studies of the clinical and radiological outcome do not exist in the current literature.

The aim of this study was to evaluate the clinical and radiological outcome after MPFLR and TTM in patients with recurrent patella instability. We hypothesized that both procedures lead to good clinical results and low redislocation rates.

Materials and methods

In this retrospective clinical study a total of 35 patients with recurrent patellar instability (more than one traumatic or nontraumatic dislocation of the patella) were included. Patients were either treated by MPFLR or TTM between 2008 and 2012. According to the following criteria either TTM or MPFLR was performed: TTTG distance greater or equal to 15.0 mm (main criterion), hyperpression on the lateral patella facet and lateral retropatellar cartilage damage of grade two or higher according to the Outerbridge classification [15]. Patients who met the main criterion and at least one of the two other criteria underwent TTM ($n = 18$), the others were treated by MPFLR ($n = 17$). Clinical examination revealed three patients ($n = 3$) in group A as well as one patient ($n = 1$) in group B with a mild valgus deformity. A slight genu varum was found in one patient ($n = 1$) of group B.

All patients were clinically and radiologically reviewed. Inclusion criteria were recurrent patellar dislocation (more than one traumatic or nontraumatic dislocation of the patella) and written consent to the study protocol. Patients under the age of 15 years as well as patients with previous surgeries, infection, tumor, quadriceps tendon rupture, patellar tendon rupture, intense leg axis deviation (valgus or varus malalignment), performed leg axis correction, patellofemoral osteoarthritis or postoperatively traumatic patellar dislocation of the affected knee were excluded from the study. The study was approved by the local Ethics Committee (Ref. No. 4683R).

The patient cohort consisted of 17 patients (12 females, 5 males), who underwent MPFLR (group A) and of 18 patients (11 females, 7 males), who underwent TTM (group B).

The patients' age at the clinical follow-up was on average 23.8 ± 6.5 years in group A and 28.7 ± 7.7 years in group B. In both groups six patients reported of recurrent patellar dislocation of the contralateral knee (35% of group A, 33% of group B). Family history of patellar instability was positive in three patients of group A (18%) and four patients of group B (22%).

Operative/surgical technique

The following surgical technique was used for the MPFLR: firstly, a preliminary diagnostic knee arthroscopy was performed in sixteen cases ($n = 16$). In some cases this arthroscopy was supplemented by cartilage shaving ($n = 6$), synovectomy ($n = 3$) or lateral retinacular release ($n = 1$). After that, the gracilis tendon ($n = 17$) was removed and prepared for its use as graft. Next an incision at the adductor tubercle was performed and the isometric insertion of the MPFL was identified. Under fluorescence guidance the exact femoral insertion of the graft was rechecked and marked with a K-wire. Proximally the graft was then fixed in the patella by using transosseus sutures. After subcutaneous and epifascial tunneling of the two free ends of the graft the K-wire was overdrilled with a hollow drill. The wires were pulled through the femur and the graft was inserted. Afterwards, the final femoral fixation of the graft was performed at 30° of flexion by using a tricalcium phosphate (TCP) bioabsorbable interference screw (BioComposite Interference Screw, Arthrex, Munich, Germany).

The TTM was performed by a modified Roux-Elmslie-Trillat procedure [16, 17]. All patients treated by this procedure ($n = 18$) firstly underwent a diagnostic knee arthroscopy as well. Additionally, in some cases retropatellar cartilage shaving ($n = 11$), synovectomy ($n = 6$) or medial capsular plication ($n = 6$) were performed. Moreover, five patients with excessive lateral hyperpression were treated with an additional lateral retinacular release ($n = 5$). After lateral incision and identification of the patellar tendon insertion, the tibial tuberosity was then detached medially, laterally and proximally, preserving an intact bony bridge distally. Afterwards the tibial tubercle was shifted medially ($n = 15$) and refixed with two AO cancellous screws and washers. In three patients ($n = 3$) the tibial tuberosity was totally detached and was then moved distally and medially.

Clinical evaluation

All patients were clinically evaluated by the first author (S. L.). Patients of group A were assessed at an average follow-up of 25.4 ± 9.7 months, patients of group B at an average follow-up of 35.2 ± 17.6 months.

Clinical evaluation included objective outcomes such as redislocation rate and physical examination of the operated knee as well as subjective outcomes. During the physical examination of the knees the following clinical parameters were assessed: full range of motion (flexion and extension), patellofemoral crepitation during knee movement, apprehension sign [18], J-sign [19], pain during palpation of the patellar facets as well as muscle atrophy of the thigh, which was identified by measuring and comparing the circumferences at 150.0 mm above the tibial tuberosity of both thighs. Furthermore validated knee scoring systems such as the Kujala Anterior Knee Pain Scale [20], the Lysholm and Gillquist Scoring Scale [21], and the Tegner Activity Scale [22] were applied.

The subjective evaluation included subjective grading of patellar instability ('feels completely stable', 'feels occasionally unstable but never dislocates', 'continues to dislocate') [23], knee pain during activity and at rest according to a 10-cm Visual Analogue Scale (VAS) [24, 25], ability of sports after surgery ('within 1 months', 'within 2 months', 'after 2–3 months', 'after 3–6 months', 'after more than 6 months'), overall individual satisfaction ('very satisfied', 'satisfied', 'not satisfied', 'absolutely not satisfied'), the will to choose the received surgical treatment again retrospectively as well as subjective improvement.

Radiological evaluation

Pre- and postoperatively all patients underwent magnetic resonance imaging scans as well as conventional radiographs of the operated knee. While preoperative MRI scans were performed by external radiologists, postoperative MRI scans were performed using a Vantage Titan 1.5T magnetic resonance system (Vantage Titan 1.5T, Toshiba Medical Systems, Otawara, Japan). Pre- and postoperative conventional radiographs of the addressed knee were performed in our clinic. The radiographs included standard posterior-anterior views, axial views at 30° of knee flexion as well as standing lateral views at 30° of flexion.

In T2-weighted axial MRI images retropatellar cartilage damage (grades 0–4) according to the Outerbridge classification [15, 26, 27] as well as TTTG distance [28] were evaluated pre- and postoperatively. The TTTG distance was measured between the midpoint of the distal insertion of the patellar tendon at the tibial tuberosity and the deepest point of the cartilaginous trochlear groove, which was obtained in the first proximal slight showing a complete cartilaginous trochlear groove [29].

Additionally, in preoperative T2-weighted axial MRI images dysplasia of the femoral trochlea (type A to D) was analyzed 30.0 mm above the femorotibial joint space [30] by using the classification system of Dejour [31].

In lateral radiographs at 30° of knee flexion the patella height was measured according to the index of Caton and Deschamps [32, 33]. An index of 1.2 or greater reflected a patella alta [34], an index lower than 0.8 a patella baja [33].

Radiologic measurements were performed by the first and last author (S. L. and A. J. V.). The acquired data have been confirmed on all images by an orthopaedic surgeon and judged to be correct.

Statistical analyses

Statistical analyses were performed by SPSS v22.0 (IBM-SPSS, New York, USA). Descriptive results are reported as mean ± standard deviation for parametric values and median (range) for nonparametric ones. Moreover, unpaired (two sample) *t* tests as well as Mann–Whitney-tests were used to compare the postoperative outcome between the two groups. Significance level was set at a p value of <0.05.

Results

Objective outcome

In each of the groups one patient reported of a non-traumatic patellar dislocation postoperatively. The patient of group A described a patellar dislocation one year after the MPFLR when standing up from a sitting position. The patellar dislocation of the patient of group B occurred one and a half years after the TTM when kneeling down. In both cases the patient himself repositioned the dislocated patella. Both patella redislocations were treated conservatively and both patients reported that the patella feels stable after the described postoperative dislocation so that no revision surgery was required.

Range of motion of the examined knees in group A and B is given in Table 1.

Persistent swelling of the knee (>6 months postoperatively) after weight bearing was reported by two patients in each group (12% of group A, 11% of group B).

In each group one patient had severe crepitation postoperatively (6% of groups A and B). Slight crepitation was found in four patients of group A (23%) and in eight patients of group B (44%). None or minimal crepitation was noticed in twelve patients of group A (71%) and in nine patients of group B (50%).

Clinical evaluation revealed no positive apprehension sign in patients of group A. In Group B one patient (6%) represented with a positive apprehension sign postoperatively. A positive J-sign was observed in three patients of

Table 1 Postoperative range of motion and atrophy of the thigh after MPFLR (group A) and TTM (group B)

Clinical parameters	Group A	Group B	*p* value
Flexion	135.0° ± 17.6° (90°–160°)	145.6° ± 14.9° (120°–160°)	0.064
(Hyper)Extension	6.9° ± 3.3° (0°–12.5°)	4.7° ± 3.2° (0°–10°)	0.053
Atrophy of the thigh	6.6 ± 17.0 mm	10.1 ± 19.4 mm	0.574

group A (18%) and in four patients of group B (22%) (Table 2).

While in group A five patients (29%) experienced pain during the palpation of the medial facet of the patella, this was observed in three patients (17%) of group B. The palpation of the lateral facet of the patella was painful for one patient of group B (6%). Moreover two patients of group B (11%) had pain during palpation of the medial and lateral facet of the patella. In each group twelve patients (71% in group A and 66% in group B) reported no pain during palpation of the medial and lateral facet of the patella.

In both groups an atrophy of the thigh at the affected knee was observed. In comparison to the girth of the contralateral thigh an atrophy of 6.6 ± 17.0 mm could be observed in patients of group A and an atrophy of 10.1 ± 19.4 mm could be detected in patients of group B (*t* test, $p = 0.574$) (Table 1).

Mean Kujala score, average Lysholm score and median level of activity (Tegner score) are given in Table 3. All applied knee scoring systems indicated no significant difference between the two groups (Table 3).

Subjective outcome

In each group seven patients (41% of group A, 39% of group B) stated that the patella 'feels completely stable'. Approximately 60% of the patients of each group (59% of group A, 61% of group B) reported that the patella 'feels occasionally unstable but never dislocates', whereas none of the patients in either group stated that the patella 'continues to dislocate' (Table 4).

Patients who received MPFLR (group A) showed an average postoperative VAS score during activity of 2.0 ± 2.1 points, compared to 3.9 ± 2.3 points in patients

Table 2 Overview of postoperative apprehension signs and J-signs of patients treated with MPFLR (group A) and TTM (group B)

Clinical-Tests, *n* (%)	Group A	Group B
Apprehension-sign		
Positive	–	1 (6)
Negative	17 (100)	17 (94)
J-sign		
Positive	3 (18)	4 (22)
Negative	14 (82)	14 (78)

Table 3 Postoperative values of knee scores for patients treated with MPFLR (group A) and TTM (group B)

Knee Score	Group A	Group B	*p* value
Kujala	84.0 ± 11.4 (57–97)	79.2 ± 13.8 (51–98)	0.263
Lysholm	82.2 ± 17.9 (45–98)	83.9 ± 14.1 (51–100)	0.768
Tegner	5 (3–9)	5 (2–6)	0.067

who received TTM (group B). This difference was statistically significant (*t* test, $p = 0.017$). Mean VAS score at rest was almost equal in both groups (0.4 ± 0.9 points in group A and 0.4 ± 1.1 points in group B). This difference was not statistically significant (*t* test, $p = 0.925$) (Table 5).

The ability to be active in sports after surgical treatment is given in Table 6.

In group A eleven patients (65%) were 'very satisfied' and six patients (35%) were 'satisfied' postoperatively. In group B six patients (33%) were 'very satisfied', half of the patients (50%) were 'satisfied' and two patients (11%) were 'absolutely not satisfied' with the surgical outcome. One patient (6%) of group B did not answer the question.

All but one patient (94%) of group A stated their will to choose the surgical treatment again, retrospectively, in group B fifteen patients (83%) stated their willingness to choose the surgical treatment again and two of eighteen patients (11%) would not have chosen their received surgery again. One patient (6%) of group B did not answer the question. In group A all patients reported a subjective improvement postoperatively. This was observed in 14 patients (78%) of group B.

Radiological outcome

In group A (MPFLR) the retropatellar cartilage damage according to the Outerbridge classification remained constant (grade 1, range grade 0–3), whereas in group B (TTM) the retropatellar cartilage damage increased postoperatively from grade 1 (range grade 1–3) to grade 2 (range grade 1–3). The described differences between the median grades of the two groups were not statistically significant, neither preoperatively (Mann–Whitney-test, $p = 0.067$) nor postoperatively (Mann–Whitney-test, $p = 0.062$). A detailed overview of the single retropatellar

Table 4 Patient's subjective grading of postoperative patellar stability after MPFLR (group A) and TTM (group B)

Subjective grading of patellar stability, *n* (%)	Group A	Group B
'Feels completely stable'	7 (41)	7 (39)
'Feels occasionally unstable but never dislocates'	10 (59)	11 (61)
'Continues to dislocate'	–	–

Table 5 Postoperative pain outcome during activity and at rest according to a visual analogue scale (VAS) in patients treated with MPFLR (group A) and TTM (group B)

Pain outcome	Group A	Group B	*p* value
VAS during activity	2.0 ± 2.1 (0–5)	3.9 ± 2.3 (0–8)	0.017*
VAS at rest	0.4 ± 0.9 (0–3)	0.4 ± 1.1 (0–4)	0.925

* Statistically significant, $p < 0.05$)

Table 7 Overview of the pre- and postoperative single retropatellar cartilage damage grades of patients treated by MPFLR (group A) and TTM (group B)

Outerbridge classification, *n* (%)	Group A	Group B
Preoperatively		
Grade 0	5 (29)	–
Grade 1	9 (53)	12 (66)
Grade 2	2 (12)	3 (17)
Grade 3	1 (6)	3 (17)
Grade 4	–	–
Postoperatively		
Grade 0	2 (12)	–
Grade 1	8 (47)	7 (39)
Grade 2	6 (35)	4 (22)
Grade 3	1 (6)	7 (39)
Grade 4	–	–

cartilage damage grades of each group (preoperatively as well as postoperatively) is given in Table 7. Due to the procedure of MPFLR the TTTG distance remained constant in group A (13.8 ± 3.2 mm) and decreased in group B from 17.5 ± 2.7 mm preoperatively to 9.3 ± 4.4 mm postoperatively. Pre- and postoperatively the difference between the average TTTG distances of both groups was statistically significant (*t* test, $p = 0.001$) (Table 8).

In each group the following types of trochlear dysplasia according to Dejour et al. were found preoperatively: type A was observed in fifteen patients of group A (88%) and in nine patients of group B (50%), type B was detected in one patient of group A (6%) and in nine patients of group B (50%), and type C was found in one patient of group A (6%). Preoperatively the mean Caton-Deschamps index was 1.09 ± 0.10 in group A and 1.06 ± 0.12 in group B (*t* test, $p = 0.550$). Patella alta was observed in three patients of each group (18% of group A, 17% of group B), whereas patella baja was not observed in the patient cohort.

Discussion

Both MPFLR (group A) and TTM (group B) lead to good clinical and radiological results followed by good to excellent outcome in the evaluated knee scores as well as increased patellar stability (low redislocation rates). Therefore we indicate that our hypothesis is true.

In the present study we could demonstrate that patients treated by TTM reported of more pain during activity according to the VAS score than patients of group A (MPFLR). These subjective outcomes could be supported statistically. Patients of group A had a VAS score during activity of 2.0 ± 2.1 points, whereas patients of group B had a VAS score during activity of 3.9 ± 2.3 points (*t* test, $p = 0.017$). One reason for this difference might be that in patients treated by TTM a tendency to increased retropatellar cartilage damage was observed, especially postoperatively. This could be proven statistically. According to the Outerbridge classification the median grade of group A remained constant (grade 1, range grade 0–3), whereas in group B it increased postoperatively from grade 1 (range grade 1–3) to grade 2 (range grade 1–3). These radiological findings are in

Table 6 Ability of sports after MPFLR (group A) and TTM (group B)

Ability of sports after surgical treatment, *n* (%)	Group A	Group B
'Within 1 month'	–	1 (6)
'Within 2 months'	3 (18)	3 (17)
'After 2–3 months'	7 (41)	3 (17)
'After 3–6 months'	2 (12)	4 (22)
'After more than 6 months'	5 (29)	7 (38)

Table 8 Pre- and postoperative retropatellar cartilage damages (median grades) according to the Outerbridge classification as well as TTTG distances of patients treated with MPFLR (group A) and TTM (group B)

Radiological data	Group A	Group B	*p* value
Outerbridge preoperatively	1 (0–3)	1 (1–3)	0.067
Outerbridge postoperatively	1 (0–3)	2 (1–3)	0.062
TTTG distance preoperatively	13.8 ± 3.2 mm (5–19.5 mm)	17.5 ± 2.7 mm (15–22 mm)	0.001*
TTTG distance postoperatively	13.8 ± 3.2 mm (5–19.5 mm)	9.3 ± 4.4 mm (0–15.2 mm)	0.001*

* Statistically significant, $p < 0.05$)

accordance with the fact that half of the patients in group B showed a trochlear dysplasia of type B, whereas in group A (MPFLR) almost 90% of the patients presented a trochlear dysplasia of type A. In this context, it should be pointed out that in a controlled laboratory study with four cadaveric knees Haver et al. could demonstrate that trochlear dysplasia of type B and D leads to higher patellofemoral contact pressures during extension and flexion compared to trochlear dysplasia of type A and C [35]. It is obvious that higher patellofemoral contact pressures might increase the risk of patella cartilage damage. The fact that slight patellofemoral crepitation during knee movement was postoperatively diagnosed in twice as many patients of group B compared to group A might also be related to our radiological findings. In this context, it could also be observed that patients after MFPLR (group A) experienced pain during palpation of the patella facets rather on the medial facet, whereas patients after TTM (group B) experienced pain during palpation of both medial and lateral patella facet. However, it should be noted that pre- and postoperatively no significant difference (Mann–Whitney-tests, $p = 0.067$ and $p = 0.062$) between the retropatellar cartilage damage of both groups according to the Outerbridge classification could be detected.

Slight differences in objective outcome parameters between the two groups were found in range of motion (flexion and extension) and in atrophy of the thigh, but none of these observed differences was statistically significant (Table 1). Other objective outcome parameters were either equal (like redislocation rate and number of patients who reported of persistent swelling of the knee after weight bearing) or almost equal (like numbers of detected positive apprehension signs and positive J-signs) in both groups (Table 2).

In this study MPFLR patients reached a mean Kujala score of 84.0 ± 11.4 points, an average Lysholm score of 82.2 ± 17.9 points and a median level of activity (Tegner score) of 5 (range 3–9) at an average follow-up of 25.4 ± 9.7 months (Table 3). This is supported by the findings of Becher et al., who reported clinical and radiological outcomes after static and dynamic MPFLR at a mean follow-up of 26.0 ± 0.6 months [36]. In Becher's study patients after static MPFLR ($n = 15$) reached a mean Kujala score of 82.0 ± 17.0 points, a mean Lysholm score of 79.0 ± 18.0 points and a mean Tegner score of 4.4 ± 1.8 points. In this context it should also be noted that in a prospective clinical study with 68 patients (72 knees) treated by isolated MPFLR Lippacher et al. detected a median Kujala score of 87.5 points after an average follow-up period of 24.7 months [37]. Further, in a prospective clinical study with 30 patients, who underwent MPFLR, Krishna Kumar et al. reported a mean Lysholm score of 88.06 points at a mean follow-up of 25.0 months [38]. Moreover, in a prospective study with 20 patients (20 knees), who were surgically treated by anatomic MPFLR, Song et al. could obtain a median Tegner score of 5 (range 4–7) after a median follow-up time of 34.5 months [39]. On the other hand patients after TTM reached a mean Kujala score of 79.2 ± 13.8 points, an average Lysholm score of 83.9 ± 14.1 points and a median level of activity (Tegner score) of 5 (range 2–6) at an average follow-up of 35.2 ± 17.6 months (Table 3). In comparison Koëter et al. found that patients with objective patellar instability treated by a modified tibial tubercle osteotomy ($n = 30$) reached a mean Kujala score of 82.0 points and a mean Lysholm score of 84.0 points at a follow-up of 24.0 months [40]. Unfortunately, the Tegner score was not evaluated in their prospective study. However, in a prospective clinical study with 15 patients (18 knees), who underwent a modified Elmslie-Trillat procedure, Marcacci et al. reported a mean Tegner score of 5 (range 3–7) at a mean follow-up of 60.0 months [41]. In this context it should also be mentioned that in a retrospective study with 18 patients (18 knees) treated by using a Roux-Elmslie-Trillat reconstruction operation Endres and Wilke could detect an average postoperative Tegner score of 4.6 ten years after treatment [42]. Furthermore, in a prospective clinical study with 35 patients (35 knees), who were surgically treated with a modified Elmslie-Trillat procedure and evaluated at an average follow-up of 98.0 ± 49.5 months, Barber and McGarry could obtain a mean postoperative Lysholm score of 83.4 ± 15.4 points [43]. In summation it can be said that the evaluated results of the applied knee scoring systems of the current study are comparable to the findings of previous studies, which reported the clinical outcome after MPFLR and TTM. However, it should be mentioned that in the above cited TTM studies, except the study of Koëter et al., mean follow-up period was much longer than in our study.

The patients' subjective grading of postoperative patellar stability was almost equal in both groups (Table 4). This correlates with the reported postoperative redislocation rate in both groups. Also mean VAS score at rest was almost equal in both groups. However, differences in the subjective outcome could be observed in ability of sports after surgery (Table 6), overall individual satisfaction, the will to choose the received surgical treatment again retrospectively as well as subjective improvement. As a result, it can be concluded that patients treated by MPFLR needed less time to participate in sports activities revealing a better subjective outcome than patients treated by TTM.

Radiological differences between group A and group B were found in the preoperatively evaluated types of trochlear dysplasia as well as in Caton-Deschamps index, but none of the differences was statistically significant ($p > 0.05$). However, the observed differences in the pre- and postoperatively evaluated TTTG distances between the two groups were statistically significant (*t* test, $p = 0.001$).

However, it is noteworthy that retropatellar cartilage damage according to the Outerbridge classification remained constant in patients after MPFLR (grade 1, range grade 0–3), whereas in patients treated by TTM retropatellar cartilage damage increased slightly from median grade 1 (range grade 1–3) to median grade 2 (range grade 1–3). These results are comparable to those of Farr et al., who reported on a collective of 26 patients (30 knees) evaluated at a mean follow-up of 20.9 ± 4.1 years after the Elmslie-Trillat procedure [44]. In these patients tibiofemoral osteoarthritis (according to Kellgren-Lawrence) of median grade 2 (range grade 0–4) as well as patellofemoral osteoarthritis (according to Sperner) of median grade 1 (range grade 0–4) could be observed. Moreover they reported that knee osteoarthritis of grade 2 or higher (according to Kellgren-Lawrence and Sperner) could be observed in about 50% of their patients. For comparison, in our present study osteoarthritis of grade 2 or higher (according to the Outerbridge classification) was observed in 61% of patients after TTM (group B). Farr et al. also stated that differences were not statistically significant. Within our patient collective a tendency to increased cartilage damage could be detected in the TTM group, whereas no statistically significant intergroup difference could be found (Mann–Whitney-test, $p = 0.062$).

Within the current literature it is still controversially discussed whether TTM is followed by osteoarthritis of the tibiofemoral and patellofemoral joints due to altered contact pressures. Kuroda et al. stated in their cadaveric study with six fresh human cadaveric knees that overmedialization of the tibial tuberosity causes abnormal joint pressures, which may lead to future complications [45]. Mani et al. deduced in a controlled laboratory study that tibiofemoral kinematic changes after tibial tuberosity surgery could alter the pressure applied to tibiofemoral cartilage [46]. Saranathan et al. found out that TTM of 10.0 mm reduces the pressure applied to lateral patellar cartilage for intact cartilage and cartilage with lateral lesions without medial cartilage overload [47]. Furthermore, in a controlled laboratory study with eight fresh-frozen cadaveric knees Stephen et al. concluded that lateral patellofemoral joint contact pressures increased with progressive lateralization of the tibial tuberosity, whereas TTM reduced these effects as well as restored patellar stability not causing excessive peak pressures [48]. So far, the described controversy could not be resolved.

The results of this retrospective study are limited by the following factors: first of all the indications of the two surgeries are different, therefore it is generally difficult to compare the outcome of both procedures. Moreover, due to the retrospective study design clinical outcome could only be evaluated postoperatively. Therefore no comparison of the pre- and postoperative clinical outcome could be evaluated. Furthermore the size of the patient cohort was comparatively small, mostly caused by the fact that only a total of 35 patients met the inclusion criteria of the present study. Additionally, the subjects of both groups were not matched in pairs. Moreover, the follow-up interval was likely too short to evaluate more significant clinical and radiological results. And finally, dysplasia of the femoral trochlear (type A to D) was analyzed in axial MRI images although Nelitz et al. stated that evaluation of trochlear dysplasia by MRI is of limited value [49].

Conclusion

Surgical treatment of recurrent patellar instability is still controversially discussed in the current literature. In our present study patients after MPFLR (group A) and TTM (group B), which were performed according to defined criteria, reached good clinical and radiological outcomes. Overall the clinical and radiological results are comparable between the two groups, although its indications are different. For this reason it is difficult to give a nuanced treatment algorithm based on our patient collective. Nevertheless we recommend to consider TTM as a patellar stabilization procedure for patients with highly increased TTTG distance, hyperpression on the lateral patella facet or increased lateral retropatellar cartilage damage. However, a tendency to increased retropatellar cartilage damage and more pain during activity could be detected after TTM.

Compliance with ethical standards

Conflict of interest Author Stefan Lobner, Author Christine Krauss, Author Frank Reichwein, Author Thilo Patzer, Author Wolfgang

Nebelung, and Author Arne J. Venjakob declare that they have no conflict of interest.

References

1. Atkin DM, Fithian DC, Marangi KS et al (2000) Characteristics of patients with primary acute lateral patellar dislocation and their recovery within the first 6 months of injury. Am J Sports Med 28:472–479
2. Waterman BR, Belmont PJ, Owens BD (2012) Patellar dislocation in the United States: role of sex, age, race, and athletic participation. J Knee Surg 25:51–57
3. Mehta VM, Inoue M, Nomura E, Fithian DC (2007) An algorithm guiding the evaluation and treatment of acute primary patellar dislocations. Sports Med Arthrosc Rev 15:78–81. doi:10.1097/JSA.0b013e318042b695
4. Hawkins RJ, Bell RH, Anisette G (1986) Acute patellar dislocations. The natural history. Am J Sports Med 14:117–120
5. Petri M, Liodakis E, Hofmeister M et al (2013) Operative vs conservative treatment of traumatic patellar dislocation: results of a prospective randomized controlled clinical trial. Arch Orthop Trauma Surg 133:209–213. doi:10.1007/s00402-012-1639-8
6. Mäenpää H, Huhtala H, Lehto MU (1997) Recurrence after patellar dislocation. Redislocation in 37/75 patients followed for 6–24 years. Acta Orthop Scand 68:424–426
7. Amis AA (2007) Current concepts on anatomy and biomechanics of patellar stability. Sports Med Arthrosc Rev 15:48–56. doi:10.1097/JSA.0b013e318053eb74
8. Senavongse W, Amis AA (2005) The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: a biomechanical study in vitro. J Bone Joint Surg Br 87:577–582. doi:10.1302/0301-620X.87B4.14768
9. Rhee S-J, Pavlou G, Oakley J et al (2012) Modern management of patellar instability. Int Orthop 36:2447–2456. doi:10.1007/s00264-012-1669-4
10. Ries Z, Bollier M (2015) Patellofemoral instability in active adolescents. J Knee Surg 28:265–277. doi:10.1055/s-0035-1549017
11. Steensen RN, Bentley JC, Trinh TQ et al (2015) The prevalence and combined prevalences of anatomic factors associated with recurrent patellar dislocation: a magnetic resonance imaging study. Am J Sports Med. doi:10.1177/0363546514563904
12. Frosch K-H, Schmeling A (2016) A new classification system of patellar instability and patellar maltracking. Arch Orthop Trauma Surg 136:485–497. doi:10.1007/s00402-015-2381-9
13. Koh JL, Stewart C (2015) Patellar instability. Orthop Clin North Am 46:147–157. doi:10.1016/j.ocl.2014.09.011
14. Alaia MJ, Cohn RM, Strauss EJ (2014) Patellar instability. Bull Hosp Jt Dis 2013(72):6–17
15. Outerbridge RE (1961) The etiology of chondromalacia patellae. J Bone Joint Surg Br 43–B:752–757
16. Cox JS (1982) Evaluation of the Roux-Elmslie-Trillat procedure for knee extensor realignment. Am J Sports Med 10:303–310
17. Trillat A, Dejour H, Couette A (1964) Diagnosis and treatment of recurrent dislocations of the patella. Rev Chir Orthopédique Réparatrice Appar Mot 50:813–824
18. Fairbank HAT (1937) Internal derangement of the knee in children and adolescents. Proc R Soc Med 30:427–432
19. Sheehan FT, Derasari A, Fine KM et al (2010) Q-angle and J-sign: indicative of maltracking subgroups in patellofemoral pain. Clin Orthop 468:266–275. doi:10.1007/s11999-009-0880-0
20. Kujala UM, Jaakkola LH, Koskinen SK et al (1993) Scoring of patellofemoral disorders. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 9:159–163
21. Lysholm J, Gillquist J (1982) Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med 10:150–154. doi:10.1177/036354658201000306
22. Tegner Y, Lysholm J (1985) Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res 198(198):43–49. doi:10.1097/00003086-198509000-00007
23. Dandy DJ (1996) Chronic patellofemoral instability. J Bone Joint Surg Br 78:328–335
24. Carlsson AM (1983) Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. Pain 16:87–101
25. Höher J, Münster A, Klein J et al (1995) Validation and application of a subjective knee questionnaire. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 3:26–33
26. Potter HG, Linklater JM, Allen AA et al (1998) Magnetic resonance imaging of articular cartilage in the knee. An evaluation with use of fast-spin-echo imaging. J Bone Joint Surg Am 80:1276–1284
27. Suh JS, Lee SH, Jeong EK, Kim DJ (2001) Magnetic resonance imaging of articular cartilage. Eur Radiol 11:2015–2025. doi:10.1007/s003300100911
28. Schoettle PB, Zanetti M, Seifert B et al (2006) The tibial tuberosity-trochlear groove distance; a comparative study between CT and MRI scanning. Knee 13:26–31. doi:10.1016/j.knee.2005.06.003
29. Pandit S, Frampton C, Stoddart J, Lynskey T (2011) Magnetic resonance imaging assessment of tibial tuberosity-trochlear groove distance: normal values for males and females. Int Orthop 35:1799–1803. doi:10.1007/s00264-011-1240-8
30. Pfirrmann CW, Zanetti M, Romero J, Hodler J (2000) Femoral trochlear dysplasia: MR findings. Radiology 216:858–864. doi:10.1148/radiology.216.3.r00se38858
31. Dejour H, Walch G, Neyret P, Adeleine P (1990) Dysplasia of the femoral trochlea. Rev Chir Orthopédique Réparatrice Appar Mot 76:45–54
32. Caton J (1989) Method of measuring the height of the patella. Acta Orthop Belg 55:385–386
33. Caton J, Deschamps G, Chambat P et al (1982) Patella infera. Apropos of 128 cases. Rev Chir Orthopédique Réparatrice Appar Mot 68:317–325
34. Caton J, Mironneau A, Walch G et al (1990) Idiopathic high patella in adolescents. Apropos of 61 surgical cases. Rev Chir Orthopédique Réparatrice Appar Mot 76:253–260
35. Haver AV, Roo KD, Beule MD et al (2015) The effect of trochlear dysplasia on patellofemoral biomechanics a cadaveric study with simulated trochlear deformities. Am J Sports Med 43:1354–1361. doi:10.1177/0363546515572143
36. Becher C, Kley K, Lobenhoffer P et al (2014) Dynamic versus static reconstruction of the medial patellofemoral ligament for recurrent lateral patellar dislocation. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 22:2452–2457. doi:10.1007/s00167-014-3020-7
37. Lippacher S, Dreyhaupt J, Williams SRM et al (2014) Reconstruction of the medial patellofemoral ligament: clinical outcomes and return to sports. Am J Sports Med 42:1661–1668. doi:10.1177/0363546514529640
38. Krishna Kumar M, Renganathan S, Joseph CJ et al (2014) Medial patellofemoral ligament reconstruction in patellar instability. Indian J Orthop 48:501–505. doi:10.4103/0019-5413.139864
39. Song SY, Kim IS, Chang HG et al (2014) Anatomic medial patellofemoral ligament reconstruction using patellar suture anchor fixation for recurrent patellar instability. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 22:2431–2437. doi:10.1007/s00167-013-2730-6
40. Koëter S, Diks MJF, Anderson PG, Wymenga AB (2007) A modified tibial tubercle osteotomy for patellar maltracking:

results at two years. J Bone Joint Surg Br 89:180–185. doi:10.1302/0301-620X.89B2.18358
41. Marcacci M, Zaffagnini S, Lo Presti M et al (2004) Treatment of chronic patellar dislocation with a modified Elmslie-Trillat procedure. Arch Orthop Trauma Surg 124:250–257. doi:10.1007/s00402-003-0511-2
42. Endres S, Wilke A (2011) A 10 year follow-up study after Roux-Elmslie-Trillat treatment for cases of patellar instability. BMC Musculoskelet Disord 12:48. doi:10.1186/1471-2474-12-48
43. Barber FA, McGarry JE (2008) Elmslie-Trillat procedure for the treatment of recurrent patellar instability. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 24:77–81. doi:10.1016/j.arthro.2007.07.028
44. Farr S, Huyer D, Sadoghi P et al (2014) Prevalence of osteoarthritis and clinical results after the Elmslie-Trillat procedure: a retrospective long-term follow-up. Int Orthop 38:61–66. doi:10.1007/s00264-013-2083-2
45. Kuroda R, Kambic H, Valdevit A, Andrish JT (2001) Articular cartilage contact pressure after tibial tuberosity transfer a cadaveric study. Am J Sports Med 29:403–409
46. Mani S, Kirkpatrick MS, Saranathan A et al (2011) Tibial tuberosity osteotomy for patellofemoral realignment alters tibiofemoral kinematics. Am J Sports Med 39:1024–1031. doi:10.1177/0363546510390188
47. Saranathan A, Kirkpatrick MS, Mani S et al (2012) The effect of tibial tuberosity realignment procedures on the patellofemoral pressure distribution. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 20:2054–2061. doi:10.1007/s00167-011-1802-8
48. Stephen JM, Lumpaopong P, Dodds AL et al (2015) The effect of tibial tuberosity medialization and lateralization on patellofemoral joint kinematics, contact mechanics, and stability. Am J Sports Med 43:186–194. doi:10.1177/0363546514554553
49. Nelitz M, Lippacher S, Reichel H, Dornacher D (2014) Evaluation of trochlear dysplasia using MRI: correlation between the classification system of Dejour and objective parameters of trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 22:120–127. doi:10.1007/s00167-012-2321-y