Clinical outcomes and predictive factors for failure with MPFL reconstruction combined with tibial tubercle osteotomy and lateral retinacular release for recurrent patellar instability

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Abstract

Background: Medial patellofemoral ligament (MPFL) reconstruction combined with tibial tubercle osteotomy (TTO) and lateral retinacular release (LRR) is one of the main treatment methods for patellar instability. So far, few studies have evaluated the clinical effectiveness and assessed potential risk factors for recurrent patellar instability.

Purpose: To report the clinical outcomes of MPFL reconstruction combined with TTO and LRR at least three years after operation and to identify potential risk factors for recurrent patellar instability.

Methods: A retrospective analysis of medical records for patients treated with MPFL, TTO and LRR from 2013 to 2017 was performed. Preoperative assessment for imaging examination included trochlear dysplasia according to Dejour classification, patella alta with the Caton-Deschamps index (CDI), tibial tubercle–trochlear groove distance. Postoperative assessment for knee function included Kujala, IKDC and Tegner scores. Failure rate which was defined by a postoperative dislocation was also reported.

Results: A total of 108 knees in 98 patients were included in the study. The mean age at operation was 19.2 ± 6.1 years (range, 13–40 years), and the mean follow-up was 61.3 ± 15.4 months (range, 36–92 months). All patients included had trochlear dysplasia (A, 24%; B, 17%; C, 35%; D, 24%), and 67% had patellar alta. The mean postoperative scores of Tegner, Kujala and IKDC were 5.3 ± 1.3 (2–8), 90.5 ± 15.5 (24–100) and 72.7 ± 12.1 (26–86). Postoperative dislocation happened in 6 patients (5.6%). Female gender was a risk factor for lower IKDC (70.7 vs 78.1, P = 0.006), Tegner (5.1 vs 6.0, P = 0.006) and Kujala (88.2 vs 96.6, P = 0.008). Age (p = 0.011) and trochlear dysplasia (p = 0.016) were considered to be two failure factors for MPFL combined with TTO and LRR.

Conclusion: As a surgical method, MPFL combined with TTO and LRR would be a reliable choice with a low failure rate (5.6%). Female gender was a risk factor for worse postoperative outcomes. Preoperative failure risk factors in this study were age and trochlear dysplasia.

Level of Evidence: Level IV; Case series

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1. What is known about this subject?
Recurrent patellar instability is a common problem, which could cause anterior knee pain, limit the motion of the knee joint, and increase the risk of patellar osteoarthritis. The stability of patellofemoral joint is maintained by the joint action of bony anatomical structure and soft tissue on patella. A few studies have proved that the surgical procedures—MPFL alone or MPFL combined with TTO—can get good results. However, few studies described the good outcome of MPFL reconstruction combined with LRR and TTO, information about multiple risk factors for poor outcomes of the combined treatment is rare, and no articles reported risk factors for failure of the combined treatment.

2. What this study adds to existing knowledge
As a surgical method, MPFL combined with TTO and LRR would be a reliable choice with a low failure rate. Female gender was a risk factor for worse postoperative outcomes. Preoperative failure risk factors in this study were age and trochlear dysplasia.

Background
Recurrent patellar instability is a common problem, which could cause patellofemoral pain, limit the motion of the knee joint, and increase the risk of patellofemoral osteoarthritis [1]. The stability of patellofemoral joint is maintained by the joint action of bony anatomical structure and soft tissue on patella.

The medial patellofemoral ligament (MPFL) is the most important soft tissue to keep patellar from lateral displacement from zero to thirty of knee flexion. It has been proved that the injury of MPFL happens during all lateral patellar dislocations [2, 3]. With the injury of MPFL, tension and contracture of lateral retinaculum always happen. Over-constraint by the lateral retinaculum is one of the causes of patellofemoral disorders, particularly pain in the patellofemoral joint, patellofemoral instability and chondromalacia of the articular cartilage of the patellofemoral joint. Therefore, MPFL reconstruction and lateral retinacular release (LRR) have become popular in the surgery for patellofemoral instability. However, patellar instability is a multifactorial problem [4], and in some cases, it could be necessary to combine MPFL reconstruction and LRR with other surgical procedures, which include bony procedures, such as distal and/or medial transfer of the anterior tibial tubercle and trochleoplasty.

Tibial tuberosity to trochlear groove (TT–TG) distance is an index for measuring the lateralization of the tibial tuberosity [5]. Except for TT-TG distance, tibial tuberosity to posterior cruciate ligament (TT-PCL) is also an ideal index for measuring the lateralization, which is not influenced by knee rotation. But numerous studies proved that the mean differences in the TT-PCL value between the control and dislocation groups were both 2 to 3 mm (smaller than MCID-5 mm), which meant that TT-PCL was not clinically meaningful. Finally, TT-TG was used for measuring the lateralization of tibial tuberosity. TT–TG distance more than 20 mm has been suggested as an indication for tubercle medialization with a tibial tubercle osteotomy [5, 6]. And Caton-Deschamps Index (CDI) more than 1.2 is an index for defining patella alta [7]. Patella alta can be corrected by the distalization of tibial tubercle. Trochlear dysplasia is common among patients with recurrent patellar instability. Trochleoplasty is recommended in case of severe trochlear dysplasia [8–10]. However, current clinical results demonstrate only fair outcomes and a high incidence of arthritis at long-term follow-up [11, 12].

So far, numerous studies described the good outcome of MPFL reconstruction alone or MPFL reconstruction with tibial tubercle osteotomy (TTO) [7, 13], but whether LRR was performed at the same time and the indications were not clear, information about multiple risk factors for poor outcomes of combined treatment of MPFL reconstruction, TTO and LRR together was rare, and few articles reported risk factors for failure of combined treatment. The purpose of this study was to report the outcomes of combined treatment and assess the potential risk factors for poor outcomes and failure (postoperative dislocation).

Methods
This study received institutional review board approval. All procedures were performed in accordance with relevant guidelines.

Patients
The patients included in the study had at least 2 patellar dislocations. One experienced surgeon (JL) performed
MPFL reconstruction combined with LRR and TTO treatment from 2013 to 2017. The indications for TTO were CDI ≥ 1.3 (transfer distally; The normal index of CDI is 1.0, the amount of distalization is \( A_{\text{normal}} - A_{\text{actual}} \) (Fig. 1) and TT-TG ≥ 20 mm (transfer medially, the amount of medialization is at least 10 mm, make sure that the distance is less than 20 mm after osteotomy). The patella was pushed toward the medial side. If the patella moved less than one fourth of the patella, the lateral retinaculum was released. A retrospective analysis of collected data from the authors’ institution was performed, and all patients who had patellar instability were included and underwent combined treatment. The patients with previous knee surgery were excluded. The details of screening patients were shown in Fig. 2.

Clinical and Radiological Assessment

The records were reviewed for preoperative data including the age at the time of surgery, body mass index (BMI), gender, and follow-up time. Preoperative radiographs were reviewed for patellar alta and trochlear dysplasia. Patellar alta was defined using a Caton-Deschamps Index (CDI) of more than 1.3 based on lateral radiographs. Trochlear dysplasia was defined using Dejour classification based on computed tomography (CT) slices. Preoperative TT-TG distance was defined based on CT slices. Measurements were performed by 1 musculoskeletal radiologist. Postoperative indicators included postoperative re-dislocation besides Tegner, IKDC and Kujala scores. The shortest postoperative follow-up time was three years.

Surgical Procedure

All surgical procedures were performed by one senior surgeon, who used the same technique. The patient was placed in supine position with a tourniquet placed on the thigh root. An autogenous hamstring tendon graft was then harvested and prepared. A 12-cm longitudinal incision was made on the medial side of patella. The patella was pushed toward the medial side. If the patella moved less than one fourth of the patella, the lateral patellar retinaculum would be partially severed for the release. The range of release was determined by the patella movement. A continuous incision which went through the capsule and lateral retinaculum ranging from, and including the vastus lateralis tendon to the joint line, 1 cm lateral to the patella was usually made. After the lateral retinaculum was released, the periosteum was dissected with osteotome at the medial or /and inferior part of tibial tubercle. Then wedge-shaped osteotomy was done at the medial or /and inferior part of tibial tubercle. The area of the bone mass was about 3.0 * 1.0 cm. After the wedge-shaped osteotomy, another wedge-shaped osteotomy was done at the tibial tubercle. The area of the bone mass with patellar tendon was about 3.0 * 1.0 cm. Then the position of the two bone mass was exchanged. The bone mass with patellar tendon was fixed with two 4.5 * 40 mm absorbable screws. After the transferring of the tibial tubercle, two parallel bone tunnels with a diameter of 4.5 mm were drilled in the medial side of the patella, and another tunnel with a diameter of 6.0 mm was drilled on the site between the adductor tubercle and the proximal part of the superficial medial collateral ligament. The grafts were placed into the bone tunnel guided by a transfemoral pin. Appropriate graft tension was obtained by cycling the knee from full extension to full flexion. The graft was then secured within the tunnel with a diameter of 6-mm interference screw and fixed at 30° of knee flexion. The detail was seen in Figs. 3 and 4.

Postoperative Functional Exercise

A quality post-operative rehabilitation program was essential to having a successful outcome from a patellar stabilization procedure. In early stage, the goals of rehabilitation would initially focus on protection for healing, mobility and range of motion. Twenty-four hours after operation, ankle pump and straight-leg raise started with

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**Fig. 1** Line A (yellow line): the distance from the lowest point of patellar-articular surface to the anterior edge of tibial plateau; Line B (red line): the length of patellar articular surface. CDI = \( A_B \); CDI\(_{\text{normal}} = 1 \); \( A_{\text{normal}} = B \); \( A_{\text{actual}} = \text{CDI}_{\text{actual}} \times B \); The amount of distalization = \( A_{\text{normal}} - A_{\text{actual}} \)
the knee joint fixed in extension position for two weeks. Then the knee flexion exercise started. At week 6, the knee flexed to 120°. The patients returned to daily activities around the third month.

Statistical analysis
All calculations were made with IBM SPSS 25.0. Statistical significance was set at P < 0.05. Number of observed values, mean and SD, and minimum and maximum were reported for quantitative data. Number of observed values and number and percentage of patients per class were reported for qualitative data. Wilcoxon sign ranked sums was used for evaluating continuous variables and χ-square analysis was used for evaluating categorical variables.

Results
Population
A total of 108 knees in 98 patients were included in the study. Of these, 10 patients (10.2%) had bilateral reconstructions. In the follow-up, 15 patients (13.3%) were
lost. The mean age at operation was 19.2 ± 6.1 years (range, 13–40 years), and the mean follow-up was 61.3 ± 15.4 months (range, 36–92 months). All patients included had trochlear dysplasia (A, 24%; B, 17%; C, 35%; D, 24%), and 67% had patellar alta. The mean CDI was 1.2 (range, 0.5–1.6); mean TT-TG distance, 22 mm (range, 17–30 mm); All data details were summarized in Table 1.

Postoperative Outcomes
Six knees (5.6%) had postoperative dislocation, 4 with medial subluxation, 4 with lateral subluxation and 4 with obvious knee pain (VAS ≥ 4), 2 with operative incision disruption, 2 with fat liquefaction. All of the TTOs were clinically and radiographically healed by 3 months. The mean scores for Kujala, Tegner and IKDC were 90.5 ± 15.5 (range, 24–100), 5.3 ± 1.3 (range, 2–8) and 72.7 ± 12.1 (range, 26–86), respectively. Patients with grade-A trochlear dysplasia had mean Kujala, Tegner and IKDC scores of 93.6, 5.5 and 72.8. Patients with grade-B trochlear dysplasia had mean Kujala, Tegner and IKDC scores of 93.3, 5.8 and 76.4. Patients with grade-C trochlear dysplasia had mean Kujala, Tegner and IKDC scores of 87.5, 5.1 and 70. Patients with grade-D trochlear dysplasia had mean Kujala, Tegner and IKDC scores of 85.3, 5.0 and 74.2. All data details were summarized in Table 1.

Table 1 Descriptive Characteristics of the Population before Surgery

| Variable                       | n(%)   |
|--------------------------------|--------|
| Sex                            |        |
| male                           | 30 (28) |
| female                         | 78 (72) |
| Age at surgery, y              |        |
| Mean ± SD                      | 19.2 ± 6.1 |
| Minimum; Maximum               | 13; 40 |
| Body mass index, kg/m²         |        |
| Mean ± SD                      | 21.7 ± 3.4 |
| Minimum; Maximum               | 16.6; 37.6 |
| Side                           |        |
| Right                          | 52 (48) |
| Left                           | 56 (52) |
| Patellar height(CDI)           |        |
| Mean ± SD                      | 1.2 ± 0.22 |
| Minimum; Maximum               | 0.5; 1.6 |
| Class of patellar height       |        |
| < 1.3                          | 36 (33) |
| ≥ 1.3                          | 72 (67) |
| Trochlear dysplasia            |        |
| Type A                         | 26 (24) |
| Type B                         | 18 (17) |
| Type C                         | 38 (35) |
| Type D                         | 26 (24) |
| TT-TG distance, mm             |        |
| Mean ± SD                      | 22 ± 3.0 |
| Minimum; Maximum               | 17; 30 |
| Class of TT-TG distance, mm    |        |
| < 20                           | 30 (28) |
| ≥ 20                           | 78 (72) |
| Postoperative Kujala score     |        |
| Mean ± SD                      | 90.5 ± 15.5 |
| Minimum; Maximum               | 24; 100 |
| Postoperative Tegner score     |        |
| Mean ± SD                      | 5.3 ± 1.3 |
| Minimum; Maximum               | 2; 8 |
| Postoperative IKDC score       |        |
| Mean ± SD                      | 72.7 ± 12.1 |
| Minimum; Maximum               | 26; 86 |
| Follow-up, m                   |        |
| Mean ± SD                      | 61.3 ± 15.4 |
| Minimum; Maximum               | 36; 92 |
| Status at the follow-up        |        |
| Success                        | 102 (94) |
| Failure                        | 6 (6) |

Fig. 4 A: two parallel bone tunnels with a diameter of 4.5 mm were drilled in the medial side of the patella. B-C: The grafts were placed into the bone tunnel guided by a trans-femoral pin. D: another tunnel with a diameter of 6.0 mm was drilled on the site between the adductor tubercle and the proximal part of the superficial medial collateral ligament, the graft was then secured within the tunnel with a diameter of 6-mm interference screw and fixed at 30° of knee flexion.
of 89.8, 5.3 and 74.2. There were no significant differences in postoperative outcomes for different grades of trochlear dysplasia (IKDC: $p = 0.587$; Tegner: $p = 0.542$; Kujala: $p = 0.542$). Patients with patellar height $\geq 1.3$ had mean Kujala, Tegner and IKDC scores of 92.5, 5.4 and 75 as compared with 89.4, 5.3 and 71.5 for those with patellar height $< 1.3$ (IKDC: $p = 0.329$; Tegner: $p = 0.882$; Kujala: $p = 0.458$). Patients with TT-TG $\geq 20$ mm had mean Kujala, Tegner and IKDC scores of 91.5, 5.4 and 73.6 as compared with 87.6, 5.1 and 70.4 for those with TT-TG $< 20$ mm (IKDC: $p = 0.398$; Tegner: $p = 0.516$; Kujala: $p = 0.418$). Patients with age $\geq 18$ had mean Kujala, Tegner and IKDC scores of 92.5, 5.4 and 75 as compared with 89.4, 5.3 and 71.5 for those with age $< 18$ (IKDC: $p = 0.329$; Tegner: $p = 0.882$; Kujala: $p = 0.458$). Patients with BMI $\geq 25$ had mean Kujala, Tegner and IKDC scores of 86.4, 5.1 and 69.8 as compared with 94.3, 5.6 and 75.5 for those with BMI $< 25$ (IKDC: $p = 0.398$; Tegner: $p = 0.516$; Kujala: $p = 0.418$). Female patients had mean Kujala, Tegner and IKDC scores of 88.2, 5.1 and 70.7 as compared with 96.6, 6.0 and 78.1 for male patients (IKDC: $p = 0.006$; Tegner: $p = 0.006$; Kujala: $p = 0.008$). The result showed that increasing trochlear dysplasia, increasing patellar height, increasing TT-TG distance, BMI and age did not have any significant impact in the improvement of their Kujala, Tegner and IKDC scores, but Female gender as risk factor had a negative impact for IKDC, Tegner and Kujala scores. All data details were summarized in Fig. 5.

**Failure Risk Factors**

The $\chi^2$-square analysis indicated that there were significant differences in the failure rates among different grades of trochlear dysplasia ($p = 0.016$), and between age $< 18$ and age $\geq 18$ ($p = 0.011$). The result showed that the failure rate was significantly associated with trochlear dysplasia and age. However, there were no significant differences in the failure rates between CDI $\geq 1.3$ and CDI $< 1.3$ ($p = 0.088$), between females and males ($p = 0.669$), between BMI $< 25$ and BMI $\geq 25$ ($p = 1.000$) and between TT-TG $< 20$ and TT-TG $\geq 20$ ($p = 0.336$). The result showed that the failure rate was not significantly associated with patellar height, sex, BMI and TT-TG distance. All data details were summarized in Table 2.

**Discussion**

The purpose of this study was to report the clinical outcomes of MPFL reconstruction combined with LRR and TTO in cases of patellar instability and to identify predictive risk factors for failure. The main finding was that the combined treatment was reliable with low failure rate. This study indicated that female gender was a risk factor for lower postoperative outcomes. Age and trochlear dysplasia were considered to be two failure factors for MPFL combined with TTO and LRR. What is more, if the patellar was pushed toward less than one fourth of the patellar width, the release of lateral retinaculum was suitable.
If TT-TG distance ≥ 20 mm, the amount of medialization-10 mm was reliable.

Previous studies showed that above 90% of the patients had trochlear dysplasia [14–16]. In the current study cohort, all the patients had trochlear dysplasia. However, the proportion should be below 100% considering the loss to follow-up. The Kujala score with the scale from 0 to 100 was most frequently utilized for measuring patient-reported outcome among patellofemoral studies [13]. The postoperative outcome was in a “good” category when a score ranged from 85 to 94.31. The mean Kujala score was 90.5 which should be considered good outcome. The mean Kujala scores of trochlear dysplasia A, B, C and D were 93.6, 93.3, 87.5 and 89.8, respectively. There were no significant differences among different grades.

This result demonstrates that the combined treatment can be successful and should be suitable for patients with severe trochlear dysplasia. Allen et al. [7] also reported that the combination of MPFL reconstruction and TTO in patients with trochlear dysplasia results in low recurrence of instability and good subjective outcomes.

In terms of anatomical structure, the slope of the lateral trochlear facet keeps the patellar from lateral displacement [17]. A flattened trochlear groove reduced lateral stability by 70% at 30 of flexion. Thus, in the treatment of recurrent lateral patellar dislocation, trochleoplasty is utilized in cases of severe trochlear dysplasia. Several studies indicated that combined MPFL reconstruction with trochleoplasty could result in good postoperative stability and patient satisfaction [18, 19]. However, recently many concerns were raised on the complication rate and the risk to the cartilage and progress of arthritis in the patellofemoral joint after this procedure [20]. In addition, the procedure is technically demanding. Trochlear dysplasia is a common finding among patients with recurrent patellar instability, which might lead to patellofemoral maltracking and especially the presence of a positive J-sign at the clinical examination. One research indicated that a significant correlation existed between a positive J-sign and severe trochlear dysplasia and a positive J-sign was a risk factor for failure. However, trochlear dysplasia did not reliably predict the risk of failure [16]. This inconsistency might be related to the Dejour classification’s fair intra- and inter-observer reliability. Trochlear dysplasia might be a risk factor of failure. In our study cohort, there were significant differences in the failure rates among different grades of trochlear dysplasia (p = 0.016), which indicated, trochlear dysplasia could predict the risk of failure. Thus, trochleoplasty as a treatment should be considered in cases of severe trochlear dysplasia.

When the patellar moves through the sulcus; its routine is not straight. When the knee is in 10 to 30° of flexion, the engagement between the patella and trochlea occurs. The relation can be affected by changes in patellar tendon length. For patients with patella alta, the engagement between the patella and trochlea occurs at greater flexion angles, leading to less bony constraint at earlier degrees of flexion [21]. Thus, in the treatment of recurrent lateral patellar dislocation, patella alta is an indication for the distalization of the tibial tubercle. A study with the largest sample size for isolated MPFL reconstruction for recurrent patellar instability indicated that CDI > 1.3 was one preoperative failure risk factor. In our study for combined treatment, patellar alta was not a failure risk factor any more due to the distalization of the tibial tubercle. Thus, TTO for patellar alta was necessary for patellofemoral stability.

TT-TG-a distance between the tibial tuberosity and the trochlear groove-exceeding 20 mm is nearly always associated with patellar instability. Patients with TT-TG > 20 mm are always recommended with TTO treatment. Several studies indicated isolated MPFL construction for patients with increased TT-TG resulted in lower postoperative outcomes and subsequent instability [22, 23]. In addition, Stephen et al. [24] proved that isolated MPFL construction would add the graft tension and resulted in degenerative changes of the graft. Thus, medialization of the tibial tubercle was necessary for patellofemoral stability. The suitable extent of medialization varied; however, postoperative TT-TG distance from 9 to 15 mm was proposed by the majority of researchers [25, 26]. The over-medializing of the tibial tubercle could increase contact pressure and cause pain [27]. In our study, our patients were with medial subluxation. Thus, Care should be taken to assess the patellar tracking within the trochlear groove for avoiding the over-medializing of the tibial tubercle.

In our study, females were observed to have worse clinical scores. There were no significant differences in age, BMI, patellar alta, trochlear dysplasia, and TT-TG between females and males which was also proved by

### Table 2 Analysis of Preoperative Failure Risk Factors of Combined Treatment

| Analyzed Factor                  | patients, n | Comparison     | P value |
|---------------------------------|-------------|----------------|---------|
| Patellar height (CDI)           | 108         | ≥ 1.3 vs < 1.3 | 0.088   |
| Sex                             | 108         | female vs male | 0.669   |
| Age, y                          | 108         | ≥ 18 vs < 18   | 0.011   |
| BMI, kg/m²                      | 108         | ≥ 25 vs ≤ 25   | 1.000   |
| TT-TG distance, mm              | 108         | ≥ 20 vs < 20   | 0.336   |
| Trochlear dysplasia             | 108         | type A vs B vs C vs D | 0.016   |
Allen et al. [7]. And several studies also proved that there were a few risk factors for recurrent patellar inability including ligamentous laxity, rotational abnormalities and higher Q angle [28, 29]. Our findings support that sex is an important factor in the postoperative outcomes. Besides trochlear dysplasia, age was observed to be a risk factor for failure. Bone grows rapidly in the period of adolescence [30]. The morphological structure of immature bone is highly responsive to its contact environment, because mechanical forces influence both osteogenesis and bone remodeling [31–33]. Improvement of patellar alignment at an early age maybe promotes better further development of the anatomic relationship between the patella and femoral trochlear groove, and on earth make patella more stable [34]. Considering the risk of growth arrest and recurvatum deformity, skeletal immaturity with an open tibial apophysis is a strict contraindication for the osteotomy. Thus, the patients younger than fourteen years old is not advised to accept the osteotomy [35, 36]. In our study, the minimum age for combined surgery was 13 years old. No patients showed up growth arrest and recurvatum deformity. The mean postoperative Kujala score of patients younger than eighteen years old was 91 which was in good category. And no recurrent dislocation happened in patients younger than eighteen years old.

Lateral retinacular release is a useful treatment for patellar inability. The imbalance of the extension mechanism caused by excessive tension of the lateral retinaculum always results in patellofemoral disorders. Although the contribution of the lateral retinaculum to the lateral stability is only 10%, it often leads to abnormal contact between the lateral surface and the trochlea under excessive tension and therefore patellar mal-tracking [37]. In patellar dislocation, medial patellar ligament injury and quadriceps femoris weakness often occur, which leads to lateral collateral ligament contracture and excessive tension. We believed that proper lateral retinaculum release was necessary to maintain the stability of patella. The main complication of lateral retinaculum release was patellar medial dislocation or subluxation, but the incidence rate was very small. This was also confirmed in this study where Only 4 patients had medial patellar subluxation.

This study had several limitations. First, this study was a retrospective analysis of patellar inability. Second, 15 patients (13.3%) were lost to follow-up despite attempts to contact them by telephone, which might cause bias risk. Third, among the patients contacted for the follow-up, no patients completed the preoperative assessment of the function of knee joint using related scales, which make us unable to evaluate the difference between preoperative and postoperative. Nevertheless, this was the first study about the function of combined treatment (MPFL reconstruction, tibial tubercle osteotomy and lateral retinacular release) at least three years after surgery and preoperative risk factors.

**Conclusion**

As a surgical method, MPFL combined with TTO and LRR would be a reliable choice with a low failure rate (5.6%). Female gender was a risk factor for worse postoperative outcomes. Preoperative failure risk factors in this study were age and trochlear dysplasia.

**Abbreviations**

MPFL: Medial patellofemoral ligament; TTO: Tibial tubercle osteotomy; LRR: Lateral retinacular release; CDI: Caton-Deschamps index; TT–TG: Tibial tuberosity to trochlear groove; TT–PCL: Tibial tuberosity to posterior cruciate ligament; CT: Computed tomography; BMI: Body mass index.

**Acknowledgements**

The authors would like to thank KB Zhang SK Lai for their participation in the data collection process of this study.

**Authors’ contributions**

NJ and XL participated in the data collection, and analysis. PS W.F and J.L contributed to the study design and conception, and revision of the manuscript. All authors read and approved the final manuscript.

**Funding**

No funding.

**Availability of data and materials**

The datasets supporting the conclusions of this article are included within the article. Raw data can be requested from the corresponding author.

**Declarations**

**Ethics approval and consent to participate**

The protocol for the study was approved by Ethics Committee on Biomedical Research of West China Hospital of Sichuan University that all investigations were conducted in conformity with ethical principles. This study met the conditions for exemption of informed consent and was approved by Ethics Committee on Biomedical Research. No administrative permissions were required to access the raw data used in this study. The data used in this study was anonymized before its use. All procedures were performed in accordance with relevant guidelines.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no financial or non-financial competing interests.

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**Received:** 19 March 2021  **Accepted:** 2 July 2021

**Published online:** 21 July 2021

**References**

1.  Fithian DC, Paxton EW, Stone ML, Silva P, Davis DK, Elias DA, White LM. Epidemiology and natural history of acute patellar dislocation. Am J Sports Med. 2004;32(5):1114–21.
2. Elias DA, White LM, Fithian DC. Acute lateral patellar dislocation at MR imaging: injury patterns of medial patellar soft-tissue restraints and osteochondral injuries of the inferomedial patella. Radiology. 2002;225(3):736–43.
3. Nomura M, Horiuchi Y, Inoue M. Correlation of MR imaging findings and open exploration of medial patellofemoral ligament injuries in acute patellar dislocations. Knee. 2002;9(2):139–43.
4. White BJ, Sherman OH. Patellofemoral instability. Bull NYU Hosp Jt Dis. 2009;67(1):22–9.
5. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J. The tubial tuberosity-trochlear groove distance: a comparative study between CT and MRI scanning. Knee. 2006;13(1):26–31.
6. Camp CL, Stuart MJ, Krych AJ, Levy BA, Bond JR, Collins MS, Dahm DL. CT and MRI measurements of tubial tubercle-trochlear groove distances are not equivalent in patients with patellar instability. Am J Sports Med. 2013;41(8):1835–40.
7. Allen MM, Krych AJ, Johnson NR, Mohan R, Stuart MJ, Dahm DL. Combined Tibial Tubercle Osteotomy and Medial Patellofemoral Ligament Reconstruction for Recurrent Lateral Patellar Instability in Patients With Multiple Anatomic Risk Factors. Arthroscopy. 2018;34(8):2420-2426.e2423.
8. Bollier M, Fullkerson JP. The role of trochlear dysplasia in patellofemoral instability. J Am Acad Orthop Surg. 2011;19(1):8–16.
9. LaPrade RF, Cram TR, James EW, Rasmussen MT. Trochlear dysplasia and the role of trochleoplasty. Clin Sports Med. 2014;33(3):531–45.
10. Longo UG, Vincenzio C, Mannering N, Ciuffreda M, Salvatore G, Berton A, Denaro V. Trochleoplasty techniques provide good clinical results in patients with trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2018;26(9):2640–58.
11. Rouanet T, Gougeon F, Fayard JM, Rémy F, Migaud H, Pasquier G. Sulusc deepening trochleoplasty for patellofemoral instability: a series of 34 cases after 15 years postoperative follow-up. Orthop Traumatol Surg Res. 2015;101(4):443–7.
12. von Knoch F, Böhm T, Bürgi ML, von Knoch M, Bereiter H. Trochleoplasty techniques provide good clinical results in patients with trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2018;26(9):2640–58.
13. Schneider DK, Grawe B, Magnussen RA, Ceasar A, Parikh SN, Wall EJ, Colosimo AJ, Kaeding CC, Myer GD. Outcomes After Isolated Medial Patellofemoral Ligament Reconstruction for the Treatment of Recurrent Lateral Patellar Dislocations: A Systematic Review and Meta-analysis. Am J Sports Med. 2016;44(11):3093–3005.
14. Dejour H, Walch G, Neyret P, Adeleine P. Dysplasia of the femoral trochea. Rev Chir Orthop Reparatrice Appar Mot. 1999;76(1):45–54.
15. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19–26.
16. Sappey-Mariner E, Sonnery-Cottet B, O'Loughlin P, Ouanezaz H, Reina Fernandez L, Kouevijodh B, Thuanat M. Clinical Outcomes and Predictive Factors for Failure With Isolated MPFL Reconstruction for Recurrent Patellar Instability: A Series of 211 Reconstructions With a Minimum Follow-up of 3 Years. Am J Sports Med. 2019;47(6):1323–30.
17. Amis AA, Senavongse W, Bull AM. Patellofemoral kinematics during knee flexion-extension: an in vitro study. J Orthop Res. 2006;24(12):2201–11.
18. Neitzel M, Williams SR. Combined trochleoplasty and medial patellofemoral ligament reconstruction for patellofemoral instability. Oper Orthop Traumatol. 2015;27(6):495–504.
19. Neumann MW, Stalder M, Schuster AJ. Reconstructive surgery for patellofemoral joint incongruency. Knee Surg Sports Traumatol Arthrosc. 2016;24(3):873–8.
20. Weber AE, Nathani A, Dines JS, Allen AA, Shubin-Stein BE, Arendt EA, Bedi A. An Algorithmic Approach to the Management of Recurrent Lateral Patellar Dislocation. J Bone Joint Surg Am. 2016;98(5):417–27.
21. Arendt EA, Fithian DC, Cohen E. Current concepts of lateral patella dislocation. Clin Sports Med. 2002;21(3):499–519.
22. Camp CL, Krych AJ, Dahm DL, Levy BA, Stuart MJ. Medial patellofemoral ligament repair for recurrent patellar dislocation. Am J Sports Med. 2010;38(11):2248–54.
23. Wagner D, Pfalzer F, Hingelbaum S, Huth J, Mauch F, Bauer G. The influence of risk factors on clinical outcomes following anatomical medial patellofemoral ligament (MPFL) reconstruction using the gracilis tendon. Knee Surg Sports Traumatol Arthrosc. 2013;21(2):318–24.
24. Stephen JM, Dodds AL, Lampaopong P, Kader D, Williams A, Amis AA. The ability of medial patellofemoral ligament reconstruction to correct patellar kinematics and contact mechanics in the presence of a lateralized tubial tubercle. Am J Sports Med. 2015;43(9):2198–207.
25. Tecklenburg K, Feller JA, Whitehead TS, Webster KE, Elzarka A. Outcome of surgery for recurrent patellar dislocation based on the distance of the tubial tuberosity to the trochlear groove. J Bone Joint Surg Br. 2010;92(10):1376–80.
26. Vairo GL, Moya-Angeler J, Siorta MA, Anderson AH, Sherbonody PS. Tibial Tubercle-Trochlear Groove Distance Is a Reliable and Accurate Indicator of Patellofemoral Instability. Clin Orthopa Relat Res. 2019;477(6):1450–8.
27. Kuroda R, Kambic H, Valdevit A, Andrish JT. Articular cartilage contact pressure after tubial tuberosity transfer: A cadaveric study. Am J Sports Med. 2001;29(4):403–409.
28. Earl JE, Vetter CS. Patellofemoral pain. Phys Med Rehabil Clin N Am 2007, 18(3):439–458, viii.
29. Hiemstra LA, Kerdilake S, Loewe M, Lafave MN. Effect of Trochlear Dysplasia on Outcomes After Isolated Soft Tissue Stabilization for Patellar Instability. Am J Sports Med. 2016;44(6):1515–23.
30. National Research C, Institute of Medicine Forum on A. In: Adolescent Development and the Biology of Puberty: Summary of a Workshop on New Research. edn. Edited by Kipke MD. Washington (DC): National Academies Press (US); 1999 by the National Academy of Sciences. All rights reserved., 1999.
31. Julián-Almárcegui C, Gómez-Cabello A, Huybrechts I, González-Aguero A, Kaufman JM, Casajús JA, Vicente-Rodríguez G. Combined effects of interaction between physical activity and nutrition on bone health in children and adolescents: a systematic review. Nutr Rev. 2015;73(3):127–39.
32. Hosseinzadeh S, Kiapour AM, Marano DA, Emami SA, Miller P, Kim YJ, Novais EN. Increased body mass index percentile is associated with decreased epiphyseal tuberous size in asymptomatic children and adolescents with healthy hips. J Child Orthop. 2020;14(3):167–74.
33. Hosseinzadeh S, Novais EN, Emami A, Portilla G, Marano DA, Kim YJ, Kiapour AM. Does the Capital Femoral Physis Bony MorphologyDiffer in Children with Symptomatic Cam-type Femoroacetabular Impingement. Clin Orthopa Relat Res. 2021;479(4):522–31.
34. Kaymaz B, Atay OA, Ergen FB, Mermekaya MU, Olgun ZD, Atesok K, Doral MN. Development of the femoral trochlear groove in rabbits with patellar malposition. Knee Surg Sports Traumatol Arthrosc. 2013;21(18):1841–8.
35. Barber FA, McGarry JE. Elmslie-Trillat procedure for the treatment of recurrent patellar instability. Arthroscopy. 2008;24(1):77–81.
36. Hinton RY, Hinton RY, Sharma KM, Novais EN, Emami A, Portilla G, Marano DA, Kim YJ, Kiapour AM. Does the Capital Femoral Physis Bony MorphologyDiffer in Children with Symptomatic Cam-type Femoroacetabular Impingement. Clin Orthopa Relat Res. 2021;479(4):522–31.
37. Christoforakis J, Bull AM, Strachan RK, Shymkiv R, Senavongse W, Amis AA. Effects of lateral retinacular release on the lateral stability of the patella. Knee Surg Sports Traumatol Arthrosc. 2006;14(3):273–7.

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