The Increased Tibiofemoral Rotation: A Potential Contributing Factor for Patellar Maltracking in Patients with Recurrent Patellar Dislocation

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Abstract

Objective: The purpose of this study was to analyze the relationship between tibiofemoral rotation and patellar maltracking in patients with recurrent patellar dislocation.

Methods: A total of 143 consecutive knees (118 patients) with clinically diagnosed recurrent patellar dislocation from January 2018 to December 2019 were retrospectively analyzed. Patellar tilt angle and bisect offset index were recorded on axial CT to assess the severity of patellar maltracking. Tibiofemoral rotation angle is measured by comparing the angle between the posterior femoral and tibial condylar lines on three-dimensional CT. The Pearson correlation was calculated to investigate the association between tibiofemoral rotation angle and patellar maltracking. Patients were divided into the rotation group (≥15°) and control group (<15°) based on the value of tibiofemoral rotation and a further comparison was performed. To further clarify the complicated relationship among tibial tubercle-trochlear groove (TT-TG), tibial tubercle-posterior cruciate ligament distance (TT-PCL), tibiofemoral rotation, and patellar maltracking, patients were divided into four subgroups according to the value of TT-TG and TT-PCL.

Results: The mean preoperative tibiofemoral rotation angle was 12° ± 6° (range, 0°–31°). Pearson correlation between patellar maltracking parameters (bisect offset index, patellar tilt angle) and various bony deformities found that the tibiofemoral rotation angle was moderately correlated with bisect offset index (r = 0.451, p < 0.001) and patellar tilt angle (r = 0.462, p < 0.001). Further results demonstrated that bisect offset index (152.1 vs 121.2, p < 0.001) and patellar tilt angle (41.2° vs 33.5°, p < 0.001) were significantly higher in the rotation group than that in control group. For patients with a TT-TG distance of >20 mm, the increased TT-TG distance was mainly caused by tibiofemoral rotation angle in group C (TT-TG > 20 mm, TT-PCL < 24 mm) and predominantly induced by tibial tubercle lateralization in group D (TT-TG > 20 mm, TT-PCL > 24 mm). Bisect offset index and patellar tilt angle were significantly higher in the group C than group D.

Conclusion: The increased tibiofemoral rotation angle is associated with patellar maltracking in patients with recurrent patellar dislocation. Patients with increased tibiofemoral rotation angle usually have more severe patellar maltracking.

Key words: patellar dislocation; patellar maltracking; tibial tubercle-trochlear groove; tibiofemoral rotation

Introduction

Patellar maltracking refers to the abnormal relationship between the patella and trochlea during knee flexion-extension, and previous studies have found that patellar maltracking is present in up to 70% of patients with recurrent patellar dislocation (RPD). J-sign is the most commonly used visual assessment of patellar maltracking in patients with RPD. The clinical significance of patellar maltracking is that it can lead to pain, instability, and mechanical malalignment. The relationship between tibiofemoral rotation and patellar maltracking has not been well studied. In this study, we aimed to investigate the association between tibiofemoral rotation and patellar maltracking in patients with recurrent patellar dislocation.
maltracking in the management of RPD has been validated by several studies in the literature. In a recent clinical study, Sappey et al. reported the clinical outcomes of 211 RPD patients treated with isolated medial patellofemoral ligament reconstruction (MPFL-R) and found that a positive J-sign was an independent risk factor for MPFL-R failure. Similarly, Zhang et al. reported that the presence of a preoperative severe patellar maltracking (high-grade J-sign) was associated with residual graft laxity after MPFL-R in patients with RPD. Moreover, one study analyzed the influence of the severity of patellar maltracking on clinical outcomes in patients with RPD, which found a close relationship between patellar maltracking and postoperative patient-reported outcomes: the more severe the patellar maltracking, the worse the functional outcomes. Therefore, the underlying causes of patellar maltracking should be fully clarified, which can guide the clinical treatment of RPD with patellar maltracking.

To date, it is most commonly viewed that patellar maltracking occurs as a result of an imbalance in the dynamic relationship between the patella and trochlea, which is often secondary to some underlying structural abnormalities, such as muscular imbalance of the quadriceps femoris, abnormal patellar height, trochlear dysplasia, increased tibial tubercle-trochlear groove (TT-TG) distance, and lower extremity rotational deformities. These deformities have been thought to increase the forced shift of the patella towards the lateral side in terminal knee extension and result in patellar maltracking.

Femoral anteversion, external tibial rotation, and tibiofemoral rotation, which are measured by comparing the angle between the posterior femoral line and tibial condylar lines and distinct from femoral or tibial torsion arising from within the respective bone, are three parameters reflecting the severity of lower extremity rotational deformities. Many studies have found that the first two parameters (increased femoral anteversion and external tibial rotation) are contributing factors for patellar maltracking in patients with recurrent patellar dislocation. In contrast, little is known about the role of tibiofemoral rotation in recurrent patellar dislocation.

Recently, tibiofemoral rotation has been identified as a potential contributing factor to recurrent patellar dislocation. Several studies found that the tibiofemoral rotation angle was significantly higher in patients with recurrent patellar dislocation than the control group. Some authors compared the tibiofemoral rotation angles in different populations and found that tibiofemoral rotation was correlated with the severity of patellar dislocation. Further studies demonstrated that tibiofemoral rotation angle was correlated with patellar lateral shift distance in a cadaveric biomechanical study. It is speculated that tibiofemoral rotation may contribute to patellar dislocation because external rotation of the tibia relative to the distal femur results in lateralization of the tibial tubercle, increased lateral tilt, attenuated medial soft tissues, and altered force vectors, all of which contribute to decreased patellar stability and patellar maltracking. These above studies suggested that the tibiofemoral rotation might play an important role in the formation of patellar maltracking in patients with recurrent patellar dislocation.

To our knowledge, no studies have systematically investigated the association between increased tibiofemoral rotation and patellar maltracking in patients with recurrent patellar dislocation. Therefore, the purpose of this study was: (i) to report the value of tibiofemoral rotation angle in patients with recurrent patellar dislocation; and (ii) to analyze the relationship between tibiofemoral rotation angle and patellar maltracking. We hypothesized that the increased tibiofemoral rotation angle is a potential contributing factor for patellar maltracking in patients with recurrent patellar dislocation.

**Materials and Methods**

A total of 169 patients were diagnosed with RPD and surgically treated in our institution from January 2018 to December 2019. The inclusion criteria were: (i) recurrent patellar dislocation; (ii) record of preoperative J-sign; (iii) presence of preoperative imaging. The exclusion criteria were: (i) revision surgery; (ii) acute first-time dislocation; (iii) lack of preoperative CT imaging. Finally, a total of 143 knees in 118 patients who met the criteria were enrolled in the study. This study was approved by our Institutional Ethics Board (IRB approval number: 01-07-2020).

**Patellar Maltracking Assessment**

Patellar maltracking was characterized by the bisect offset index (BOI) and patellar tilt angle on CT. BOI, which assesses medial or lateral subluxation of the patella, quantifies the normalized width of the patella lateral to the trochlear groove. The BOI is calculated by dividing the length along the patellar width from the lateral-most point to the line through the groove by the total width of the patella. Patellar tilt angle is measured as the angle formed between the posterior condylar axis and the patellar width line (Figure 1). Moreover, knee range of motion (ROM) and J-sign are also assessed during physical examination.

**Lower-Leg Rotational Parameters Assessment**

CT scans were performed on an Aquilion One scanner (Toshiba Medical Systems, America) for all patients with RPD during a maximum quadriceps contraction preoperatively. The Digital Imaging and Communications in Medicine data from the hip-knee-ankle CT scan were reconstructed into three-dimensional models with Mimics Research 20.0 (Materialize, Belgium) to measure the rotational parameters of the lower extremity according to the method described previously. The femoral anteversion angle is defined as the angle formed between the axis of the femoral head–neck and distal femur. Tibiofemoral rotation angle is measured by comparing the angle between the posterior femoral and tibial condylar lines. A positive angle...
indicates internal rotation of the distal femur relative to the proximal tibia. The tibial torsion angle is assessed by measuring the rotational angle of the proximal tibia relative to the distal tibia (Figure 2). The inter- and intro-observer inter-class correlation coefficient (ICC) were 0.92 and 0.91 for femoral anteversion angle, 0.89 and 0.88 for tibiofemoral rotation angle, 0.93 and 0.94 for tibial torsion angle.

**Radiological Measurements**
The knee radiographs included the anteroposterior view and the lateral view with 30° of knee flexion. The Caton-Deschamps Index (CDI) was used to measure patellar height, and patella alta was defined as CDI ≥1.2. Trochlear dysplasia was detected on the true lateral view of the knee and classified according to the Dejour classification system. CT scans were performed for all patients with RPD during a maximum quadriceps contraction preoperatively. All patients were examined with computerized axial tomography for the measurement of the TT-TG distance according to the method described by Camp et al. The TT-TG is evaluated by measuring the distance between the most anterior point of the tibial tuberosity and the deepest point of the trochlear groove using two lines drawn perpendicular to the tangent to the posterior borders of the femoral condyles. TT-TG distance of more than 20 mm is believed to be nearly always associated with patellar instability. An alternative method for assessing tibial tubercle position was proposed measuring the distance in reference to the posterior cruciate ligament and

**Tibial Tubercle-Trochlear Groove (TT-TG) and Tibial Tubercle-Posterior Cruciate Ligament (TT-PCL) Measurement**

CT scans were performed for all patients with RPD during a maximum quadriceps contraction preoperatively. All patients were examined with computerized axial tomography for the measurement of the TT-TG distance according to the method described by Camp et al. The TT-TG is evaluated by measuring the distance between the most anterior point of the tibial tuberosity and the deepest point of the trochlear groove using two lines drawn perpendicular to the tangent to the posterior borders of the femoral condyles. TT-TG distance of more than 20 mm is believed to be nearly always associated with patellar instability. An alternative method for assessing tibial tubercle position was proposed measuring the distance in reference to the posterior cruciate ligament and
not to the trochlea (TT-PCL)\textsuperscript{24}, which reflected the true lateralization of the tibial tubercle relative to the proximal tibia, with proposed pathologic threshold of 24 mm.

To further clarify the complicated relationship among TT-TG, TT-PCL, tibiofemoral rotation, and patellar tracking, patients were divided into four subgroups according to TT-TG and TT-PCL (Group A: TT-TG < 20 mm, TT-PCL < 24 mm; Group B: TT-TG < 20 mm, TT-PCL > 24 mm; Group C: TT-TG > 20 mm, TT-PCL < 24 mm; Group D: TT-TG > 20 mm, TT-PCL > 24 mm).

Statistical Analyses

Statistical analyses were performed with the SPSS 20.0 software package (IBM, Chicago, US). Pearson’s chi-square test or Fisher’s exact test was used to compare categorical variables. For comparisons of continuous variables, Student’s t-test or Mann–Whitney U-test was used. The Pearson correlation (normal data) or Spearman’s rank correlation coefficient (non-normal data) was calculated. A comparison of patellar maltracking was performed between the rotation group and control group. p values <0.05 were considered significant and all p values were two-tailed.

Results

General Results

A total of 143 knees in 118 patients with RPD were included in the present study. One hundred and four patients experienced patellar dislocations during activities of daily living and 14 patients with competitive sports. No patients showed limited knee ROM preoperatively.

Relationship between Patellar Maltracking and Bony Deformities

The mean tibiofemoral rotation angle was 12° ± 6° (range, 0°–31°) (Table 1). Pearson correlation between patellar maltracking parameters (BOI, lateral tilt) and various bony deformities found that the tibiofemoral rotation was moderately correlated with patellar tilt angle ($r = 0.462, p < 0.001$) and BOI ($r = 0.451, p < 0.001$) (Table 2).

Association between Tibiofemoral Rotation and Patellar Maltracking

The association between tibiofemoral rotation and patellar maltracking was further analyzed. Results demonstrated that the BOI (152.1 vs 121.2, $p < 0.001$) and patellar tilt angle (41.2° vs 33.5°, $p < 0.001$) were significantly higher in the rotation group (tibiofemoral rotation≥15°) than that in control group (tibiofemoral rotation<15°) (Table 3).

Comparison among the Four Subgroups

The results of comparison among the four subgroups were showed in Table 4. For patients with a TT-TG distance of <20 mm, no significant difference was found in BOI (117 vs109, $t = 1.012, p = 0.315$) and patellar tilt angle (31.7 vs 29.1, $t = 0.399, p = 0.691$) between these two subgroups. For patients with a TT-TG distance of >20 mm, Group C had normal TT-PCL and increased tibiofemoral rotation, in contrast, Group D had increased TT-PCL and relatively normal tibiofemoral rotation. In other words, the increased TT-TG was mainly caused by tibiofemoral rotation in Group C and was predominantly induced by tibial tubercle lateralization in Group D. Further comparison showed that the BOI (159 vs 127, $t = 13.764, p < 0.001$) and patellar tilt angle (43.0 vs 36.6, $t = 5.643, p < 0.001$) were significantly higher in the Group C than Group D.

Discussion

Main Findings of this Study

The most important finding of this study is that the increased tibiofemoral rotation angle is associated with patellar maltracking in patients with RPD. Tibiofemoral rotation-induced TT-TG abnormality deserves more attentions in clinical practice, because these patients usually have more serious patellar maltracking compared with tibial tubercle lateralization-caused TT-TG abnormality.

Influence of Tibiofemoral Rotation on Patellar Tracking

Tibiofemoral rotation angle, as an important component of rotational parameters of the lower extremity, has been found to be higher in patients with RPD than that in healthy population\textsuperscript{16,18,19,25}, which indicates that an increased tibiofemoral rotation angle may be a potential risk factor for RPD. However, few studies have investigated the association between the increased tibiofemoral rotation and patellar maltracking in the literature. Lin et al. compared the degree of tibiofemoral rotation in different populations and found that tibiofemoral rotation was correlated with the severity of patellar dislocation, with the greatest value in fixed or obligatory dislocation patients\textsuperscript{13}. Keshmiri et al. analyzed the influence of rotational limb alignment parameters on patellar kinematics, which demonstrated that tibiofemoral rotation produced a significant influence on patellar medial-lateral

### TABLE 1 Demographic information of the included patients

| Variate                  | Mean ± SD (range) |
|-------------------------|-------------------|
| Age                     | 20.8 ± 5.8 (16–38) |
| Femoral anteversion     | 28 ± 11 (4–70)    |
| Tibiofemoral rotation   | 12 ± 6 (0–31)     |
| Tibial torsion           | 30 ± 8 (8–55)     |
| TT-TG                   | 20.1 ± 3.9 (10.3–32.6) |
| TT-PCL                  | 23.0 ± 2.4 (12.1–31.2) |
| Patellar height          | 1.19 ± 0.21 (0.73–1.78) |
| Trochlear dysplasia      | 9/64/53/3/14      |
| (normal/type A/ B/ C/ D)|                   |
| J-sign (positive/negative)| 103/40            |

*Abbreviations: SD, standard deviation; TT-TG, tibial tuberosity-trochlear groove; TT-PCL, tibial tubercle-posterior cruciate ligament.*
TABLE 2 Pearson correlation between patellar maltracking and bony deformities

| Variate          | BOI          | Patellar tilt angle |
|------------------|--------------|---------------------|
|                  | r            | p value             | r                | p value             |
| Femoral anteversion | 0.289        | **0.002**           | 0.264            | **0.004**           |
| Tibial torsion    | 0.063        | 0.499               | 0.129            | 0.166               |
| Tibiofemoral torsion | 0.451        | **<0.001**          | 0.462            | **<0.001**          |
| Patellar height   | 0.306        | **0.001**           | 0.192            | **0.044**           |
| TT-TG             | 0.548        | **<0.001**          | **0.559**        | **<0.001**          |
| TT-PCL            | 0.143        | 0.235               | 0.097            | 0.321               |

*Abbreviations: BOI, bisect offset index; bolded values indicate statistical significance (p < 0.05); TT-TG, tibial tuberosity-trochlear groove; TT-PCL, tibial tubercle-posterior cruciate ligament.

TABLE 3 Comparison results between rotation group and control group

| Variables          | Rotation group | Control group | Statistic value |
|--------------------|----------------|---------------|-----------------|
| Age                | 21.2 ± 6.7     | 20.7 ± 5.4    | t = 0.497, p = 0.620 |
| Gender (F/M)       | 31/6           | 90/16         | χ² = 0.027, p = 0.871 |
| Femoral anteversion| 29 ± 13        | 27 ± 10       | t = 1.033, p = 0.303 |
| Tibial torsion     | 29 ± 7         | 30 ± 9        | t = −1.552, p = 0.123 |
| Tibiofemoral Rotation | 19 ± 3     | 9 ± 4         | t = 13.970, p < 0.001 |
| Patella height     | 1.27 ± 0.23    | 1.16 ± 0.20   | t = 2.664, p = 0.009 |
| Severe trochlear dysplasia | 22 | 44 | χ² = 3.556, p = 0.059 |
| TT-TG              | 21.9 ± 4.2     | 19.4 ± 3.6    | t = 3.529, p = 0.001 |
| TT-PCL             | 21.2 ± 3.2     | 23.6 ± 2.2    | t = 2.354, p = 0.021 |
| BOI                | 152.1 ± 46.8   | 121.2 ± 35.7  | t = 3.851, p = 0.001 |
| Patellar tilt angle | 41.2 ± 12.2   | 33.5 ± 10.4   | t = 3.439, p = 0.001 |

Abbreviations: BOI, bisect offset index; bolded values indicate statistical significance (p < 0.05); F/M, female/male; TT-TG, tibial tuberosity-trochlear groove; TT-PCL, tibial tubercle-posterior cruciate ligament.

TABLE 4 Subgroup analysis results based on TT-TG and TT-PCL

| TT-TG < 20 mm | TT-TG > 20 mm |
|---------------|---------------|
| TT-PCL < 24   | TT-PCL > 24   | Statistic value |
| TT-PCL < 24   | TT-PCL > 24   | Statistic value |
| Number        | 41            | 27            | 43            | 32            |
| Age           | 20.9          | 20.1          | t = 0.648, p = 0.519 | 21.2          | 20.7          | t = 0.485, p = 0.629 |
| Gender (F/M)  | 35/6          | 22/5          | χ² = 0.281, p = 0.743 | 38/5          | 26/6          | χ² = 0.743, p = 0.513 |
| Affected sige  | 24/17         | 15/12         | χ² = 0.059, p = 0.808 | 21/22         | 15/17         | χ² = 0.028, p = 0.866 |
| (L/R) TT-TG    | 16.9 ± 2.6    | 17.3 ± 1.7    | t = −0.370, p = 0.712 | 22.8 ± 3.2    | 22.9 ± 2.5    | t = −0.137, p = 0.891 |
| TT-PCL         | 20.3 ± 2.9    | 26.4 ± 2.3    | t = −4.137, p < 0.001 | 21.0 ± 3.6    | 26.4 ± 2.0    | t = 5.783, p < 0.001 |
| Tibiofemoral Rotation | 12 ± 6 | 6 ± 4 | t = 12.456, p < 0.001 | 15 ± 5 | 11 ± 5 | t = 7.451, p < 0.001 |
| Femoral Antversion | 28 ± 9 | 27 ± 10 | t = 0.993, p = 0.324 | 29 ± 15 | 25 ± 9 | t = 1.473, p = 0.145 |
| Tibial Torsion  | 30 ± 8        | 29 ± 7        | t = 0.538, p = 0.592 | 29 ± 7        | 31 ± 9        | t = −1.247, p = 0.216 |
| CDI            | 1.13 ± 0.19   | 1.16 ± 0.17   | t = −1.241, p = 0.219 | 1.20 ± 0.22   | 1.22 ± 0.20   | t = −1.077, p = 0.285 |
| Severe TD, n (%) | 17 (41%)     | 8 (30%)       | χ² = 0.980, p = 0.322 | 24 (56%)      | 16 (50%)      | χ² = 0.249, p = 0.618 |
| BOI            | 117 ± 38      | 109 ± 16      | t = 1.012, p = 0.315 | 159 ± 51      | 127 ± 24      | t = 13.764, p < 0.001 |
| Patellar Tilt angle | 31.7 ± 11.7 | 29.1 ± 7.4 | t = 0.399, p = 0.691 | 43.0 ± 11.3 | 36.6 ± 7.9 | t = 5.643, p < 0.001 |

*Abbreviations: BOI, bisect offset index; bolded values indicate statistical significance (p < 0.05); TT-TG, tibial tuberosity-trochlear groove; TT-PCL, tibial tubercle-posterior cruciate ligament; CDI, Caton–Deschamps index; TD, trochlear dysplasia.

Shift in cadaveric knees. Consistent with the study of Keshmiri, the present study found that the tibiofemoral rotation was moderately correlated with the patellar tilt angle and BOI, but with one main difference: this present research was conducted in patients with RPD but not in normal cadaveric knees. Based on the above results, one possibility, far from proved, is that the increased tibiofemoral rotation angle is a contributing factor for patellar maltracking in patients with RPD. However, it must be noted that patella height was significantly higher in the rotation group than the control group as described in Table 3, the patella might be as much the origin for patellar maltracking as the tibiofemoral rotation, and further studies are needed to demonstrated the complex relationship between tibiofemoral rotation and patellar maltracking.
**Relationship between TT-TG and Tibiofemoral Rotation**

TT-TG distance has long been thought to reflect the lateralization of the tibial tubercle and is commonly used as an indicator for tibial tubercle medialization. However, recent studies found that the TT-TG was in fact an amalgamated measure of true lateralization of the tibial tubercle and the tibiofemoral rotation. TenSho et al. found that TT-TG distance had no linear correlation with tibial tubercle lateralization; however, tibiofemoral rotation strongly correlated with the TT-TG distance \( r = 0.69 \) in patients with RPD, therefore, they concluded that TT-TG distance was affected more by tibiofemoral rotation than by tibial tubercle lateralization; therefore, its use as an indicator for tibial tubercle transfer might be inappropriate. Similarly, Anley et al. also declared that an increased TT-TG may result from the true lateralization of the tibial tubercle, an increased tibiofemoral rotation, or both. However, if a tibial tubercle medialization is performed in a patient without major tibial tubercle lateralization (such as patients with a TT-TG > 20 mm, but TT-PCL < 24 mm), the patellar tracking may not normalize, and abnormal stress on the medial patellofemoral joint may persist because the underlying cause of increased TT-TG distance in these patients has not been settled precisely. Parikh et al. stated that tibial tubercle osteotomy could increase external torsion of the tibia and exacerbate changes in the presence of underlying rotational malalignment. Nakagawa et al. reported the long-term results of tibial tubercle osteotomy in 39 patients and found that the osteoarthritic changes of the patellofemoral joint had advanced in up to 42% of patients. Therefore, surgeons should recognize that this procedure may not always represent a patient-centered treatment in some patients who have a TT-TG elevated by knee rotation and not by lateralization of the tibial tubercle. In these patients, it may be appropriate to use another technique (e.g. derotational osteotomy, trochleoplasty) that is based on individual pathological conditions. Thus, indications for tibial tubercle medialization for the treatment of RPD should not merely be determined by the TT-TG distance, but also another value that directly reflects tibial tubercle lateralization at the proximal part of the tibia, such as the TT-PCL distance.

**Correlation between TT-TG and Patellar Maltracking**

The correlation between TT-TG and patellar maltracking has been reported. Williams et al. evaluated the role of TT-TG distance in patellofemoral kinematics using dynamic CT and found that an association existed between TT-TG distance and the patellar tracking parameters, which was in line with the present study. To further clarify the complicated relationship among TT-TG, TT-PCL, tibiofemoral rotation, and patellar maltracking, patients were divided into four subgroups. The most interesting finding is that if the increased TT-TG distance is mainly caused by abnormal tibiofemoral rotation, which accounting for 57% of all cases with increased TT-TG in the present study, patients usually have severe patellar maltracking, which further suggested the obvious correlation between tibiofemoral rotation and patellar maltracking in RPD.

**The Limitations of the Study**

There were several limitations of this study. First, patellar maltracking was assessed using static CT measurements, which may underestimate or overestimate the severity of the true patellar maltracking. Second, in the present study, patients are divided into rotation group (tibiofemoral rotation ≥ 15) and control group (tibiofemoral rotation < 15), which is without theoretical justification because little research on this has yet been done and further studies are needed to confirm what is the threshold of pathological tibiofemoral rotation angle. Third, although the present study found a potential correlation between tibiofemoral rotation and patellar maltracking, we did not further investigate the potential causes of increased tibiofemoral rotation and how to correct this rotational deformity.

**Conclusion**

The increased tibiofemoral rotation angle is associated with patellar maltracking in patients with recurrent patellar dislocation. Patients with increased tibiofemoral rotation angle usually have more severe patellar maltracking. Therefore, tibiofemoral rotation angle should be measured routinely preoperatively to assess the patellar tracking more accurately.

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**Conflicts of Interest**

The authors declare that they have no conflict of interest.

**Authors Contributions**

Guan Wu participated in study design, data collection, and drafted the manuscript. Hui Zhang and GuanYang Song carried out the radiological measurements. Tong Zheng participated in the data collection and statistical analysis. YanWei Cao carried out the radiological measurements. Yue Li participated in the study design and data collection. Zhi Jun Zhang conceived of the study, and participated in its design and helped to draft the manuscript. All authors read and approved the final manuscript.

**Ethics Approval**

All procedures performed in this retrospective study were in accordance with the ethical standards of the Beijing Jishuitan hospital, and this study was performed after obtaining approval from our institutional review board (IRB, No. 20200701).
Consent to Participate
All patients provided informed consent before participating in this study.

Consent for Publication
All patients provided informed consent for publication.

Reference
1. Jibiri Z, Jamieson P, Rakhaa KS, Sampaio ML, Dervin G. Patellar maltracking: an update on the diagnosis and treatment strategies. Insights Imaging. 2019;10:65–5.
2. Xue Z, Song GY, Lui X, Zhang H, Wu Q, Qian Y, et al. Excessive lateral patellar translation on axial computed tomography indicates positive patellar J-sign. Knee Surg Sports Traumatol Arthrosc. 2018;26:3620–9.
3. Best MJ, Tanaka MJ, Demehri S, Cosgarea AJ. Accuracy and reliability of the visual assessment of patellar tracking. Am J Sports Med. 2020;48:370–5.
4. Sappey-Mariner E, Sonnery-Cottet B, O’Loughlin P, et al. 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;47:1323–30.
5. Zhang Z, Song G, Zheng T, Ni Q, Feng H, Zhang H. The presence of a preoperative high-grade J-sign and femoral tunnel malposition are associated with residual graft laxity after MPFL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2021;29:1183–90.
6. Zhang Z, Zhang H, Song G, Zheng T, Feng H. A pre-operative grade 3 J-sign adversely affects short-term clinical outcome and is more likely to yield MPFL residual graft laxity in recurrent patellar dislocation. Knee Surg Sports Traumatol Arthrosc. 2020;28:2147–56.
7. Pal S, Draper CE, Fredericon M, Gold GE, Delp SL, Beaufre GS, et al. Patellar Maltracking correlates with vastus Medialis activation delay in patellar femoral pain patients. Am J Sports Med. 2011;39:590–8.
8. Ward SR, Terk MR, Powers CM. Patella Alta: association with patellofemoral alignment and changes in contact area during weight-bearing. J Bone Joint Surg Am. 2007;90:1749–55.
9. Elayini R, Elias J, Saranathan A, Feng H, Guseila LM, Morschler MA, et al. Antomical factors influencing patellar tracking in the unstable patellofemoral joint. Knee Surg Sports Traumatol Arthrosc. 2014;22:2334–41.
10. Van HA, De RK, De BM, et al. The effect of trochlear dysplasia on patellofemoral maltracking: a cadaveric study with simulated trochlear deformities. Am J Sports Med. 2015;43:1354–61.
11. Frosch KH, Schmenling A. A new classification system of patellar instability and patellar maltracking. Arch Orthop Trauma Surg. 2016;136:485–97.
12. Balcarek P, Radebold T, Schulz X, Vogel D. Geometry of torsional malalignment syndrome: trochlear dysplasia but not torsion predicts lateral patellar instability. Knee Surg Sports Traumatol Arthrosc. 2019;7:2325967119829790. https://doi.org/10.1177/2325967119829790.
13. Lin KH, James EW, Atkinson AH, Schlichte LM, Wang G, Green DW. Increased tibiofemoral rotation on MRI with increasing clinical severity of patellar instability. Knee Surg Sports Traumatol Arthrosc. 2021;29:3735–42. https://doi.org/10.1007/s00167-020-06382-x.
14. Schueda MA, Astur DC, Bier RS, Bier DS, Astur N, Cohen M. Use of computed tomography to determine the risk of patellar dislocation in 921 patients with patellar instability. Open Access J Sports Med. 2015;6:55–62.
15. Dickschas J, Harer J, Pfefferkorn R, Streek W. Operative treatment of patellofemoral maltracking with torsional osteotomy. Arch Orthop Trauma Surg. 2012;132:289–96.
16. Diederichs G, Kohlitz TF, Heiler MO, Vollinberg B, Scheffler S. Magnetic resonance imaging analysis of trochlear alignment in patients with patellar dislocations. Am J Sports Med. 2013;41:51–7.
17. Prakash J, Seon JK, Ahn HW, Choi KJ, Im CJ, Song EK. Factors affecting Tibial tuberosity-trochlear groove distance in recurrent patellar dislocation. Clin Orthop Surg. 2018;10:420–5.
18. Tensho K, Aoka M, Shimodaita H, Takanashi S, Ikegami S, Kato H, et al. What components comprise the measurement of the Tibial tuberosity-trochlear groove distance in a patellar dislocation population? J Bone Joint Surg Am. 2015;97:1441–8.
19. Takagi S, Sato T, Watanabe S, Tanfufi O, Mochizuki T, Omori G, et al. Alignment in the transverse plane, but not sagittal or coronal plane, affects the risk of recurrent patella dislocation. Knee Surg Sports Traumatol Arthrosc. 2018;26:2891–8.
20. Keshmiri A, Maderbacher G, Baier C, Zeman F, Grifta D, Springorum HR. Significant influence of rotational limb alignment parameters on patellar kinematics: an invitro study. Knee Surg Sports Traumatol Arthrosc. 2016;24:2407–14.
21. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994;2:19–26.
22. Dejour D, Le Couture B. Osteotomies in patello-femoral instabilities. Sports Med. 2007;37:139–46.
23. Camp CL, Kych A, Stuart MJ. CT and MRI measurements of Tibial tubercle-trochlear groove distances are not equivalent in patients with patellar instability. Am J Sports Med. 2013;41:1835–40.
24. Anley CM, Morris GV, Saltiha A, James SL, Snow M. Defining the role of the Tibial tubercle-trochlear groove and Tibial tubercle-posterior cruciate ligament distances in the work-up of patients with patellofemoral disorders. Am J Sports Med. 2015;43:1348–53.
25. Prakash J, Seon JK, Woo SH, Jin C, Song EK. Comparison of radiological parameters between Normal and patellar dislocation groups in Korean population: a rotational profile CT-based study. Knee Surg Relat Res. 2016;28:302–11.
26. Tensho K, Shimodaita H, Aoka M, Koyama S, Hatanaka D, Ikegami S. Lateralization of the Tibial tubercle in recurrent patellar dislocation: verification using multiple methods to evaluate the Tibial tubercle. J Bone Joint Surg Am. 2018;100:e58.
27. Elias JJ, Scherholt NT, Guseila LM, Cosgarea AJ. Dynamic tracking influenced by anatomy in patellar instability. Knee. 2016;23:450–5.
28. Parikh S, Noyes FR. Patellofemoral disorders: role of computed tomography and magnetic resonance imaging in defining abnormal rotational lower limb alignment. Sports Health. 2011;3:158–69.
29. Nakagawa K, Wada Y, Minamidke T, Tsuichiya A, Moriya H. Deterioration of long-term clinical results after the Elmslie-Trillat procedure for dislocation of the patella. J Bone Joint Surg Br. 2002;84:861–4.
30. Williams A, Elias J, Tanaka M, et al. The relationship between Tibial tuberosity-trochlear groove distance and abnormal patellar tracking in patients with unilateral patellar instability. Art Ther. 2016;32:55–61.