Original Article
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# Patterns of Avulsion and Osteochondral Fractures Associated with Patellar Dislocations: A Descriptive Study Using 3-Dimensional Computed Tomography

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**Background:** This retrospective study aimed to analyze avulsion and osteochondral fractures associated with patellar dislocation using 3-dimensional (3D) computed tomography (CT).

**Methods:** A retrospective analysis was conducted on patients admitted between 2015 and 2023 with acute or recurrent patellar dislocations. A musculoskeletal radiologist and 2 orthopedic surgeons evaluated CT scans of 148 patients (160 knees) to identify and categorize all avulsion and osteochondral fractures. The included fracture patterns were as follows: pattern I: medial patellofemoral ligament (MPFL) avulsion from the upper two-thirds of the patella, pattern II: medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) avulsion from the lower one-third, pattern III: inferomedial patellar facet osteochondral fracture, pattern IV: lateral femoral condyle osteochondral fracture, and pattern V: MPFL avulsion from the femoral footprint. The dimensions of patellar articular surface osteochondral fractures were measured, and patient age, sex, and side were recorded. Descriptive statistics and chi-squared tests were performed.

**Results:** A total of 148 patients (93 female and 55 male patients) with a mean age of 18.7 ± 6.8 years were included. Of these, 116 patients (72.5%) had 1 or more fractures, with 71 (44.4%) having isolated lesions and 45 (28.1%) having combined lesions. Pattern II was the most prevalent, observed in 66 knees (41.2%), followed by pattern I in 52 knees (32.5%), and pattern III in 45 knees (28.1%). Patterns IV and V were seen in 4 (2.5%) and 1 (0.6%) knee, respectively. The mean articular fragment size in pattern III was 128.4 ± 95.6 $mm^2$ (range, 12–412.5 $mm^2$), all involving the inferomedial facet of the patella. Osteochondral fragments were found in the lateral gutter (35.5%), anterior joint space (51.1%), posterior joint space (8.9%), and suprapatellar space (4.5%). No significant sex differences were observed in isolated versus combined lesions ($p$ = 0.542) or fracture patterns ($p$ = 0.274).

**Conclusions:** This study, the first to evaluate fractures after patellar dislocation using 3D CT, identified 5 distinct fracture patterns. The results show that MPTL/MPML injuries are more common than previously thought, challenging traditional views on patellar dislocation injuries and emphasizing the need for a comprehensive diagnostic approach.

**Keywords:** *Patellofemoral joint, Patellar dislocation, Joint instability, Patellar ligament, Patella fracture*

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Acute lateral patellar dislocations are often caused by a non-contact twisting injury to the knee or, less commonly, by direct trauma to the medial aspect of the knee. The typical mechanism of injury is valgus loading of the knee and external rotation of the tibia with the knee in a semi-flexed position and the foot planted on the ground. In a typical lateral patellar dislocation, the patella completely dislocates from the trochlear groove, hits the lateral femoral condyle, and usually reduces spontaneously.[1] Complex injuries occur during both dislocation and reduction of the patella, including medial soft tissue and ligament tears, chondral damage, patellar and femoral avulsion, and/or osteochondral fractures, resulting in damage to multiple structures at multiple sites around the knee joint.[2,3]

Direct radiography is the first-line imaging modality for patellar dislocation. However, radiography often fails to detect these injuries and provides limited information about the soft tissues. Magnetic resonance imaging (MRI), with its excellent soft tissue, cartilage, and bone imaging capabilities, is currently used as the gold standard imaging modality in patellar dislocations.[4,5] The extent, location, and frequency of these injuries have been thoroughly investigated and described in several previous studies. In their review of 35 articles encompassing 2,558 patients, Kluczynski et al.[2] reported that 94.7% of individuals with acute patellar dislocation exhibited a torn medial patellofemoral ligament (MPFL). The most common sites of injury were the patellar insertion (37.1%), femoral insertion (36.8%), combined sites (25.1%), and midsubstance (15.6%).[2] Similarly, Migliorini et al.[3] conducted a review of 42 articles involving 2,254 patients and found that 98% had tears of the MPFL on MRI, predominantly on the patellar side (48%), followed by the femoral insertion (34%) and the medial portion (18%). Additionally, 85% of patients exhibited patellar chondral damage, 47% demonstrated trochlear chondral damage, and intra-articular loose bodies were observed in 11.5% of patients. The majority of these studies employed MRI and focused on MPFL injuries and patellar osteochondral fractures.

On the other hand, computed tomography (CT) can also be used for diagnostic work-up but is less preferred, especially in the pediatric age group, because of the risk of radiation exposure. However, it is still used because it is more readily available in emergency departments and less expensive than MRI.[6,7] In addition, the ability of CT to provide multiplanar and 3-dimensional (3D) evaluation is particularly useful in determining donor sites (sites of fragment detachment), sizes, and intra-articular locations of osteochondral and avulsion fractures. Although there are many studies in the literature evaluating patellar dislocations using MRI, there is a limited number of studies using CT. This study postulates that distinct patterns of avulsion and osteochondral fractures occur with patellar dislocations. These patterns can be systematically categorized using 3D CT based on the corresponding anatomy of the medial patellofemoral complex. Moreover, it is postulated that injuries to the medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) are more prevalent than previously documented, challenging the conventional focus on MPFL injuries as the primary concern.

## METHODS

This study was conducted in accordance with the ethical guidelines of the 1964 Declaration of Helsinki and its subsequent revisions. The Institutional Review Board reviewed and approved the study protocol (Antalya Training and Research Hospital; IRB No. 2023/145). Informed consent was not applicable in this retrospective radiographic study.

### Patients and Study Design

This retrospective study was conducted on patients who were admitted either to the emergency department or orthopedic outpatient clinic with a history of acute or recurrent patellar dislocation between January 2015 and January 2023. Among these patients, those who underwent knee CT were identified and included in the study. Patients with prior surgical operations and congenital patellar dislocations were excluded from the study.

### Assessment of CT Scans

Radiological assessments were performed on digital CT images stored in picture archiving and communication systems (PACS) using the software program Sectra IDS7 (version 18.2, Sectra AB) on the digital workstation. Both multiplanar 2D (axial, coronal, sagittal, and oblique planes) and 3D reconstructions were analyzed. Evaluations were performed by a panel consisting of a musculoskeletal radiologist (KKK) and 2 orthopedic surgeons (OK and FD) experienced in sports traumatology and PF instability in the same session. All decisions were made unanimously, and a consensus decision was reached. Only bony structures, medial patellar pericapsular avulsion fractures, and fractures of the articular surface of the femoral condyles were evaluated. Soft-tissue injuries were not assessed due to CT's limited ability to evaluate soft tissue. A total of 148 patients with 160 knee CTs were assessed, and 5 elemental fracture types were identified based on the donor site of fractures and the anatomy of the medial patellofemoral complex. The medial patellofemoral complex is comprised of 4 distinct components: the MPFL, the medial quadriceps tendon femoral ligament (MQTFL), the MPTL, and the MPML. While the MPFL is the primary restraint against lateral patellar dislocation, the MQTFL, MPTL and MPML also play an important role in patellar stabilization, particularly at higher degrees of knee flexion. The MPTL connects the inferomedial aspect of the patella to the tibia, while the MPML connects the patella to the medial meniscus. These ligaments serve as secondary stabilizers, influencing the control of patellar tilt and rotation, particularly in the context of trochlear dysplasia (Fig. 1).[8,9]

However, while these 5 elemental fracture types could be observed in isolation, multiple fractures could occur in the same patient. Table 1 provides descriptions of the fractures. Furthermore, the size of the intra-articular osteochondral fractures was measured, and their locations were recorded due to their critical role in guiding treatment decisions and optimizing surgical planning.

### Description of Fracture Patterns

On the medial side of the patella, avulsion fractures were observed in 2 different locations. The first pattern (pattern I) (Fig. 2) occurred at the 2/3 superior pole of the patella, corresponding to the MPFL footprint, and the other (pattern II) (Fig. 3) was more distal at the 1/3 inferior pole of the patella, corresponding to the attachment of the MPTL and MPML ligaments. Both fractures were small extra-articular avulsion fractures. The third pattern (pattern III) was an intra-articular fracture involving an osteochondral fragment of the inferomedial articular facet of the patella due to lateral dislocation of the patella and impaction on the lateral femoral condyle (Fig. 4). The osteochondral fragment almost always involved the inferomedial facet of the patella, occasionally extending over the entire crest. Because these osteochondral fragments are accessible within the joint space, they were identified in various locations. The fourth pattern (pattern IV) formed with the exact mechanism as the third pattern, but it is a lateral condyle fracture due to the coup-countercoup mechanism.

**Table 1.** Definitions of 5 Elemental Fractures Observed in Patellar Dislocations

| Fracture pattern | Definition |
|---|---|
| Pattern I | MPFL avulsion fracture from the patella. The fragment is located in the upper 2 / 3 of the patella. |
| Pattern II | MPTL & MPML avulsion fracture from the patella. The fragment is located in the lower 1 / 3 of the patella. |
| Pattern III | Inferomedial patellar facet osteochondral fracture |
| Pattern IV | Lateral femoral condylar osteochondral fracture |
| Pattern V | MPFL avulsion fracture from the femoral footprint |

MPFL: medial patellofemoral ligament, MPTL: medial patellotibial ligament, MPML: medial patellomeniscal ligament.

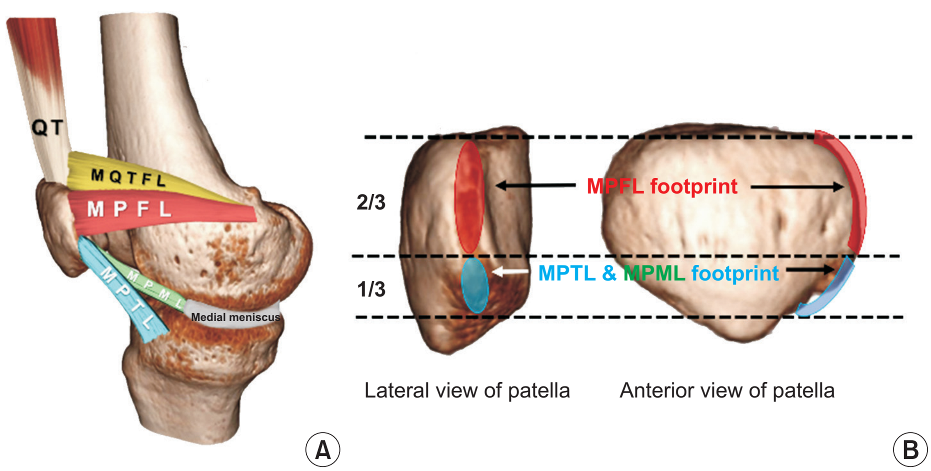


**Fig. 1.** Anatomical representation of the patella and its medial ligamentous attachments, showing the footprints of the medial patellofemoral ligament (MPFL), medial patellotibial ligament (MPTL), and medial patellomeniscal ligament (MPML). (A) Medial aspect of the knee joint showing the MPFL, medial quadriceps tendon femoral ligament (MQTFL), MPTL, and MPML, as well as the medial meniscus. (B) Lateral and anterior views of the patella depicting the distinct footprints of the MPFL, MPTL, and MPML. The MPFL footprint is indicated in red, highlighting its extent along the upper two-thirds of the patella, while the blue area represents the combined footprints of the MPTL and MPML on the lower third, demonstrating their relative positions. QT: quadriceps tendon.

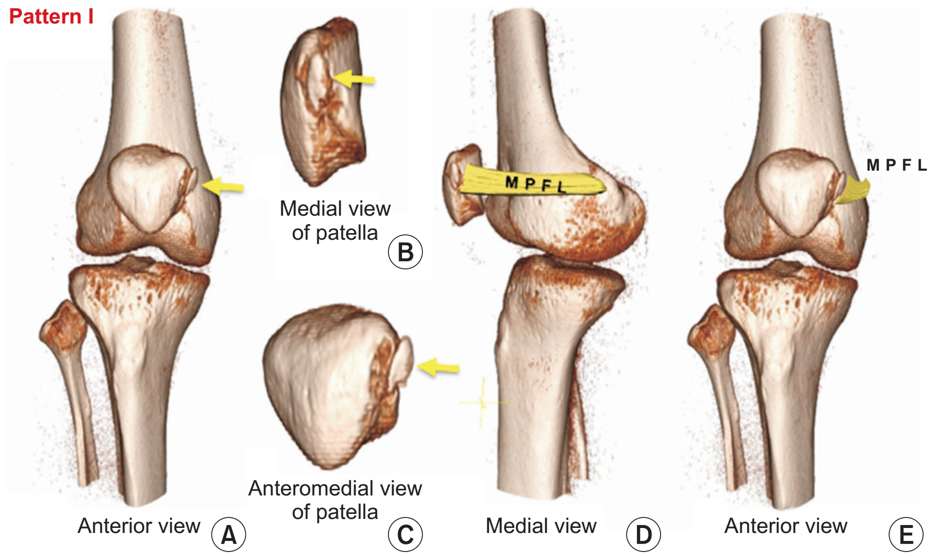


**Fig. 2.** Avulsion fracture of the medial patellofemoral ligament (MPFL) from the patella (pattern I). (A) The anterior view of the knee with a yellow arrow indicating the site of the MPFL avulsion fracture. (B) A medial view of the patella where the yellow arrow points to the exact location of the ligament's detachment and the avulsed fragment. (C) An anteromedial view with a yellow arrow marking the fracture site and fragment. (D) A medial view of the knee, illustrating the MPFL labeled in yellow, signifying its attachment point on the avulsed fragment. (E) A subsequent anterior view focusing on the MPFL's position relative to the knee joint.

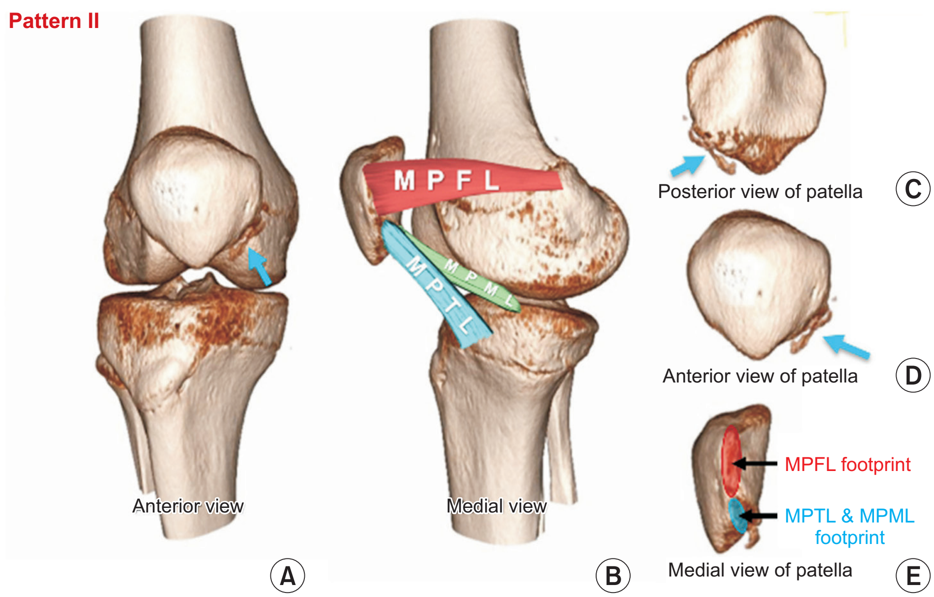


**Fig. 3.** Avulsion fracture of the medial patellotibial ligament (MPTL) and medial patellomeniscal ligament (MPML) from the patella (pattern II). (A) The anterior view of the knee with a blue arrow indicating the medial patellofemoral ligament (MPFL) and MPML avulsion fracture. (B) The patellar ligaments on the medial aspect of the knee. Note that the avulsed fragment corresponds to the attachment site of the MPTL and MPML ligaments. (C, D) The posterior and anterior views of the patella and avulsed fragment (blue arrows). (E) The medial view of the patella and the footprints of the MPFL (red circle) and MPTL & MPML (blue circle). It is obviously seen that the fragment belongs to the patellar footprint of the MPTL and MPML.

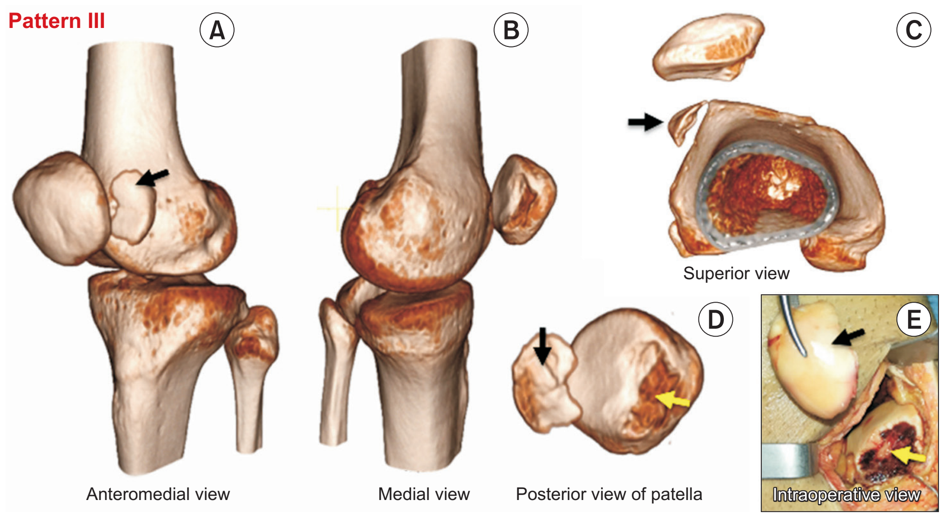


**Fig. 4.** Osteochondral avulsion fracture from the patella (pattern III). (A) The anterolateral view of the knee shows the osteochondral fragment trapped in lateral gutter (black arrow). (B) The medial view of the knee joint highlights the location of the patellar fracture. (C) A superior view of the knee, detailing the osteochondral fracture (black arrow) within the lateral gutter. (D) The posterior view of the patella with a yellow arrow denoting the site of the avulsion and the fragment (black arrow). (E) The intraoperative view showcasing both the osteochondral fracture marked by a black arrow and the site of fracture on the articular surface of the patella (yellow arrow).

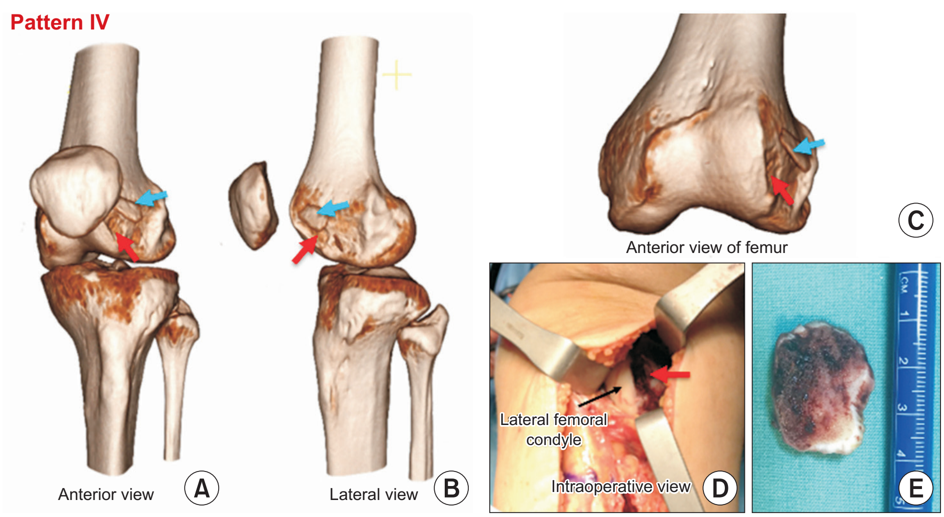


**Fig. 5.** Osteochondral fracture of the lateral femoral condyle (pattern IV). (A, B) The anterior and lateral views of the knee show both the osteochondral fracture (blue arrow) and the site of fracture on the lateral femoral condyle (red arrow). (C) The anterior view of the femur. The patella is removed to visualize the fracture more clearly. The osteochondral fracture and the site of the fracture are seen. (D) Intraoperative view showing the site of fracture (red arrow). (E) A large (3 cm × 2 cm) osteochondral fragment is seen.

It could be seen as a free osteochondral fragment falling into the joint or an impaction fracture of the lateral femoral condyle (Fig. 5). The fifth fracture was observed on the femoral footprint of MPFL at the medial side of the femur (Fig. 6).

### Statistical Analysis

Descriptive statistics included means, standard deviations, numbers, and percentages. A comparison of categorical variables was performed using the chi-square test. Continuous variables between independent groups were compared with the Student *t*-test. All statistical analyses were performed using SPSS version 23 (IBM Corp.). A *p*-value less than 0.05 was accepted as significant.

## RESULTS

There were 148 patients (93 female and 55 male patients) with a mean age of 18.7 ± 6.8 years (range, 10–44 years). Twelve patients had bilateral involvement, and a total of 160 knees were examined: 69 right (43.1%) and 91 left (56.9%) knees were involved. In 89 knees (55.6%), CT was performed immediately after acute dislocation, and in 71 knees (44.4%), after recurrent dislocation. While no frac-

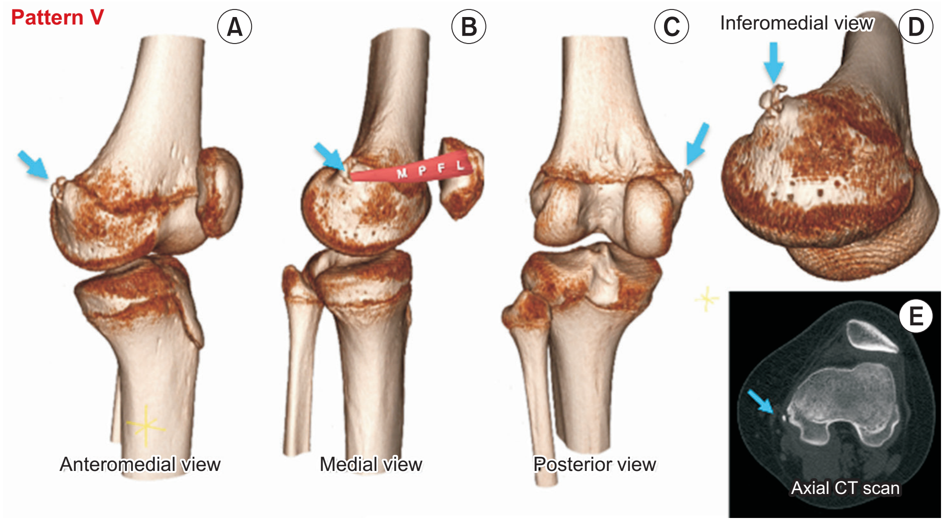


**Fig. 6.** Avulsion fracture of the medial patellofemoral ligament (MPFL) from its femoral footprint (pattern V). (A) Anteromedial view of the knee showing the avulsion fracture at the site of MPFL footprint (blue arrow). (B) Lateral view of the knee showing the illustrated MPFL and the avulsion fracture (blue arrow). (C, D) The posterior and inferomedial view of the knee, showing the avulsion fracture (blue arrows). (E) The axial computed tomography (CT) image showing the avulsion fracture (blue arrow).

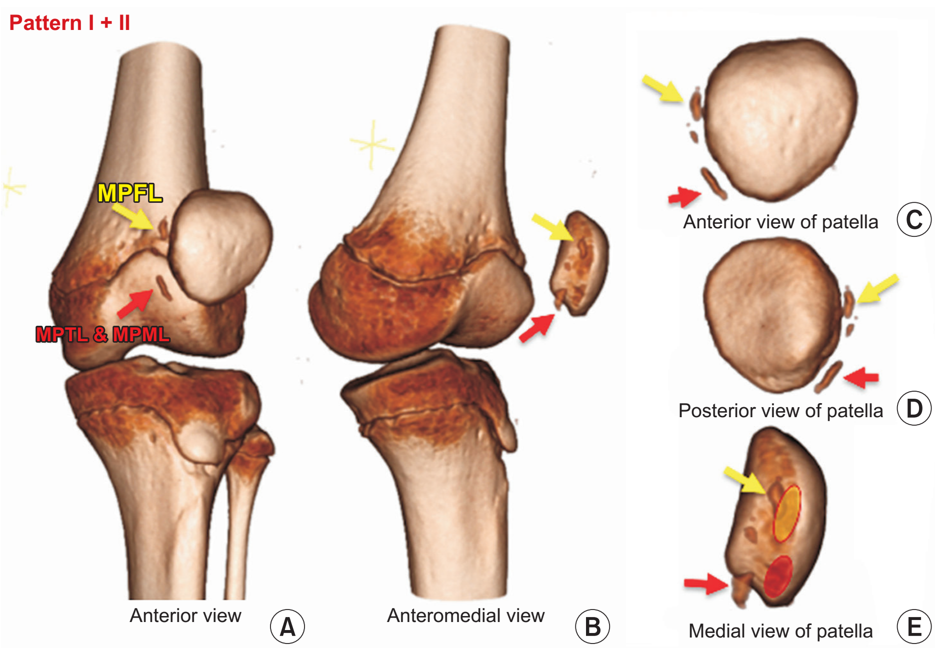


**Fig. 7.** Combination of pattern I and II fractures. Anterior (A) and anteromedial (B) views of the knee joint show two avulsion fractures. The superior avulsion fracture is formed by the medial patellofemoral ligament (MPFL; yellow arrow), and the inferior fracture is formed by the medial patellotibial ligament (MPTL) & and medial patellomeniscal ligament (MPML; red arrow). Anterior (C), posterior (D), and medial (E) views of the patella clearly show the distinction of fragments. The yellow arrows show the MPFL avulsion fracture, and the red arrows show the MPTL and MPML avulsion fracture. The yellow circle shows the MPFL patellar footprint, and the red circle shows the MPTL and MPML patellar footprint.

ture was found in 44 of the knees examined (27.5%), 1 or more of the fracture types were found in combination in 116 of the knees (72.5%).

Seventy-one knees (44.4%) had isolated lesions, and 45 (28.1%) had combined lesions. Isolated fracture patterns were observed with the following frequencies: Pattern I was observed in 21 knees (13.1%), pattern II in 26 knees (16.3%), pattern III in 23 knees (14.4%), and pattern V in 1 knee (0.6%). None of the patients had isolated pattern IV fractures. Various combinations of fractures were also observed, but simultaneous occurrence of pattern I and pattern II was the most common combined fracture pattern, which was seen in 20 knees (12.5%) (Fig. 7). Table 2 presents the distribution of fractures among the study population. The supplemental figures include more examples of the combined fractures (Figs. 8-12).

When fracture patterns were evaluated in 160 knees, either as isolated or combined injuries, pattern II emerged as the most common, identified in 66 knees (41.25%). This was followed by pattern I, observed in 52 knees (32.50%), and pattern III, found in 45 knees (28.1%). The least frequent patterns were pattern IV, noted in 4 knees (2.5%), and pattern V, detected in 1 knee (0.6%). The mean fragment size in pattern III intra-articular fractures was 128.4 ± 95.6 $mm^2$ (range, 12–412.5 $mm^2$). All of these fractures involved the inferomedial facet of the patella. The free osteochondral fragments were trapped in the lateral gutter in 16 knees (35.5%), anterior joint space in 23 knees (51.1%), posterior joint space in 4 knees (8.9%), and suprapatellar joint space in 2 knees (4.5%).

A statistically significant association was observed between sex and the occurrence of fractures ($p$ = 0.025), with male patients demonstrating a higher proportion of fractures (83.9%) compared to female patients (66.3%). No significant difference was observed between the sexes concerning isolated versus combined lesions ($p$ = 0.542) or specific fracture patterns ($p$ = 0.274) (Table 3). Furthermore, the mean age of patients with and without fractures was comparable (18.5 ± 6.5 vs. 19.0 ± 7.6, $p$ = 0.662).

**Table 2.** Distribution of Fracture Patterns Observed in the Patients

| Fracture pattern | | Male | Female | Total |
|---|---|---|---|---|
| No. of fractures | | 9 (5.6) | 35 (21.9) | 44 (27.5) |
| Isolated | Pattern I | 8 (5.0) | 13 (8.1) | 21 (13.1) |
| | Pattern II | 9 (5.6) | 17 (10.6) | 26 (16.3) |
| | Pattern III | 12 (7.5) | 11 (6.9) | 23 (14.4) |
| | Pattern V | 0 | 1 (0.6) | 1 (0.6) |
| Combined | Pattern I + II | 6 (3.8) | 14 (8.8) | 20 (12.5) |
| | Pattern I + III | 2 (1.3) | 1 (0.6) | 3 (1.9) |
| | Pattern I + IV | 2 (1.3) | 0 | 2 (1.3) |
| | Pattern II + III | 3 (1.9) | 9 (5.6) | 12 (7.5) |
| | Pattern II + IV | 1 (0.6) | 0 | 1 (0.6) |
| | Pattern I + II + III | 4 (2.5) | 2 (1.3) | 6 (3.8) |
| | Pattern II + III + IV | 0 | 1 (0.6) | 1 (0.6) |
| Total | | 56 (35) | 104 (65) | 160 (100) |

Values are presented as the number of knees (% of the total count).

## DISCUSSION

This retrospective study investigated fracture patterns associated with patellar dislocations using 3D CT, highlighting the complexity and variability of these injuries. The results demonstrate the efficacy of 3D CT in identifying and categorizing avulsion and osteochondral fractures, with 5 distinct patterns contributing to a deeper understanding of the biomechanical implications. Notably, the predominance of Pattern II avulsion fractures involving the inferior pole of the patella suggests that MPTL/MPML injuries are as common as MPFL injuries, contrary to previous knowledge. The absence of fractures at the ligament attachment sites does not rule out ligamentous damage, as only bony injuries are visible on CT. Since ligament injuries can occur as soft-tissue avulsions or mid-substance tears, the study's findings should be interpreted with this limitation in mind. While this study primarily analyzes fracture patterns associated with patellar dislocations, it also has significant clinical implications. The classification

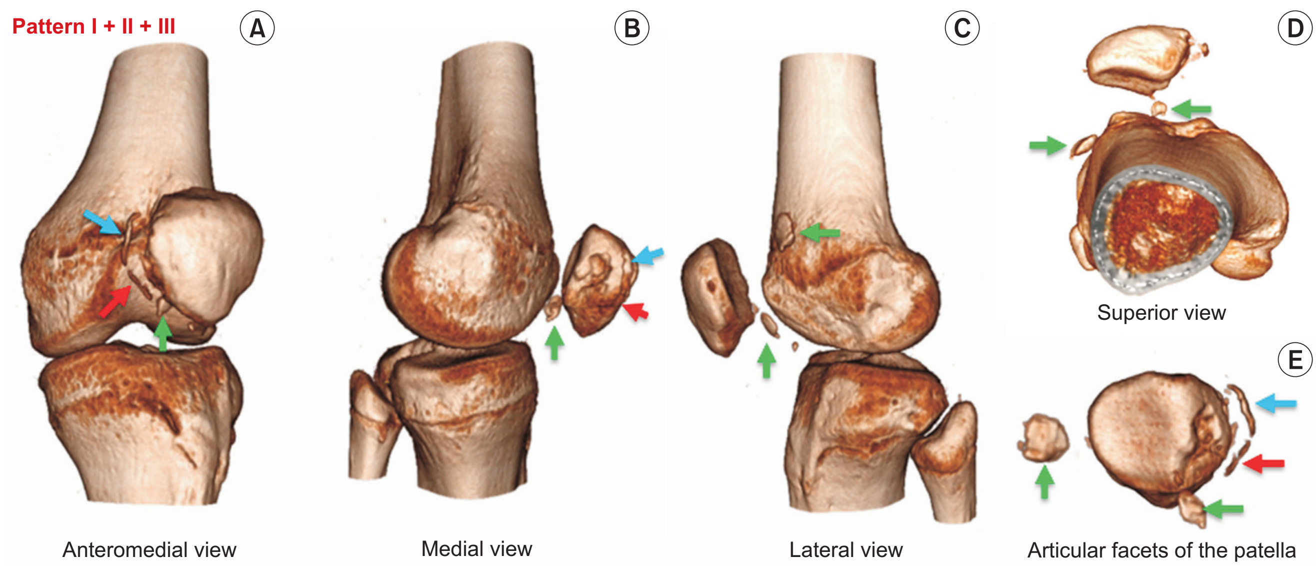


**Fig. 8.** Combination of pattern I, II, and III fractures. (A-E) Combination of pattern I, II, and III fractures in various views of the knee joint and the patella. The blue arrows show the medial patellofemoral ligament avulsion fracture, the red arrows show the medial patellotibial ligament & medial patellomeniscal ligament avulsion fracture, and the green arrows show the osteochondral fracture of the patella.

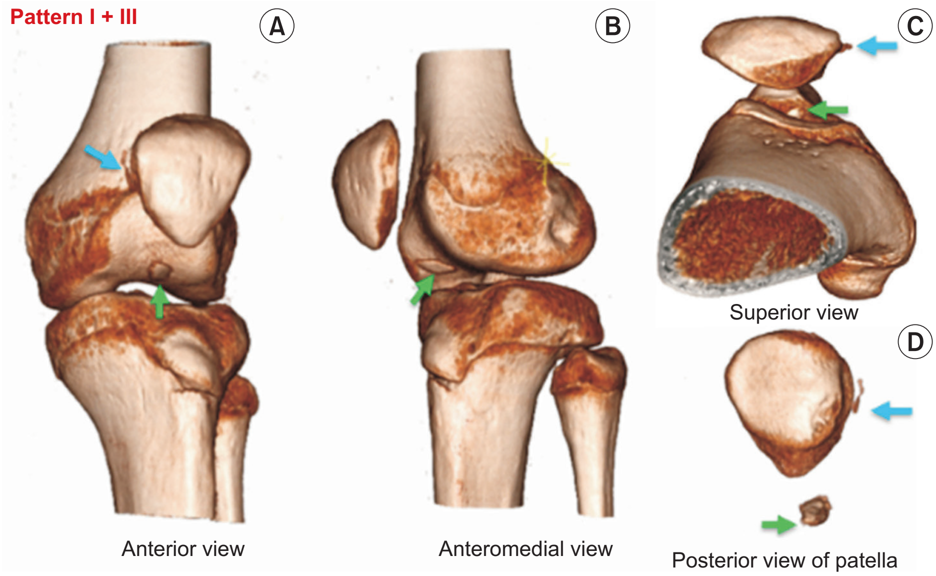


**Fig. 9.** (A-D) Combination of pattern I and III fractures in various views of the knee joint and the patella. The blue arrows show the medial patellofemoral ligament avulsion fracture, and the green arrows show the osteochondral fracture of the patella.

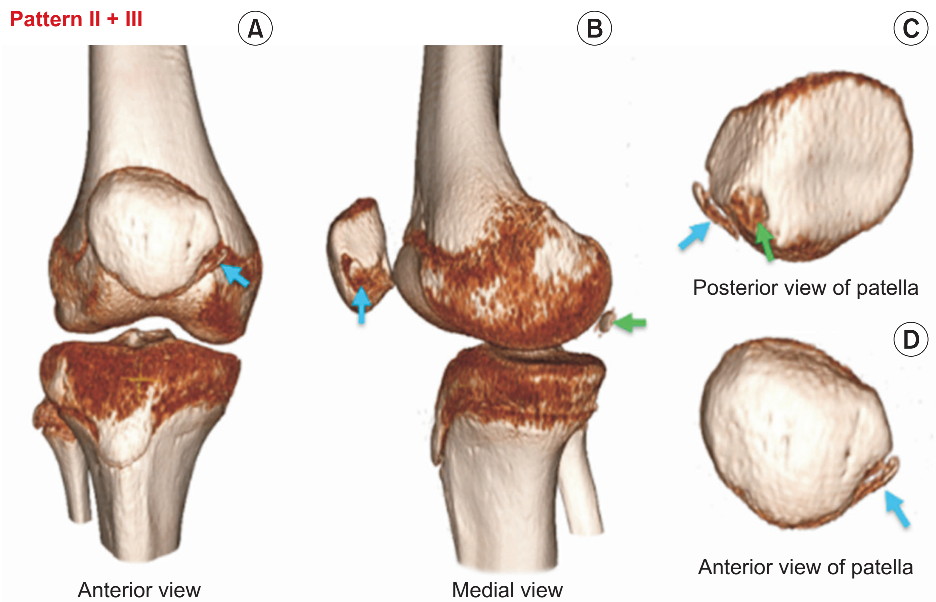


**Fig. 10.** (A-D) Combination of pattern II and III fractures in various views of the knee joint and the patella. The blue arrows show the medial patellotibial ligament and medial patellomeniscal ligament avulsion fracture, and the green arrows show the osteochondral fracture of the patella.

of fracture patterns provides a clearer understanding of the biomechanical forces in lateral patellar dislocations. It is valuable for writing detailed radiology reports, standardizing injury descriptions, and improving physician communication. Clinically, identifying and categorizing fracture patterns enhances diagnostic precision and informs surgical planning. Understanding the prevalence and location of fractures helps surgeons effectively locate and address fragments during procedures, ultimately contributing to better patient outcomes through tailored and effective interventions.

A key finding of this study is that MPTL/MPML avulsion fractures were present in approximately 40% of the knees examined. This is a noteworthy observation, given that most existing literature focuses on MPFL injuries, frequently neglecting the role of MPTL/MPML in patellar stabilization. The underreporting of these injuries in previous studies may be attributed to the limitations of MRI in visualizing these ligaments, in contrast to the detailed 3D reconstructions provided by CT. The absence of fractures on CT does not preclude the possibility of ligamentous injury, as soft-tissue damage can occur independently. This indicates that MPTL/MPML injuries may be more prevalent than our findings suggest, emphasizing the necessity for future studies to utilize MRI and CT to comprehensively evaluate the full spectrum of injuries fol-

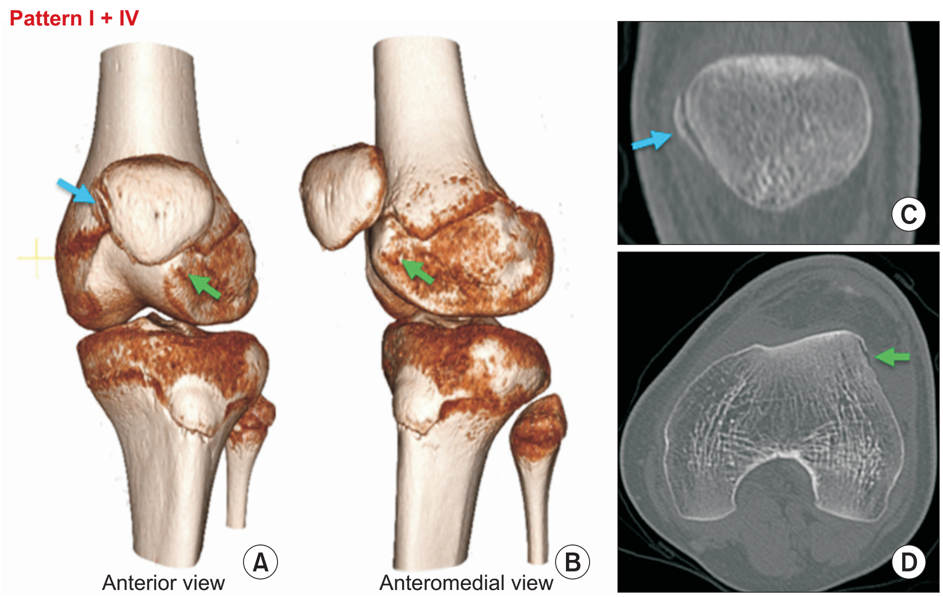


**Fig. 11.** (A-D) Combination of pattern I and IV fractures in various views of the knee joint and the patella. The blue arrows show the medial patellofemoral ligament avulsion fracture, and the green arrows show the osteochondral fracture of the lateral femoral condyle.

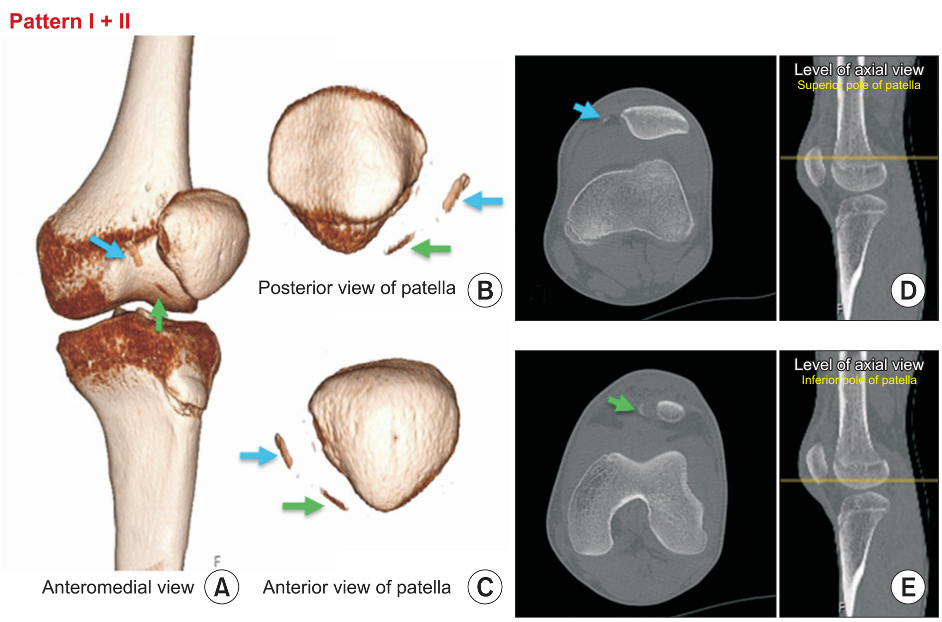


**Fig. 12.** (A-C) Combination of pattern I and II fractures in various views of the knee joint and the patella. The blue arrows show the medial patellofemoral ligament (MPFL) avulsion fracture, and the green arrows show the medial patellotibial ligament (MPTL) avulsion fracture. Axial computed tomography scans (D, E) and corresponding levels show both avulsion fractures. The blue arrows show the MPFL avulsion fracture, and the green arrows show the MPTL avulsion fracture.

lowing patellar dislocation.

Our findings challenge the traditional view that medial patellar margin fractures are solely caused by MPFL injury. Toritsuka et al.[10] observed in their study of 7 patients with lateral patellar dislocation that medial marginal fractures were continuously attached to the MPFL, suggesting these should be recognized as avulsion fractures of the MPFL insertion site. Sillanpaa et al.[11] identified 3 types of MPFL injuries at the patellar attachment: ligamentous disruption (type P0), bony avulsion from the medial margin (type P1), and bony avulsion involving articular cartilage from the medial facet (type P2), all linked to MPFL traction. MPTL injuries, however, were largely unmentioned in studies focusing on acute lateral patella dislocations using MRI. Migliorini et al.[12] found that 92% of the 175 patients studied had MPFL injuries, predominantly on the patellar side, along with frequent chondral damage at the patellar crest and lateral femoral epicondyle. Similarly, Anazor and Evangelou,[13] in their MRI-based study of 61 cases, reported a 95% incidence of MPFL tears, along with osteochondral injuries, loose bodies (27.9%), MCL injuries (18%), meniscal injuries (8.2%), and ACL injuries (1.6%). Our study suggests that MPTL/MPML injuries may also play a significant role, expanding the understanding of the

**Table 3.** Summary of Sex Differences with Fracture Patterns

| Variable | Male | Female | *p*-value |
|---|---|---|---|
| Age (yr) | 17.5 ± 5.1 | 19.3 ± 7.5 | 0.118* |
| Fracture occurrence | | | 0.025† |
| Fracture | 47 (83.9) | 69 (66.3) | |
| No fracture | 9 (16.1) | 35 (33.7) | |
| Fracture pattern | | | 0.542† |
| Isolated | 29 (61.7) | 42 (60.9) | |
| Combined | 18 (38.3) | 27 (39.1) | |
| Categorized fracture pattern | | | 0.274† |
| Pattern I | 8 (17.0) | 13 (18.8) | |
| Pattern II | 9 (19.1) | 17 (24.6) | |
| Pattern III | 12 (25.5) | 11 (15.9) | |
| Pattern V | 0 | 1 (1.4) | |
| Pattern I + II | 6 (12.8) | 14 (20.3) | |
| Pattern I + III | 2 (4.3) | 1 (1.4) | |
| Pattern I + IV | 2 (4.3) | 0 | |
| Pattern II + III | 3 (6.4) | 9 (13.0) | |
| Pattern II + IV | 1 (2.1) | 0 | |
| Pattern I + II + III | 4 (8.5) | 2 (2.9) | |
| Pattern II + III + IV | 0 | 1 (1.4) | |

Values are presented as mean ± standard deviation or number (% within sex).
*Student *t*-test. †Chi-square test.

mechanisms behind patellar dislocation injuries.

Moreover, the difficulty in assessing MPTL and MPML with MRI was highlighted by few previous studies. Varada et al.[14] analyzed 212 knee MRI scans taken after acute patellar dislocation, and all small osseous fragments at the medial patellar margin were defined as patellar MPFL avulsion fractures without any mention of the MPTL/MPML injuries. The difficulty in adequately assessing the MPTL and MPML using MRI may be a major reason for the underreporting of these injuries. The study by Zandee van Rilland et al.,[15] which included a review of 196 MRI scans, found that while primary stabilizers such as the MPFL and lateral patellofemoral ligament were clearly visible on MRI, secondary stabilizers such as the MPTL were less frequently and less clearly depicted. These findings also support our decision to use CT in this study. The detailed visualization of fracture patterns provided by CT allows us to identify injuries that may have been overlooked with MRI alone, further underscoring the importance of combining imaging modalities in future research.

In contrast to most studies that primarily focus on MPFL injuries, there are fewer studies addressing MPTL/MPML injuries. Burks et al.[16] examined injuries from experimental patellar dislocation in 10 cadaveric knees using MRI and surgical dissection, finding that 3 had avulsion fractures on the inferomedial side of the patella, corresponding to the MPTL attachment site. Tompkins et al.[17] analyzed 157 patients with primary lateral patellar dislocations, reporting that in 67 cases (47.2%) with partial medial retinacular injury, the tear was located in the footprint of the MPTL and MPML on the inferomedial patella. Similarly, Mochizuki et al.,[18] in a study of 131 patients with first-time acute traumatic patellar dislocation, found that 84% of patellar avulsion fractures occurred at the inferomedial border, involving MPTL/MPML attachments. Samelis et al.[19] reported a case of a 13-year-old female athlete with acute traumatic lateral patellar dislocation where MRI revealed an avulsion fracture at the inferomedial patellar border. Interestingly, the MPFL was intact, but the patella could be dislocated beyond 30° of knee flexion. The patient was successfully treated with primary repair of the isolated MPTL rupture. They proposed the concept of the "triangular space of patellar dislocation," an anatomical area critical for patellar stability, bounded by the patellar tendon, medial collateral ligament, and proximal medial patellar ligaments. Disruption of this space, reinforced by the MPTL and MPML ligaments, is often necessary for patellar dislocation, frequently resulting in MPTL/MPML rupture.[19]

The MPFL is the primary ligamentous restraint against lateral patellar dislocation, providing 50% to 60% of the restraining force during the first 30° of knee flexion.[20-23] Following an acute patellar dislocation, most patients experience MPFL tears, leading to a loss of this crucial stabilizing structure, making MPFL reconstruction a key component of patellofemoral instability surgery.[24,25] Over the past 2 decades, understanding of the medial patellofemoral complex's anatomy and biomechanics has deepened. Philippot et al.[23] used a cadaveric model to assess patellar motion, finding that the combined role of the MPTL and MPML in preventing lateral patellar movement increases with knee flexion, significantly contributing to patellar tilt and rotation at higher degrees of flexion. This role is even more crucial in trochlear dysplasia, where bony interlocking is weakened as knee flexion increases. Simultaneous MPFL and MPTL reconstruction has recently gained popularity, especially for treating recurrent patellar instability. Although the indications for this combined procedure are still being refined, recent meta-analyses and systematic reviews have shown it to effectively reduce the risk of recurrence.[26,27] Baumann et al.[26] reported favorable clinical outcomes for MPTL reconstruction, particularly when combined with MPFL reconstruction, with low redislocation rates and improved patellar stability. Similarly, Abbaszadeh et al.[27] found that this combined procedure significantly reduced recurrent patellar dislocation. In a recent study, Davidoni et al.[28] reported an 84% redislocation survival rate at a mean follow-up of 16 years for patients undergoing MPTL reconstruction, suggesting that repairing the MPTL after patellar dislocations could significantly improve stability.

This study has several limitations that should be considered. The most critical limitation of our study is the use of CT, which, while advantageous for evaluating bony structures and providing detailed 3D assessments, is not suitable for assessing soft-tissue injuries, such as those involving the MPFL and other ligaments. Previous studies have predominantly used MRI to evaluate soft-tissue injuries associated with patellar dislocations. Although our study provides valuable insights into the fracture patterns associated with patellar dislocations, the inability of CT to evaluate soft-tissue injuries should be considered when interpreting our findings. However, CT allowed for detailed 3D examinations that allowed for accurate localization of fractures and fracture donor sites. Another limitation is the retrospective design, which included both acute and recurrent dislocations. This may have introduced variability, as some new injuries may have been added in recurrent cases, or some fractures from initial dislocations may have healed, potentially affecting the findings. The relatively small sample size may limit the generalizability of our findings, particularly in subgroups with less common injury patterns. Further studies with larger cohorts may provide more detailed data. We did not analyze inter- and intraobserver reliability, but relied on consensus decisions by a panel of 3 experienced clinicians, which may introduce some bias. Finally, the lack of clinical data prevents us from assessing the outcomes of these fracture patterns over time, particularly with regard to the development of posttraumatic osteoarthritis or the effectiveness of different treatment strategies.

In conclusion, this study, the first in the literature to evaluate fractures after patellar dislocation using 3D CT, identified 5 distinct fracture patterns and demonstrated that these injuries often occur in combination. Importantly, the findings suggest that MPTL/MPML injuries are more common than previously thought, challenging traditional views of patellar dislocation injuries. These findings highlight the complexity of patellar dislocations and underscore the importance of a thorough diagnostic and therapeutic approach tailored to individual injury patterns.

## CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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