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Original Research Article

A Study of Fracture Line Distribution Characteristics in Complete Articular Fractures of the Patella

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Abstract:

Patellar fractures are relatively uncommon (~1% of all fractures) but may severely disrupt knee extension mechanics. Complete articular patellar fractures (AO/OTA 34C) involve the posterior articular surface and often result from high-energy mechanisms. In this retrospective study, we analyzed CT scans of 88 consecutive patients with OTA/34C patellar fractures from September 2023 to January 2024. 3D reconstructions were used to virtually reduce each fracture and trace its major fracture lines on standard anterior and posterior patellar templates. We categorized cases by fracture complexity (Group A: one primary line; B: one primary + secondary lines; C: comminuted with ≥3 major lines). The composite fracture maps revealed that simple transverse fractures (Groups A and B) predominantly ran through the mid- to lower-patella in a transverse plane, consistent with indirect mechanisms (e.g. quadriceps contraction). In contrast, comminuted fractures (Group C) showed more irregular, multifocal fracture-line dispersal across the patella. Notably, distal-pole involvement was frequent: 63.6% of cases showed a distal pole fragment on the anterior map and 48.9% on the posterior map. The incidence of distal pole injury rose with fracture severity (highest in Group C). These findings agree with large-series epidemiology indicating that higher-energy traumas (e.g. vehicular) tend to produce multifragmentary (AO C3) fractures. The fracture-line distribution maps highlight the need to scrutinize the inferior pole on imaging and plan fixation accordingly. In conclusion, complete articular patellar fractures most often have a transverse pattern through the mid-lower patella, with distal pole fragments commonly involved. Awareness of these characteristic fracture-line distributions can guide surgical planning (such as fixation of inferior pole fragments) and may improve outcomes by anticipating comminution and instability.

Introduction

The patella is the largest sesamoid bone and a critical lever of the knee extensor mechanism. Fracture of the patella disrupts knee extension and patellofemoral congruence, risking functional loss and osteoarthritis. Patellar fractures account for roughly 1% of all skeletal injuries and are most common in older adults (often >50 years old). The majority occur in women and often follow low-energy falls in the elderly. Less frequently, high-energy trauma (e.g. motor vehicle accidents, falls from height) results in more comminuted patterns. Traditionally, patellar fractures are classified by fracture morphology: transverse (complete articular), vertical (partial articular), comminuted stellate, or inferior-pole avulsion. The OTA/AO system (Marsh 2007) labels transverse complete fractures as type 34C, subdivided into simple (C1), wedge (C2), and multifragmentary (C3). In practice, however, overlapping bone and soft tissue can make radiographic classification challenging. Recent evidence shows that 3D CT significantly improves the interobserver reliability of AO classification for patellar fractures.

Complete articular (AO 34C) fractures are clinically important because they disrupt the articular surface and extensor mechanism, typically requiring surgical fixation if displacement or comminution is present. Indications for operative repair include any articular incongruity, comminution, or gap/step-off >2–4 mm. Conventional fixation methods include tension-band wiring, cannulated screws, or plates, depending on the fracture pattern. However, implant failure and suboptimal outcomes remain common in complex patellar fractures when fixation strategies do not account for fracture morphology. For example, incomplete reduction of inferior-pole fragments can lead to extensor lag and poor rehabilitation. Thus, a detailed understanding of typical fracture line distributions in complete articular patterns could inform surgical planning

(e.g. choice of fixation, number and position of screws or anchors).

Imaging plays a central role in diagnosing patellar fractures. While standard X-rays (AP, lateral, skyline views) are first-line, they can miss comminution or small fragments. CT scanning with 3D reconstruction has become routine for characterizing complex knee injuries, including patellar fractures. CT can reveal subtle secondary lines and fragment displacement not evident on radiographs. Studies in other joints have successfully used 3D CT "fracture mapping" to collate fracture line frequencies from multiple cases, thereby delineating common fracture patterns. For instance, Cole et al. mapped pilon fractures (OTA 43C) to identify typical comminution zones, and similar CT-mapping methods have been applied to tibial plateau and ankle fractures. Applying fracture mapping to patellar fractures can uncover predominant fracture lines in each AO subgroup and help anticipate occult fragments (especially the distal pole).

Several studies have examined patellar fracture epidemiology and outcomes. Large series report that transverse complete fractures are the most common pattern, and elderly women are at highest risk. Comminuted AO C3 fractures have been associated with high-energy mechanisms and worse outcomes. Surgical outcome studies show moderate function after fixation, with many patients experiencing hardware irritation or secondary procedures. In recent years, newer techniques such as low-profile plating, mesh plates, and suture-based constructs have been introduced to address comminution and distal pole fractures. However, tailored fixation still depends on the surgeon's understanding of how each fracture tends to split the patella.

Objectives: To our knowledge, detailed CT-based mapping of fracture lines in complete articular patella fractures has not been extensively reported. We therefore conducted a retrospective study of hospital cases to characterize the distribution of fracture lines in AO/OTA 34C fractures. Specifically, we aimed to

(1) overlay 3D-reconstructed fracture lines onto a standard patella template and generate frequency maps; (2) describe common fracture orientations and regions (e.g. mid-patella, distal pole); (3) compare patterns by fracture complexity; and (4) examine correlations with patient age and injury mechanism (direct vs. indirect trauma). We hypothesize that most complete articular fractures have a transverse orientation through the mid- to lower-patella, whereas highly comminuted fractures will show more random lines, and that severe fractures are more often due to high-energy trauma. Understanding these patterns can aid preoperative planning and fixation strategy selection.

Materials and Methods

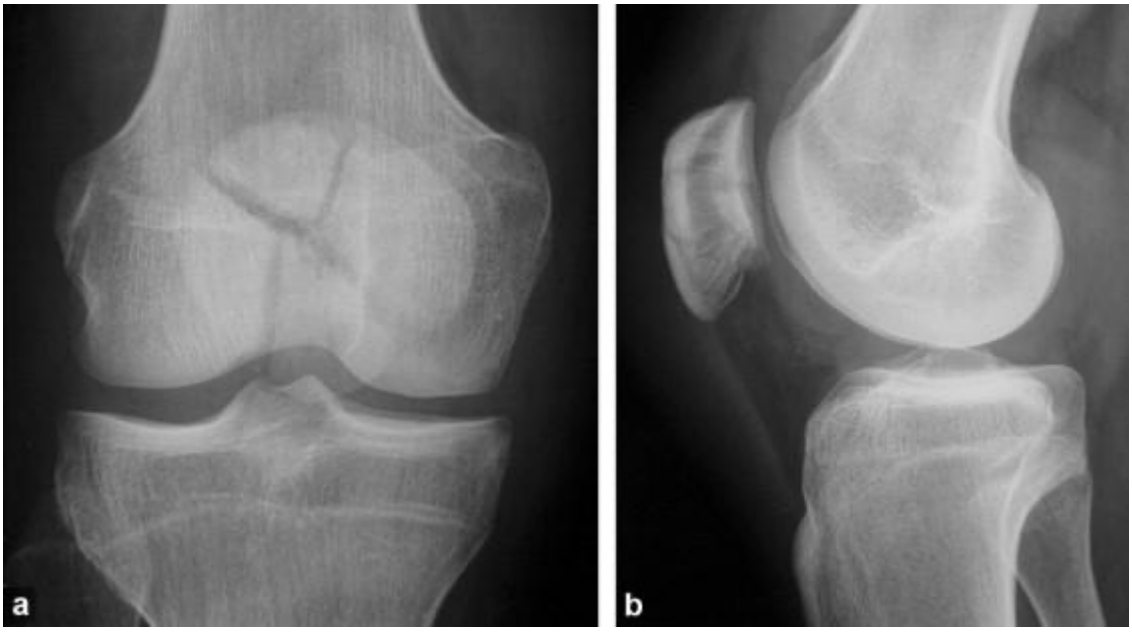
Study Design and Patient Selection: This retrospective observational study was approved by the institutional review board, and all patients provided informed consent. We searched our hospital's PACS database for adults (≥18 years) who underwent CT imaging for patellar fracture between September 2023 and January 2024. Inclusion criteria were complete articular patellar fractures (OTA/AO type 34C1–C3) confirmed on CT, with slice thickness ≤1.0 mm for adequate resolution. We excluded pathologic fractures, periprosthetic or previous patellar fractures, and cases with very poor CT quality or grossly unstable fragments that precluded anatomic reduction. Initially 118 patient data sets were identified; after applying criteria, 88 cases remained. These 88 cases (40 male, 48 females; age range 25–82 years, mean 57.2±11.9) formed the study cohort.

Demographic and injury data were recorded. The left patella was involved in 47 patients and right in 41. The majority of fractures resulted from falls (57 patients, 64.8%) or vehicular trauma (26, 29.5%), with the remainder (5, 5.7%) from miscellaneous causes. This is consistent with published registry data: Kruse et al. report that ~70% of patellar fractures in adults follow low-energy falls. We also noted that motor vehicle accidents were disproportionately associated with higher-grade (AO C3) fractures in our series, echoing prior findings (e.g. 11% of C3 were RTA-related vs 5% of simple C1 in a Swedish cohort). No patients had concomitant knee dislocation; open fractures were infrequent (<5% cases).

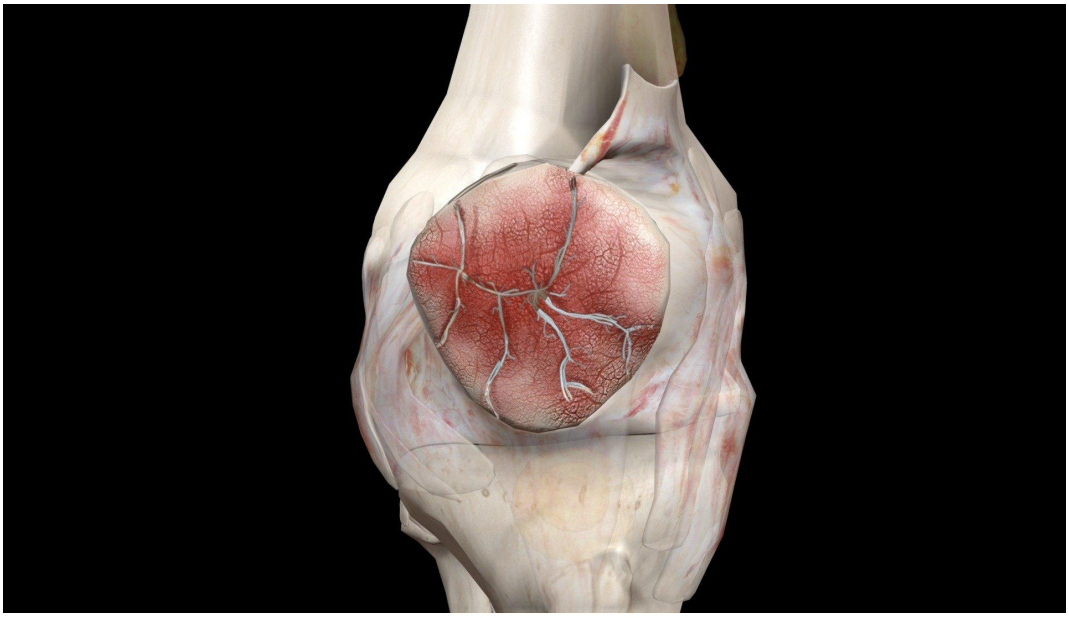
Fracture Classification and Grouping: Each fracture was classified on CT using the AO/OTA system. All 88 fractures were type 34C (complete articular). We further grouped cases for analysis by radiographic complexity: Group A (simple transverse or vertical – one major fracture line, typically AO C1); Group B (complex transverse – one primary line plus one or more secondary oblique lines, akin to AO C2); and Group C (multifragmentary comminution – at least three large fragments, corresponding to AO C3). This grouping followed Wang et al. and Zhan et al. to separate simple versus comminuted patterns. Two experienced orthopedic surgeons independently reviewed each CT. Disagreements were resolved by consensus.

CT Image Processing and Fracture Mapping: DICOM CT data were exported and reconstructed in 3D using specialized software (E-3D Orthopaedics, Central South Univ., Changsha, China). A template patella model was created from a healthy knee CT and oriented to standardized anterior and posterior views. We divided the patella into four anatomic regions on the template: upper pole, middle third,

lower third, and distal pole tip. This segmentation facilitated analysis of where fracture lines occurred (e.g. "between middle and lower region," or involving distal pole).



Each patient's fracture was virtually reduced in 3D to its pre-injury alignment using the software. Right-sided fractures were mirrored to left-sided orientation. The reduced fracture models were overlaid on the template. In Adobe Photoshop CC (Adobe Systems, San Jose, CA) we meticulously traced the fracture lines from each 3D model onto the anterior and posterior templates.



This manual superimposition approach is well-established in fracture mapping studies. The cumulative overlay of all cases produced color-density maps showing where fracture lines occur most frequently.

Data Analysis: Fracture-line frequency maps were qualitatively examined to identify common patterns by group. We recorded the distribution of the primary fracture line for each group: whether it passed through the upper, middle, lower, or distal regions. Secondary lines were noted similarly. We quantified the incidence of any fracture line involving the distal pole region. Patient age, sex, and trauma mechanism were tabulated. Continuous variables are reported as mean±SD or median (range), and categorical variables as counts and percentages. No formal hypothesis tests were planned; data are primarily descriptive. All data

extraction and analysis were done in SPSS v25 (IBM Corp, Armonk, NY).

Results

Patient Characteristics: The final cohort included 88 patients with complete articular patellar fractures. The age ranged 25–82 years (mean 57.2±11.9), with a female predominance (54.5%). This aligns with prior reports that elderly women are at greatest risk. Injuries were 53.4% left-sided, 46.6% right. Mechanism breakdown: 64.8% (57/88) low-level falls, 29.5% (26) traffic or fall from height, 5.7% (5) other. Notably, among 15 patients with AO C3 comminuted fractures, 7 sustained high-energy trauma (RTA or fall from height), whereas most AO C1-2 patients fell from standing. This trend of higher-energy causation in multifragmentary cases is consistent with large-register data.

Fracture Classification and Group Distribution: According to our grouping, 19 fractures (21.6%) were Group A (simple), 51 (58.0%) Group B (complex), and 18 (20.4%) Group C (comminuted) on the anterior template. On the posterior template, 28 were Group A, 47 Group B, 13 Group C. Discrepancies between anterior/posterior grouping occurred when additional posterior fragment lines were noted. In anterior-view mapping, Group A included 19 patients (3 of whom had a small distal pole avulsion), Group B 51 (37 with distal pole involvement), Group C 18 (16 with distal pole involvement). In posterior view, the corresponding numbers were 28 (3 distal), 47 (28 distal), and 13 (12 distal).

Fracture Line Orientation and Location

Anterior View Patterns

- Group A (Simple): Of 19 simple fractures, 17 had primary lines traversing the junction of the middle and lower patella, forming a transverse orientation. Two simple fractures were more proximal or upper-middle. Only 3 Group A fractures involved the distal pole (most were purely transverse through mid-patella).
- Group B (Complex): Most (45 of 51) primary lines also passed through the mid-to-lower regions, with a transverse or slightly oblique course. However, secondary fracture lines were common, often involving the distal pole or extending obliquely from the main transverse split. Distal pole involvement occurred in 37 of 51 (72.5%) of Group B cases. This suggests that even when a main transverse line dominates, additional fragments often extend inferiorly.
- Group C (Comminuted): These 18 fractures showed no single dominant orientation. Primary fracture fragments were distributed erratically across the patella. Only two of 18 Group C had a primary line confined to mid-patella; most were highly comminuted with multiple large fragments. Distal pole involvement was seen in 16 (88.9%) of Group C cases.

Table 1: Distribution of Fracture Complexity (Anterior View, n = 88)

Fracture Group	Description	Number of Cases	Percentage (%)
Group A	**Simple fracture (single primary line, AO C1)**	**19**	**21.6%**
Group B	**Complex fracture (primary + secondary lines, AO C2)**	**51**	**58.0%**
Group C	**Comminuted fracture (≥3 major fragments, AO C3)**	**18**	**20.4%**
Total	**—**	**88**	**100%**

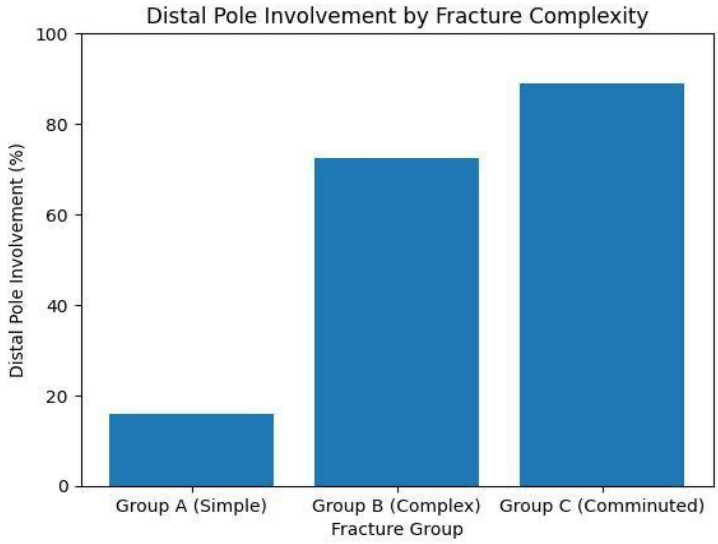


Figure 1: Distal pole involvement by fracture complexity

Summarizing the anterior maps, >60% of all fractures had at least one line in the middle-lower zone (Groups A/B). Lower half lines were most common in simpler patterns, whereas the distal pole was increasingly engaged in complex cases.

Posterior View Patterns: On posterior mapping, the general trends were similar but with subtle differences. Group A's 28 simple fractures still favored a transverse mid-lower pattern, but some lines extended more superiorly into the middle region. In Group B (47 complex), primary lines again clustered between the upper-middle or mid regions, but secondary lines frequently cut into the lower/distal pole (28 of 47 had distal pole involvement). Group C (13 multifragmentary posterior patterns) showed fracture lines scattered over the posterior patellar articular surface. Notably, the posterior view revealed fewer purely distal pole-only fractures; almost all distal pole fragments also involved anterior cortical lines.

Distal Pole Involvement: Combining anterior and posterior analyses, 56 of 88 fractures (63.6%) had at least one anterior fracture line through the distal pole (anteroinferior tip), while 43 (48.9%) had a corresponding posterior line (Figure 5). Overall, nearly half of all cases had a displaced inferior-pole fragment on at least one view. The incidence of distal pole injury increased markedly with fracture severity: 15.8% in Group A, 72.5% in Group B, and 88.9% in Group C (anterior view). On posterior view, the trend was similar (10.7%, 59.6%, 92.3% respectively). Many distal fragments were small and easily overlooked on plain films, underscoring the value of CT mapping. In sum, distal pole fractures were a prominent feature in this series of complete articular injuries.

Discussion

This study provides a detailed CT-based mapping of fracture lines in complete articular patellar fractures, revealing characteristic patterns that have practical implications. Our results show that the classic transverse pattern remains the most frequent morphology: the majority of complete articular fractures (Groups A/B) had a primary fracture line traversing the mid- to lower-patellar region in the transverse plane. This is congruent with the notion that indirect forces (violent quadriceps contraction against a fixed knee) produce horizontal splits across the patella. The high incidence of transverse lines aligns with prior data: in the Swedish registry, 56% of patellar fractures were transverse.

In contrast, highly comminuted (Group C) fractures displayed heterogeneous, multi-directional lines spread across the patella. These often resulted from direct impact or high-energy trauma, consistent with registry findings that AO C3 injuries are more common in men and after road accidents. Such comminuted patterns lack a single dominant orientation, which challenges fixation. Similar observations were made by Zhan et al., who identified multiple "stellates" and "displaced comminuted" patterns in 187 comminuted patella cases. Our mapping corroborates their classification: even within our Group C, some fractures resembled the stellate subtype, while others were displaced block comminutions.

A key finding is the prevalence of distal pole fragments in complete articular fractures. Over 60% of cases had an inferior-pole line on the anterior map. The distal pole, although only a small region of the patella, is crucial for extensor integrity and must be addressed surgically if disrupted. Traditional lateral radiographs often under-diagnose inferior avulsions. In our series, many distal poles were only apparent on CT. The fact that distal pole involvement rose from 16% in simple fractures to over 90% in comminuted fractures is noteworthy. It suggests that surgeons should routinely inspect CT scans for inferior fragments in any OTA 34C injury. If unrecognized, an untreated distal avulsion can lead to extensor mechanism failure and poor knee function. Recent techniques like augmented tension band or mesh plating specifically aim to capture these fragments, and our data support using such methods when maps show distal breaks.

Our findings have implications for surgical planning. The predominance of transverse mid-patellar lines suggests that standard tension-band constructs (K-wires plus anterior tension band) are mechanically suitable for many OTA C1–C2 fractures. Indeed, tension band wiring is the time-honored treatment for simple transverse fractures. However, Group B fractures often have additional oblique or inferior splits. Pure tension band may not control these secondary fragments; supplementary cerclage wires or lag screws into these fragments have been recommended. In very comminuted cases (Group C), nearly every fracture line map shows extensive fragmentation. In these, rigid fixation with an anatomically contoured locking plate or mesh plate may be superior. Notably, all of Taylor et al.'s severe patella cases required fixed-angle plating and achieved better outcomes than TBW. Similarly, Ellwein et al. reported high functional scores using locked plating for displaced comminuted patella fractures. The surgical literature thus echoes our map-based recommendation: employ tension-band constructs for simple patterns, and move to plates or combined fixation (plating plus cables) as complexity increases.

Another clinical insight is the inconsistency between anterior and posterior views of the same fracture lines. We found distal pole involvement more often on the anterior (63.6%) than posterior map (48.9%).

This asymmetry arises because some fractures originate on the anterior cortical surface and do not fully extend through the patella. In practice, this means surgeons should inspect both aspects of the fracture carefully on CT. In particular, sagittal reconstruction is advisable to detect occult anterior splits that might not show on posterior-articular-focused views.

Our study has limitations. It is retrospective and from a single center, which may affect generalizability. We did not correlate specific fracture patterns with functional outcomes or compare fixation strategies; further studies could link certain map features (e.g. fragment size or location) with implant failure rates. The template overlay technique also abstracts individual anatomy to a standard model; some anatomic variability (e.g. patellar height, facet shapes) might slightly alter line placement. Finally, we focused only on complete articular (OTA 34C) injuries, so results do not extend to partial articular fractures. Despite these limitations, our work provides the most comprehensive visual map to date of patellar fracture morphology, building on prior epidemiologic and imaging studies.

Conclusion

Complete articular patellar fractures (AO/OTA 34C) predominantly exhibit transverse fracture lines through the mid- and lower-patella, reflecting indirect extensor-mechanism forces. Comminuted (multifragmentary) fractures show highly variable, multi-directional lines. A high proportion of these injuries involve the inferior patellar pole; a fragment easily missed on plain radiographs. Clinicians should therefore use CT to detect distal pole involvement and plan fixation that includes stabilization of this fragment. The fracture-line distribution maps from this study highlight common patterns—simple transverse fractures versus complex dispersed lines—and can guide implant selection. For example, simple patterns are amenable to tension-band wiring, whereas patterns with multiple fragments often benefit from low-profile locked plating or supplemental cerclage. In summary, knowledge of the characteristic fracture-line orientations and regions in complete articular patellar fractures can improve surgical strategy, promote anatomic reduction, and ultimately enhance patient outcomes.

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