

Tibial plateau fractures: Fracture patterns and computed tomography evaluation of tibial plateau fractures in winter sports

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Abstract

The purpose was to analyze tibial plateau fractures (TPF) by computed tomography (CT) by creating a frequency map (FM). We hypothesized that a FM shows clinically important aspects of involvement that are not expressed in classic classifications. 185 TPF were retrospectively evaluated in this single center study. We created a FM onto an axial template of an intact subarticular tibial plateau and separated the joint surface in 9 areas, counted the frequency of involvement. The FM gives information of location and grade of damage and expressed three major fracture areas in 76%. 5 specific fracture types add up to 51%. The dorsal parts of the tibial plateau are involved in a higher percentage (+8%). True lateral fractures are less often than plane radiographs suggest. An impression was found in 50%. The complexity of TPFs is high, but 5 specific types could be identified in >50%. The complexity is not sufficiently covered in common classifications, especially the dorsal involvement. The FM is a simple and useful tool that complements common classifications and can be used as guideline for surgical treatment.

Introduction

Tibial plateau fractures are frequently intra-articular injuries with high potential of developing chronic pain, limited knee motion, post traumatic osteoarthritis and other related complications.¹

Treating these injuries with open reduction and internal fixation can be very challenging.²⁻⁵ The classification of tibial plateau fractures using Schatzker or OTA/AO classification are based on anterior

oposterior radiographs without consideration of the posterior tibial plateau.³ As a result, these two dimensional images often lead the surgeons view toward medial or lateral fixation to address the injury without considering a posterior fixation.⁶ The outcome of lateral or medial applied locking plates shows good results, but several surgeons have emphasized the importance of posterior fixation.^{4,7} Reduction and fixation of posterior fragments of the tibial plateau is important because these fragments can possible not stabilized by lateral or medial implants. This, amongst other problems, may cause a secondary loss of reduction or malreduction with joint incongruency and consecutive therapeutic problems.⁸ Since computed tomography is commonly used to evaluate the joint involvement in these fractures, the finding of posterolateral or posteromedial fragments has increased.^{6,8-11} The understanding of the morphologic characteristics of tibial plateau fractures with new classification systems using computed tomography (CT) or magnet resonance imaging (MRI) were proposed.^{6,12} Molenaars and colleagues were the first to describe an imaging technique with CT to develop a *fracture mapping* for tibial plateau fractures.¹²

With use of axial plane CT images, fracture lines and zones of Communication are superimposed to create a visual map of major and minor fracture lines.¹² This understanding of complex fractures of tibial plateau fractures can guide the surgeon for choosing the surgical approach and fracture-specific fixation.

The purpose of this study was to evaluate the fracture patterns of a large series of tibial plateau fractures with creation of a frequency map (FM) to determine location and degree of damage to the joint surface.

Materials and Methods

We reviewed 185 CT scans and plain radiographs. All patients had a sports injury, 82.7% could be related to a skiing accident, 17.3% to other activities in winter sports, like sliding, snowboarding. 104 female and 81 male patients, with an average age of 53 years. Patient demographics are shown in Table 1.

We retrospectively analyzed plain radiographs and CT images of tibial plateau fractures in a level ACU1 trauma center. The International Classification of Diseases, Ninth Revision (ICD-9) codes were used for patients with tibial plateau fractures to search the database between Jan 2013 and Jan 2015 for these types of injuries. All patients with fractures of the

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tibial plateau were included in this study. Any of the patients with complete x-ray and CT imaging were included; in total 184 patients with 185 tibial plateau fractures. As almost every injury in our center happened in winter sports, we excluded anyone else.

The first step of the study was to systematically assess and scale all plane radiographs using the Schatzker and AO classification. Two observers, consultants, were randomized to evaluate the fractures via a web-based platform. The second step consisted of evaluating the CT-scans and creating a frequency map using an axial template of an intact subarticular tibial plateau. Therefore we separated the joint surface into 9 different areas (3 lateral, 3 medial and 3 tibial spine) and counted the frequency of injuries that affected each area (Figure 1). An anterior and posterior, lateral and medial tangent was drawn to the tibial plateau on the level of the subchondral joint-line. The area in between is divided in 3 equal fields from anterior to posterior (1,2,3) Lateral and Medial fields are separated from the

eminentia perpendicular to the tangents right along the border of the intermedial tubercles. The use of the frequency map in clinical practice is shown in Figure 2. By reviewing the axial, sagittal, transversal and 3D reconstruction of the CT Images, the affected areas were graded with 1 and unaffected areas with 0. Fracture dislocation was defined as fragment displacement of more than 2 mm.

The joint depression was measured with the crosshair tool using the largest diameter of the images of the lesions in axial, coronal and sagittal reconstructed views. Its volume was calculated approximatively using the geometric cone calculation:

$$V = \frac{1}{3} \pi r^2 h$$

The area of depression was marked on the frequency map.

The k statistical test was used to analyze intraobserver reliability. All of the calculations were performed using SAS software, version 9.1 (SAS Institute, Cary, NC, USA). The k coefficient ranges from -1 (complete

disagreement) to 1 (complete agreement). Zero represents an agreement that is purely by chance only. k Ranges are defined as follows: 0.0 to 0.20, slight reliability; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.60 to 0.80, substantial agreement; and 0.81 to 1, excellent agreement.

Results

Evaluating the plane x-ray images, 106 fractures scaled as Schatzker type 1, 2 or 3; 45 Schatzker type 4 and 34 Schatzker type 5 or 6. 4 scaled as orthopedic trauma asso-

ciation type A, 116 type B and 65 type C fractures.

Frequency map (CT-based)

The use of the frequency map in clinical practice is shown in Figure 1. Any fracture was translated into the schematic raster of the frequency map described above.

The frequency of each of the affected areas in the sample of the 185 fractures is shown in Figure 3. Three major characteristics were found: the lateral joint area represented 45% of the injuries; the combination of lateral, tibia spine and medial area were 23%; and the lateral in combination with tibial spine were 16% (Table 2).

Table 1. General data and division according to Schatzker and AO classification.

Variable	N.
Sex (N)	
M	81
F	104
Age (mean/range)	53/19-85
BMI (mean, kg/m ²)	22.8
Side of fracture (N)	
Left	73
Right	112
Schatzker classification (N%)	
I,II,III	106/57
IV	45/24
V,VI	34/18
AO classification (N%)	
A	4/7
B	116/62
C	65/31

Table 2. Fracture division according to the frequency map.

Combinations	N.	%
L	84	45
L + E	29	16
E	17	9
L + E + M	43	23
E + M	8	5
M	4	2

L, Lateral; E, Eminentia / tibial spine; M, Medial.

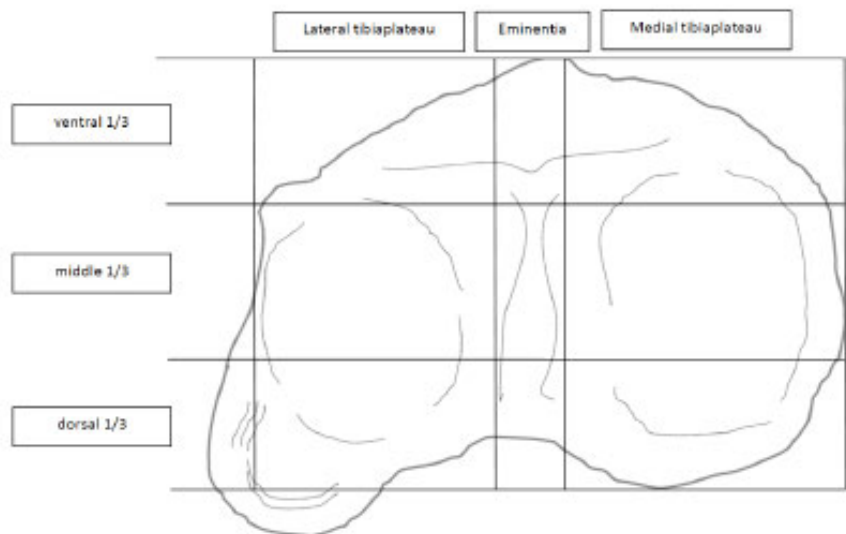


Figure 1. Application of the fracture map: draw an anterior and posterior, lateral and medial tangent to the plateau on the level of the subchondral joint-line, the area in between is divided in 3 equal fields from anterior to posterior (1,2,3) Lateral and Medial fields are separated from the eminentia perpendicular to the tangents right along the border of the intermedial tubercles.

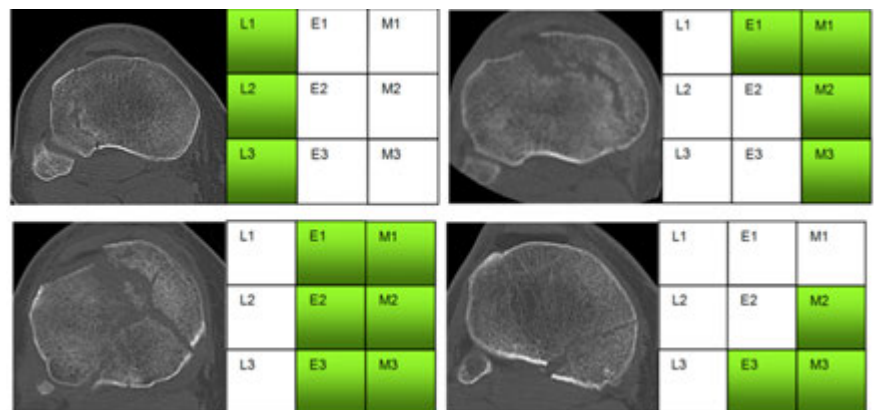


Figure 2. Four different examples of application of the frequency map. The upper left shows a Schatzker Type 1. The upper right image and the lower left image shows involvement of the medial plateau in combination with the tibial spine. On the lower right there is involvement of the dorsal medial tibial plateau.

A more detailed look at the frequency map shows that there are 5 common combinations (Table 3). These 5 combinations add up to 50.8% of the total number of injury combinations. All of the fractures that involved a medial joint area showed an individual fracture pattern and were mostly bicondylar. Fractures only affecting the medial plateau were rare (2%). However, a wide range of possible injury combinations of affected areas can also be seen. Fractures, that involved only the lateral joint accounted for 76 cases, which equates to 41.1%. Furthermore we noticed a more frequent involvement of the posterior areas. In the lateral, medial areas and tibial spine the respectively posterior area is affected more often than the anterior fields as shown in Figure 3.

Using the frequency map in the collective of patients led to the descriptive statistical data presented. Using the frequency map as a method of individual fracture interpretation translates a possible complex fracture into a simple scheme. This helps in understanding and leads to a possible surgical strategy Figure 4.

The location of impression is shown in Table 4. In 77 cases the area of impression is located laterally and there are only 3 cases in which a medial impression was found.

In total 93 tibial plateau fractures had an impression which means 49.7% of the injuries were split-fractures without any impression. The mean volume of impres-

Table 3. Fracture characteristics according to the frequency map.

Combinations	N.	%
L1+L2	14	8
L1+L2+L3	52	28
L2+L3	10	5
E1+E2+E3	10	5
L3+E1+E2+E3	8	4

Table 4. Location of impression according to the frequency map.

	N
L1	21
L2	34
L3	22
E1	1
E2	2
E3	10
M1	0
M2	1
M3	2

L, Lateral; E, Eminentia / tibial spine; M, Medial.

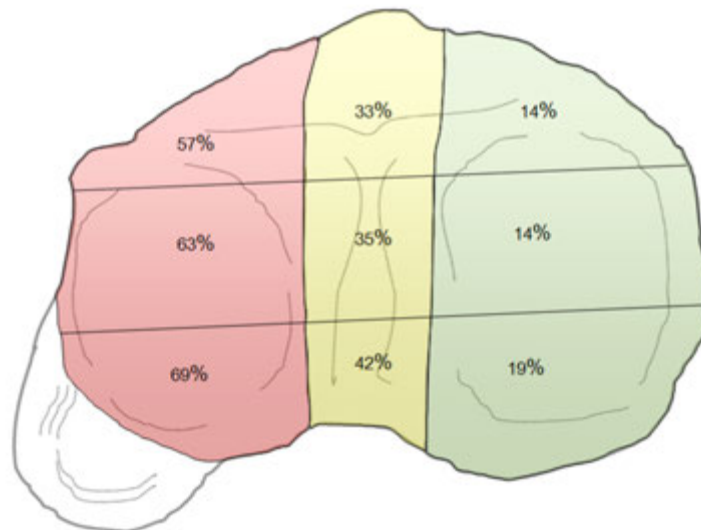


Figure 3. Percentage of involvement.

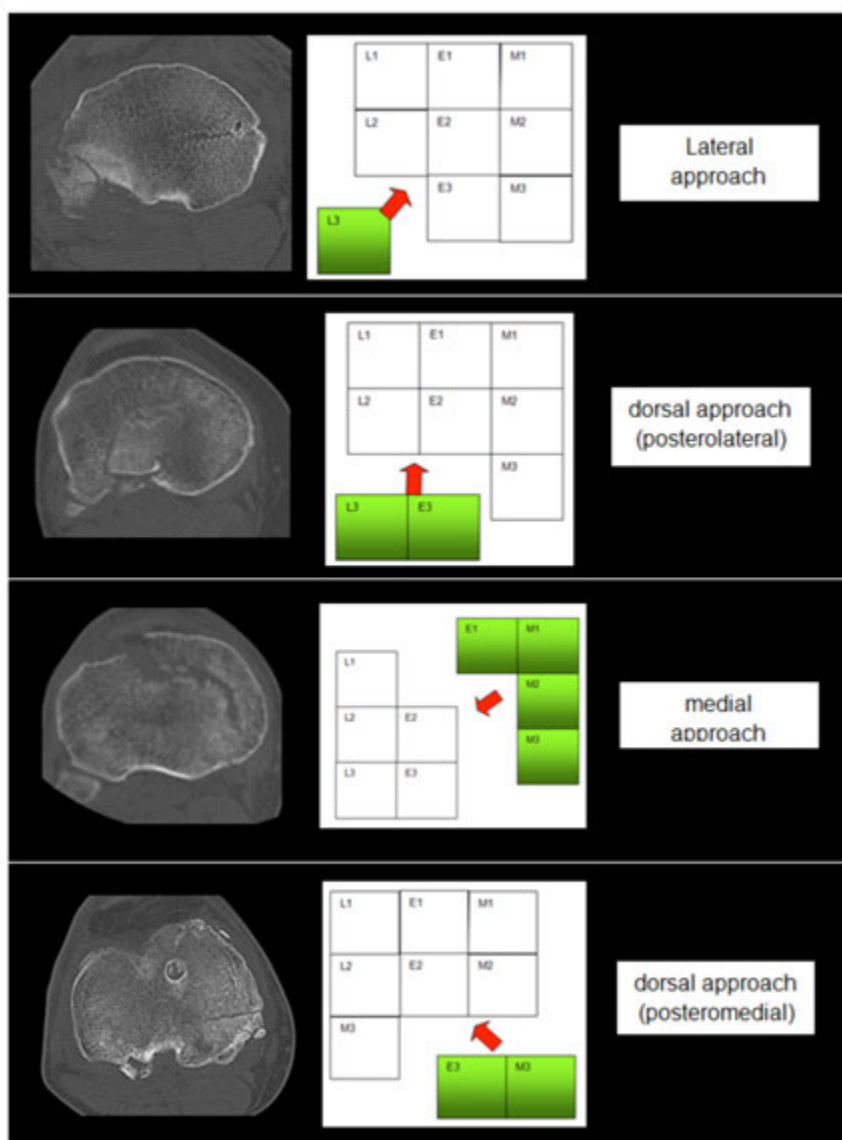


Figure 4. Surgical approach depending on involved areas.

sion was 3.25 cm³. The mean kappa value for inter-observer reliability regarding transfer of the radiological data to the frequency map was 0.85 representing *excellent agreement*.

Discussion

Tibial plateau fractures are complex injuries of the tibial head and joint surface.

Even though common classification systems are standard in literature and for clinical evaluation for tibial plateau fractures they have typically been based on anteroposterior radiographs.¹²

The plane radiographs are viewed as a rough estimate of the type of fracture and are used for operative planning. However the interpreting surgeon tends to underestimate the severity of the fracture.^{2,13,14} Therefore CT-imaging is already an important and commonly used tool in operative practice as conclusive interpretation of plane radiographs is only possible with additive CT. But interpretation is not standardized yet.

The aim of this study was to improve understanding of tibial plateau fractures by developing a systematic CT evaluation to enhance the existing classification system that uses plane radiographs. We postulated that plain radiographs don't provide the necessary information to the surgeon. And the use of a CT based frequency map and the translation into a simplified mapping will offer further facts to define operative planning and to improve comparability of studies. With our study we could express a discrepancy between common classification and true extent of the fracture expressed by CT. We were able to find 106 Schatzker type I-III injuries, 57%, on plane radiographs, compared to the CT evaluation which affirmed only 76, 41% of our collective as true lateral. That shows, that we underestimate the damage to the tibial plateau using the Schatzker classification in 30 cases. Zeltser *et al.* described similar results. 71.4% of *splits* on XR were labeled *combined* after CT evaluation and 58.3% of the *depressions* were labeled *combined*.³

These results confirm that CT is essential in evaluating the extent of the tibial plateau fractures, because plain radiographs are fair reliable and do not always guide the surgeon in choosing the surgical approach and fracture-specific fixation. Several studies favored characterization of the fractures over classification.^{2,13,14}

Analyzing fractures by a frequency map is a useful and easy modality to improve understanding.

Dividing the tibial joint surface in 9 areas simplified the interpretation of the CT while simultaneously raising clinical practicability of the offered information. The frequency map separates the tibial plateau into central, dorsal and anterior areas of the joint surface in comparison to the fracture map of Molnaars *et al.*, which regarded every single fracture-line separately. Only a computer based analysis can summarize and concentrate their data into areas of major involvement.

The tibial plateau fractures in this study show three major fracture characteristics in the frequency map: the lateral joint area, found in 45% of the injuries; a combination of lateral, tibia spine and medial area, found in 23% of the injuries; and lateral in combination with the tibial spine, found in 16% of the injuries. Molenaars *et al.* described four different types of fracture characteristics which account for all their evaluated fractures.⁵

In contrast we found five fracture combinations which account for 50% of all fractures in our study. The other 50% of the fractures are in variable configurations. As seen in Table 3. Three of the major involved fracture areas can be further subdivided into various other combinations, which means that tibial plateau fractures are not a consistent compound and cannot be easily classified by CT. Nevertheless the frequency map helps subdivide fractures and is a simple way to describe them by involved areas, which improves comparability of fractures in studies and could potentially enable a standardized descriptive method and helps for planning the operative procedure (Figure 2).

Other studies already suggested that characterization of tibial plateau fractures using a fracture map may be more reliable to compare other similar studies and could be a guideline for preoperative planning.^{13,14}

A detailed look at the resultant frequency map shows that the three lateral joint areas are affected in 63% which coincides with literature.^{4,6,12} Due to the joint surface shape there is a more frequent involvement of the lateral plateau in this type of injuries.¹² Axial loading results in a split fracture on the concave medial side. On the other hand axial loading results in multi fragment depression with widening of the lateral compartment.^{12,15}

However the frequency map indicates frequent combinations of the lateral areas with other joint areas. 113 fractures were lateral or lateral in combination with fractures of the eminentia. Additionally 65 fractures of the study involve only the anterior or posterior lateral tibial plateau. Medial joint areas are mostly involved in complex

bicondylar fractures and unicondylar medial fractures are rare.

This study also confirms that posteromedial and complex medial splits in bicondylar fractures are often combined with multi fragment lateral depression.¹⁵

Posterior shear fractures are mostly characterized as bicondylar.^{11,13} Weil and Colleagues classified posteromedial shear fractures as Schatzker IV and bicondylar shear type as Schatzker V or VI,¹⁶ although bicondylar posterior shear-type fractures do not fit into the type IV, V, VI in Schatzker's classification.^{13,17} As confirmed by this study the frequency map shows that multi-fragmentary fractures involving all joint areas crossing the tibial plateau do not yet have a classification system.

Also the description of the dorsal tibial plateau, especially the isolated medial or lateral fragment is not sufficient yet and cannot be found in common classifications.¹² We could detect that all posterior areas (L3, E3, M3) are more frequently involved than the central and anterior areas, which underlines the importance of the dorsal plateau. As we evaluated mainly skiing accidents a trauma mechanism of high energy on a flexed knee with tibial roll-back combined with valgus and rotational forces is probable and might explain the mainly dorsolateral areas of impact. This interpretation is supported by biomechanical findings of Pinskerova *et al.* and Moro-oka *et al.*^{18,19} If an involvement of the posterior joint area is not recognized, the surgeon could choose an approach that doesn't address the posterior fragments.

The knowledge of the precise extent of damage to the plateau such as its location and morphology of fragments helps in the decision-making for the surgical approach or combination of approaches.

In response to this Luo and colleagues created a CT *three column* classification system based on their experience.⁶

The limitation in this classification system regards the posteromedial fractures with extension to the lateral plateau and isolated postero-medial or postero-lateral involvement.^{16,20} Moreover Schatzker shows significant better intraobserver reliability.^{16,20} But agreement was fair for both in their study.²⁰

In our frequency map we address all posterior areas separately, which is closer to the true anatomic fracture morphology. The inter-observer reliability in our study was high and is comparable with Schatzker evaluations.²⁰ This can be explained by the simple way of CT interpretation.

In total 50% of the fractures revealed an impression of the joint and we could show that the location of impression is laterally in

83% of the injuries. The central weight bearing area of the tibial plateau is mainly involved. In the frequency map the location of impression is indicated but degree is not described exactly and our calculation of the volume is only approximate and done as an addition. Exact values may be an important factor for operative planning and prognostic prediction. Special CT programs exist, that offer precise calculation. It is important for the surgeon to have a tool, which is easy to use, and which offers preoperative planning. With the knowledge of involved areas we can make an advice for the surgical approach (Figure 4). If there is a fracture involving the dorsal lateral and/or medial segment in combination with the tibial spine segment- matching with the dorsal column, we suggest a dorsal central approach for fixation. But if only the lateral or medial dorsal segment is involved we suggest a dorsal lateral or medial approach. For more complex fractures which involve all 3 compartments a combination of approaches and fixation should be considered. In contrast to Molenaars fracture mapping we offer a practical tool for every surgeon without dependence on computer software to evaluate the fracture course and degree of damage to the bony tibial plateau. And it can be used for preoperative planning for surgical approach and as we can locate the exact parts of damage we can plan possible techniques of fixation. But for clinical practice further interpretation is essential as we have to consider the ligament insertions to the plateau. For example, is there a PCL avulsion if area E3 is effected? With this data we offer a descriptive tool which may contribute to the decision of treatment but does not offer the solution. The suggested operative guideline drawn out of the frequency map is according to clinical experience. However, the aim of this study was to evaluate tibial plateau fractures in a frequency map and to offer a descriptive tool as a help for treatment guidelines. As we cannot offer a clinical approval it is just a fundament for further investigation.

Another critical point of this study is that the patient collective may be slightly different than in most studies because it included only patients with an isolated trauma to the knee in winter sports, which may indicate a high energy mechanism, while the exact mechanism of trauma is mostly unknown. The observed collective is a sportive group, even though we found a wide range of age, rather than a regular average of people and energy of impactation may differ largely. We had no cases of direct

trauma to the knee such as blunt force. Comparing our collective to an osteoporotic low-energy- group could be an interesting further investigation. However the frequency map method can be easily transferred and used on any kind of trauma to the tibial plateau. With this study we could present a frequency map based on a large number of patients. We created a systematic schedule which divides the tibial plateau into 9 fields. This method is easily repeatable in clinical practice, to describe tibial plateau fractures as additional information to classifications of plane radiographs and is a further tool for surgical treatment. Furthermore it gives extensive information for the development of a CT classification. In further studies we are working on prognostic indicators and a classification based on the presented frequency map.

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