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Articular coronal fracture angle of posteromedial tibial plateau fragments: A computed tomography fracture mapping study

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ABSTRACT

Objectives: The purpose of this study is to analyze posteromedial fragment morphology using two-dimensional computed tomography fracture mapping and to compare posteromedial fragment morphology in various Schatzker type tibial plateau fractures.

Materials & methods: One hundred twenty-seven consecutive AO/OTA B- and C-type tibial plateau fractures were retrospectively analyzed using 2DCT fracture mapping. The posteromedial articular fracture angle and articular surface areas of all fractures with posteromedial fragments were calculated. Based on biomechanical studies, posteromedial fragments with coronal fracture angles >68° were considered amenable for anterolateral stabilization with standardized plating. Kruskall-Wallis non-parametric test was used for statistical comparison of morphological features of posteromedial fragments between the various Schatzker types.

Results: Forty-seven out of 127 tibial plateau fractures included a posteromedial fragment. The mean posteromedial articular fracture angle was 44° (range: 2°-90°, standard deviation: 23°). Forty fragments (85%) had a fracture angle of <68°, increasing the risk for insufficient stabilization with standardized anterolateral plating. The mean articular surface area was 34% of the entire tibial plateau (range: 7%–53%, SD: 12%). There were no significant differences in posteromedial fragment morphology between Schatzker type IV, V, and VI fractures.

Discussion and conclusion: Posteromedial fragments commonly occur not only in Schatzker type V and VI, but also in Schatzker type IV tibial plateau fractures. Eighty-five percent of tibial plateau fractures with a posteromedial fragment may benefit from non-standard customized lateral plating, or may require an additional medial or posterior surgical approach for fracture-specific fixation to optimize screw purchase and biomechanical stability.

Introduction

Tibial plateau fractures (TPFs) are one of the most challenging traumatic fractures to treat. Inadequate treatment may result in knee instability or deformity and early-onset osteoarthritis [1–3]. Patients with TPFs are over 5 times more likely to undergo total knee arthroplasty within 10 years after injury [4]. Traditionally, TPFs are stratified according to Schatzker's classification into lateral (type I, II, and III), medial (type IV), bicondylar fractures (V), and TPFs involving a fracture of the shaft (type VI) [5]. However, due to the wide variety of fracture patterns, stratification of TPFs has limited clinical value [6,7]. Furthermore, the variation in fracture morphology of TPFs demands a fracture-specific and individualized surgical approach. As a result, the criteria used in surgical decision-making in TPFs are difficult to standardize and vary among surgeons [8,9].

In general, a lateral surgical approach with a locking plate/screw device is preferred for fragment fixation in TPFs, as this surgical technique is considered relatively uncomplicated and carries a low risk for iatrogenic damage to nerves and blood vessels [10]. Several authors have proposed an additional medial or posterior surgical approach in TPFs with medial or posterior tibial

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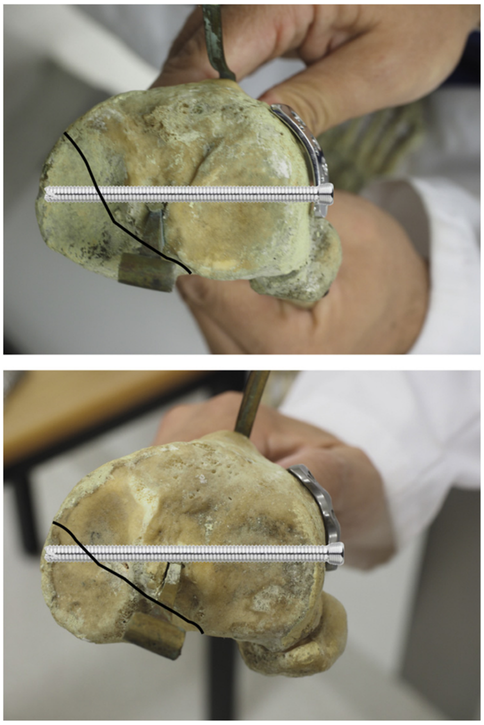

Fig. 1. Schematic examples of screws passed perpendicular through standard anterolateral proximal locking plates (on dry bone specimen) at risk for inadequate fixation of a posteromedial fragment.

condyle involvement, as posteriorly located tibial plateau fractures are frequently unstable with knee flexion [11–16]. As shown in Fig. 1, a particular medial TPF fragment at risk for inadequate fracture fixation through a single anterolateral plate is the posteromedial fragment [17–19].

In 1967, Hohl was the first to publish a study on the posteromedial fragment and found it to occur in the majority of bicondylar TPFs [20]. Barei et al. (2008) and Higgins et al. (2009) described the morphometric properties of posteromedial fragments including the medial articular fracture angle (MAFA) in cohorts of bicondylar TPFs [21,22]. The articular fracture angle is one of the most important parameters for pre-operative planning, as it determines optimal screw placement and angulation. However, in both studies, the MAFA is determined prior to reduction and therefore represents the coronal fragment orientation in space rather than the "real" articular fracture angle of the posteromedial fragment. Due to frequent multi-fragmentation, displacement, and condylar widening, the fracture angle of posteromedial fragments is often difficult to assess in conventional CT imaging software and has therefore not been described before. Correcting for fragment displacement, the novel technique of two-dimensional computed tomography (2DCT) fracture mapping [6,23,24] can be used to accurately measure the posteromedial articular coronal fragment angle and may improve pre-operative planning for optimal screw configuration.

We recently presented a study on 2DCT fracture mapping of the tibial plateau [6]. Based on the tibial plateau fracture map, we proposed four main fracture characteristics of TPFs: lateral (split) fragments, posteromedial fragments, tibial tubercle fragments, and zones of comminution including the tibial spine (i.e, eminence) [25]. Analysis of the tibial plateau fracture map suggests the presence of posteromedial fragments in a substantial proportion of Schatzker type IV fractures, in addition to the known presence of posteromedial fragments in Schatzker type V and VI fractures. In the current study, we aim to further analyze the morphology of the posteromedial fragment in TPFs, including the assessment of the articular coronal fragment angle. To the best of our knowledge, 2DCT fracture mapping has not been previously used to analyze posteromedial fragment morphology.

The purpose of this study is to analyze posteromedial fragment morphology using 2DCT fracture mapping and to compare posteromedial fragment morphology in the various Schatzker type TPFs. We hypothesize that posteromedial fragments are common in Schatzker type IV, V, and VI fractures and that a substantial proportion of these fragments is at increased risk for insufficient stabilization with standardized anterolateral plating.

Materials and methods

Subject selection

A retrospective search was performed for imaging data of patients with an AO/OTA B- or C-type TPF [26] in a level I and level III trauma center (Academic Medical Center and Sint Lucas Andreas Hospital, Amsterdam, The Netherlands). International Classification of Diseases, Ninth Revision (ICD-9) codes for orthopaedic surgery performed between 2000 and 2013 were used to search the surgery database of the level I trauma center. The key phrase "CT Lower Extremity" was used to search the Picture Archiving and Communication System (PACS) database at the level III trauma center for patients treated for a TPF. Good-quality CT scans of 127

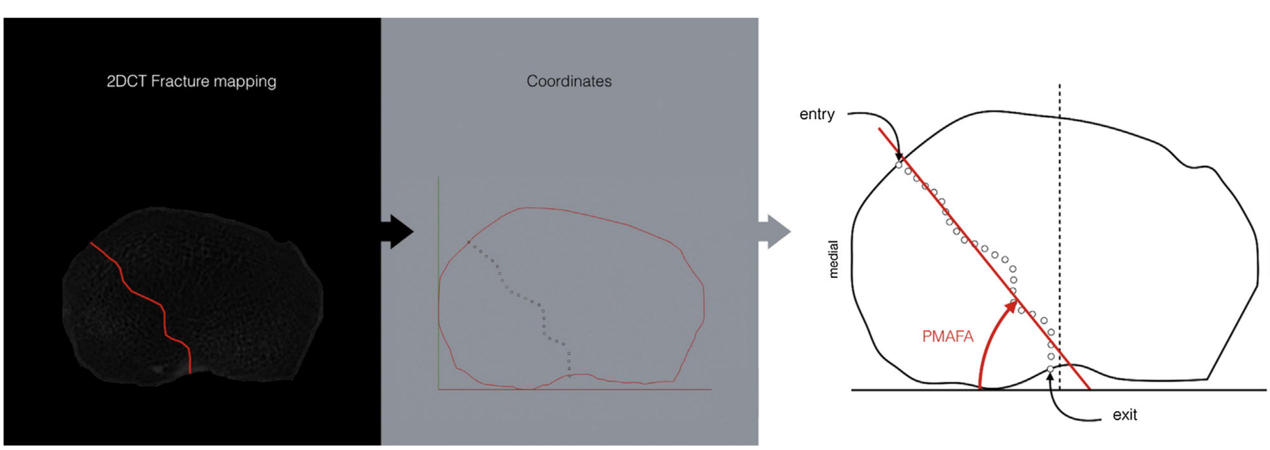

Fig. 2. Conversion from 2DCT fracture line (left) to coordinates (middle), and subsequent calculation of the posteromedial articular fracture angle (PMAFA). The template tibial plateau represents an axial view of a subarticular right tibial plateau.

TPFs were available for analysis (<3.0 mm slide thickness). These CT scans were analyzed in a previous study on TPF characteristics using the fracture mapping technique as coined by Cole et al. [6,23]. Fractures were classified according to Schatzker by the consensus of two authors (RJM and JND). In the current study, all TPFs with a posteromedial fragment were included for analysis. A posteromedial fragment was defined as a fracture line entering the cortex of the medial column and exiting the cortex of the posterior column (at the articular level), with a fracture angle of no more than 90°, so as to exclude anteromedial fragments [27].

Two-dimensional computed tomography (2DCT) fracture mapping

2DCT fracture mapping of the 127 TPFs resulted in the previously published tibial plateau fracture map [6]. Fracture mapping is a method to visualize fracture patterns by tracing, drawing, and superimposing fracture lines on a standardized template. We refer to our previous publication for a detailed description of fracture mapping techniques in TPFs.

Articular fracture angle and surface area

The fracture lines of the posteromedial fragments in the original tibial plateau fracture map were converted to coordinates in Rhinoceros 5 software (McNeel, Seattle, WA) for analysis (Fig. 2). A standardized distance between coordinates was applied. A computer-generated single straight line was placed through the fracture line coordinates, representing the mean orientation of the fracture line on the tibial plateau. The angle of the posteromedial articular fracture line relative to the coronal plane was determined and considered the posteromedial articular fracture angle (PMAFA) adopted and modified from Barei et al. [21].

Anterolateral plates for the fixation of TPFs are designed to have the subchondral screws in the coronal plane. Biomechanical studies have suggested that screws should not be positioned at >20° from perpendicular to the fracture line – corresponding to posteromedial coronal fracture angles <68° – and recent data suggest that interference strength and stiffness are best when locking screws are inserted perpendicular to the plate (Fig. 3) [28,29]. Therefore, in this study, posteromedial fragments with a PMAFA >68° are considered amenable for fixation with screws placed through an anterolateral plate. This angle was derived by subtracting 22° from the sagittal plane, perpendicular to the screws placed at 90° to an anterolateral plate.

For each subject, the articular surface of the posteromedial fragment was determined and calculated as the percentage of the entire tibial plateau and the medial tibial plateau. The lateral border of the medial tibial plateau was defined as a sagittal line passing through the tibial spine. The percentage of articular surface on the posteromedial fragment relative to the remainder of the tibial plateau was obtained by dividing the surface area of the posteromedial fragment by the entire tibial plateau surface area. A similar calculation was performed to obtain the percentage of articular surface of the posteromedial fragment relative to the medial plateau and the percentage of the articular fragment surface on the medial and lateral side of the tibial plateau.

Statistical analysis

Matlab's statistics toolbox (version 2015b) was used for statistical analysis. Kruskall-Wallis non-parametric tests were used for statistical comparison of morphological features (i.e., PMAFA, fragment surface area) of posteromedial fragments between various Schatzker types. Linear regression analysis was performed to examine the statistical association between PMAFA and fragment surface area.

Results

Subjects

Forty-seven out of 127 TPFs were found to include a posteromedial fragment. These fragments were observed in the majority of Schatzker type IV, V, and VI fractures (see Table 1 for details), in 30 female and 17 male patients, ranging from 21 to 89 years (mean: 49 years). Of note, the demographics of the entire TPF case series can be found in Molenaars et al. [6]. There were no significant differences in demographic characteristics of posteromedial versus non-posteromedial cases (see Table – Supplemental Digital Content 1 – for demographic details).

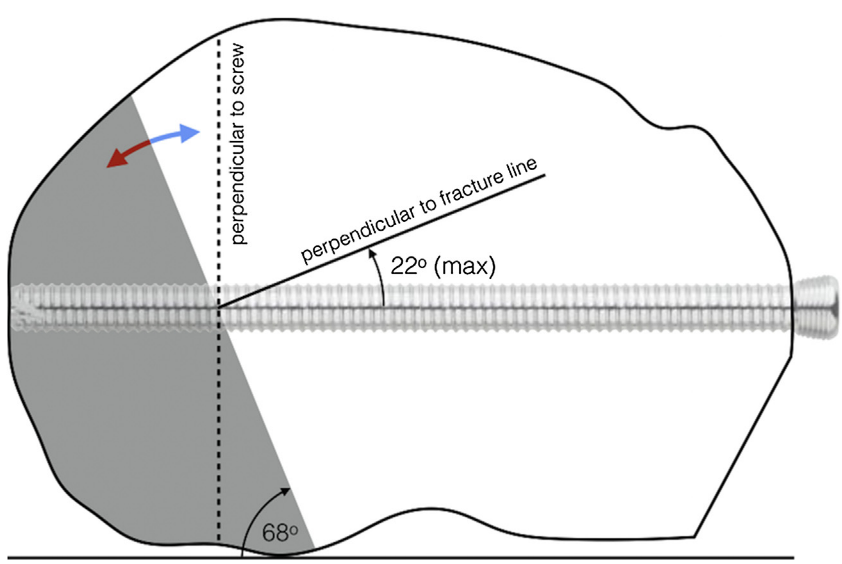

Fig. 3. Biomechanical studies suggest that screws should not be positioned at more that 22° from perpendicular to the fracture line, corresponding to posteromedial coronal fracture angles below 68° when using standardized anterolateral plating.

Table 1
Posteromedial fragments in Schatzker type I-VI tibial plateau fractures.

Variable	*Schatzker classification*				
	type I-III	type IV	type V	type VI	**overall**
Tibial plateau fractures	64	15	26	22	**127**
with posteromedial fragment	0 (0%)	9 (60%)	20 (77%)	18 (82%)	**47 (37%)**

point of rotation at the level of the tibial spine. The exit point cluster at the center and lateral side of the posterior column while the entry points are distributed along the complete medial column.

Posteromedial articular fracture angle (PMAFA)

Across the subjects, the mean PMAFA was found to be 44° (range: 2° to 90°, standard deviation (SD): 23°). Fig. 5 shows the approximation of a normal distribution of PMAFAs in a histogram. Table 2 shows the comparison of posteromedial fragments among different Schatzker types. There were no statistically significant

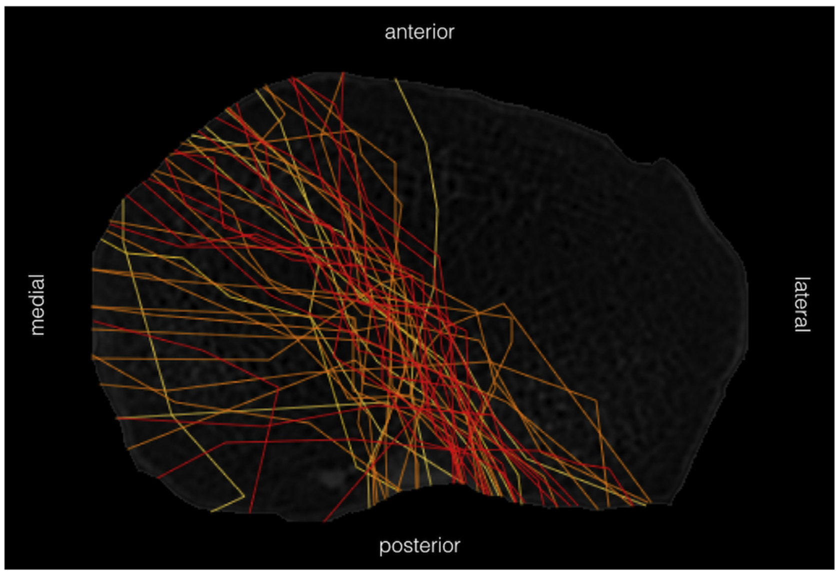

Fig. 4. Posteromedial fragment fracture map. Yellow = Schatzker type IV fragments; Orange = Schatzker type V fragments; Red = Schatzker type VI fragments. Of note, fracture maps per Schatzker can be found in Supplemental Digital Content 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Posteromedial fragment fracture map

The selection of the posteromedial fragments from the tibial plateau fracture map and subsequent tracing, drawing, and superimposing of the fracture lines resulted in the posteromedial fragment fracture map (Fig. 4, Supplemental Digital Content 2). The posteromedial fragment fracture lines present in a fan-shaped pattern, ranging from anteroposterior to coronal, with an optical

differences in PMAFA between posteromedial fragments in Schatzker type IV, V, and VI fractures. Eighty-five percent of posteromedial fragments (40/47) had a PMAFA smaller than 68°, considered at risk for unstable fixation.

Articular surface area

The mean fragment surface area was 34% of the entire plateau (range: 7%–53%, SD: 12%) and 59% of the medial plateau (range: 12%–

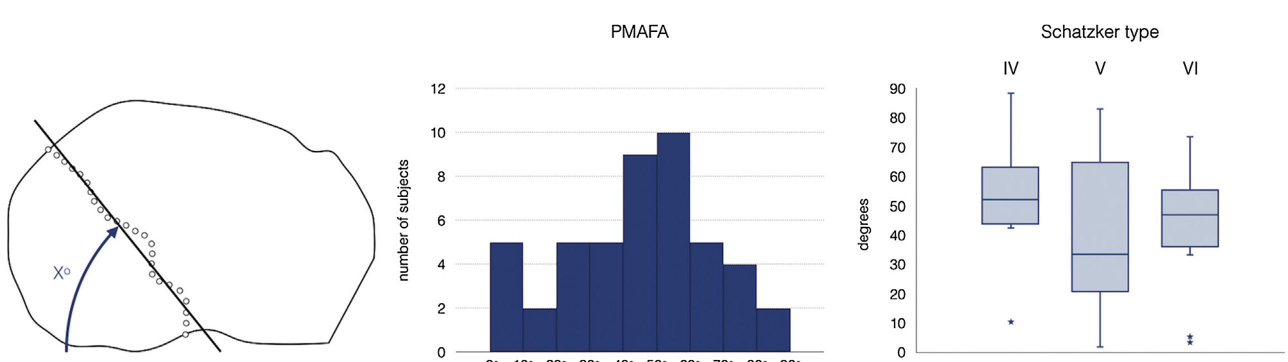

Fig. 5. Posteromedial articular fragment angle (PMAFA) in 47 posteromedial fragments. Histogram: PMAFA approximates a normal distribution. Box plot: there is no significant difference between PMAFA of Schatzker type IV, V, and VI posteromedial fragments.

Table 2
Comparison of posteromedial fragments in different Schatzker type tibial plateau fractures.

	Schatzker classification			
	type IV	type V	type VI	p-value**
Variable				
PMAFA*				
Mean (SD)	52.5° (21.3°)	39.2° (26.2°)	45.6° (18.1°)	
Median (25th quartile ; 75th quartile)	52.4° (43.6 ; 63.8)	34.2° (20.6 ; 65.0)	48.2° (37.4 ; 56.3)	0.38
Percentage of entire plateau				
Mean (SD)	33.1% (16.3%)	32.8% (10.1%)	36.3% (12.5%)	
Median (25th quartile ; 75th quartile)	40.0% (16.4 ; 45.1)	33.5% (26.0 ; 41.4)	39.3% (34.2 ; 43.9)	0.45
Percentage of medial plateau				
Mean (SD)	58.2% (28.3%)	55.6% (20.1%)	63.2% (23.0%)	
Median (25th quartile ; 75th quartile)	69.0% (30.0 ; 75.2)	55.7% (41.4 ; 75.6)	69.5% (60.4 ; 78.4)	0.48

*PMAFA = posteromedial articular fracture angle, in degrees.
**Group differences were tested with Kruskal-Wallis one-way analysis of variance by ranks.

fracture mapping. The MAFA – as coined by Barei et al. [21] – was modified for the purpose of this study (i.e., after hypothetical fracture reduction of the posteromedial fragment; PMAFA) and was found to average 44°. The mean fragment surface area that involved the posteromedial fragment was approximately one third of the entire tibial plateau and 60% of the medial plateau, and 72% of the fragments were continuous with a variable portion of the lateral tibial plateau.

We found that posteromedial fragments are common in both Schatzker type IV and Schatzker type V and VI fractures. There we no statistically significant differences in fracture morphology between posteromedial fragments originating from Schatzker type IV, V, and VI fractures in terms of size or coronal fracture line orientation. In previous literature, the posteromedial fragment is examined in cohorts of Schatzker type V and VI fractures only [21,22]. Based on our current results, posteromedial fragments in Schatzker type IV fractures are morphologically similar to those in Schatzker type V and VI.

After virtual reduction of the posteromedial fragment (fracture mapping) and calculation of the PMAFA, the majority of posteromedial fragments present with a medio-lateral fracture line orientation (PMAFA <68°) that may predispose to inadequate stabilization with screws inserted through an anterolateral plate

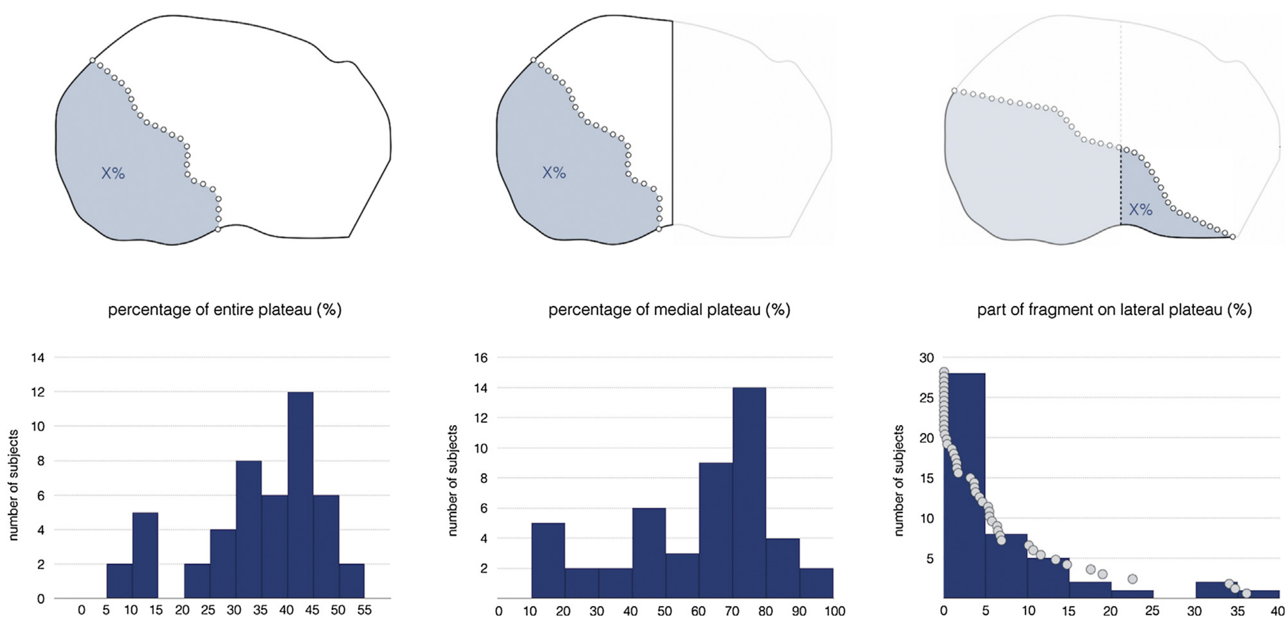

Fig. 6. Fragment surface areas as percentage of the entire tibial plateau (left), percentage of the medial tibial plateau (middle), and the portion of the lateral part of the fragment relative to the medial part of the fragment (right).

97%, SD: 23%)(Fig. 6). In the current study, 72% of the posteromedial fragments cross the midline and exit the tibial plateau on the lateral side. In these fragments, the average portion of the lateral part of the fragment relative to the medial part of the fragment is 9% (range: 0.1%–36%, SD: 10%). There were no statistically significant differences in fragment surface areas between Schatzker type IV, V, and VI fragments (Table 2). There was a significant positive correlation between PMAFA and fragment surface area ($r = .63$, $P < 0.001$), signifying that smaller posteromedial fragments are associated with a more mediolateral fracture orientation on the tibial plateau.

Discussion

The primary purpose of our study was to quantify the morphology of the posteromedial fragment in TPFs using 2DCT (Fig. 7). Fixation may be further compromised in smaller fragments by insufficient screw purchase in these small fragments. Patients with these TPF components may benefit from an additional medial or posterior surgical approach and fracture specific fixation as biomechanical studies suggest that even small posteromedial fragments can be unstable and displace, resulting in worse clinical outcomes (Fig. 8) [17].

In previous studies, the MAFA has been used as a measure of the posteromedial fragment angle [21,22]. The MAFA is defined as the angle between the major medial articular fracture line and the posterior femoral axis (PFCA). As a result, the MAFA is subject to displacement of the fragment, and provides details on the preoperative fragment location and orientation (internal or external rotation). In the management of TPFs, surgeons perform reduction of fragments with the use of a bone holding forceps prior

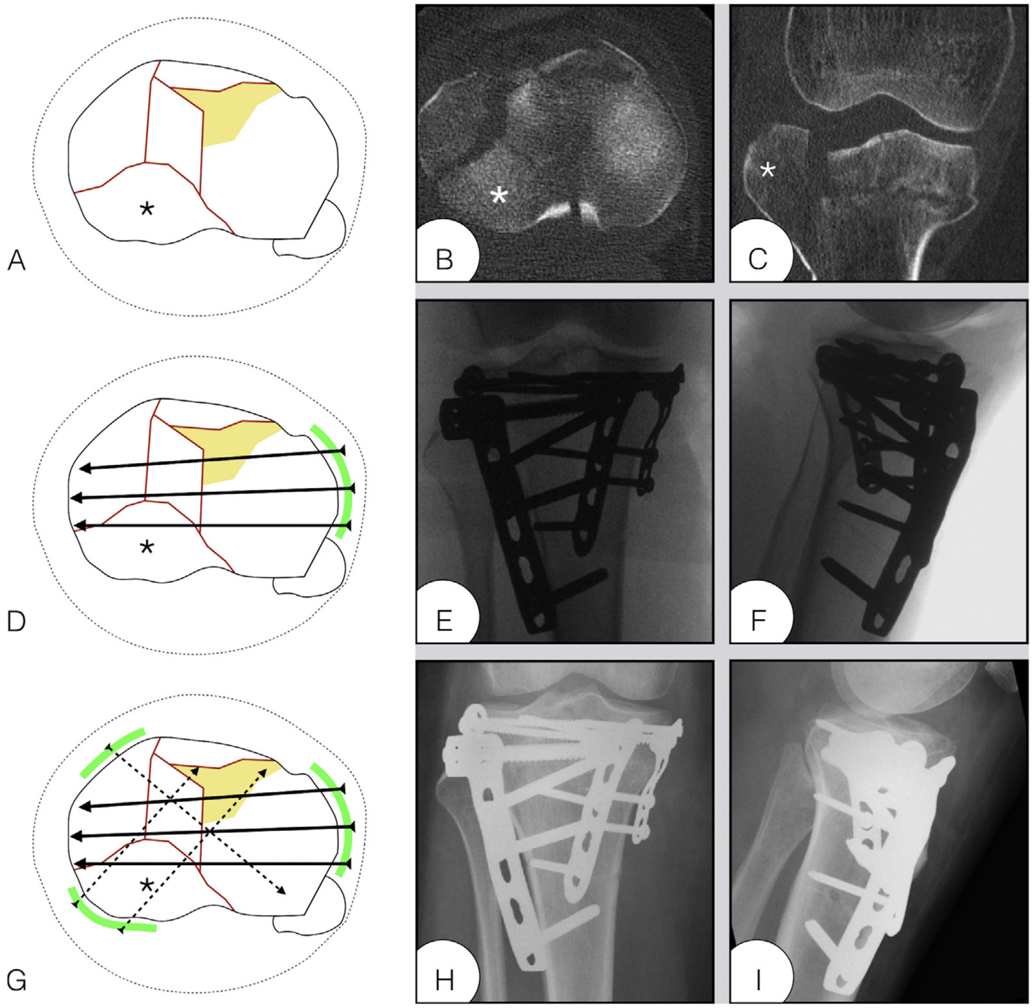

Fig. 7. A) Fracture map of the fracture depicted in B and C used for preoperative planning. B) Transverse and C) coronal CT scan images of a bicondylar tibial plateau fracture with a relatively non-displaced posteromedial fragment (*). Preoperative planning clearly demonstrates that the posteromedial fragment was not amendable to adequate fixation through an anterolateral plate alone (D). As a result, this fracture was treated with fragment specific fixation involving an anterolateral plate, a posteromedial plate, and an anteromedial plate, as illustrated in the intraoperative images (E and F) and final preoperative planning sketch (G). H and I) One year postoperative X-rays demonstrating maintenance of reduction after fracture healing.

to fixation with fixed-angle screw/plate devices. As 2DCT fracture mapping represents the TPF after fragment reduction, the calculated PMAFA in the current study represents the orientation of the articular fracture angle of the posteromedial fragment on the tibial plateau. Fig. 9 further elucidates the conceptual difference between the MAFA used in previous studies and the modified PMAFA used in the current study. The PMAFA may be useful to determine if a medial or posterior surgical approach is desirable in addition to fracture specific fixation of the concomitant anteromedial fragment (i.e., tibial tubercle) or lateral component of the overall injury pattern.

The fragment surface areas found in this study are fairly consistent with the results of the morphological studies by Barei et al. and Higgins et al. [21,22]. In the current study, the incidence of posteromedial fragments in bicondylar TPFs is slightly higher (80% versus 59–74%) and the mean fragment surface area is somewhat larger than previously described (34% versus 23–25%).

Several limitations of this study must be considered. Although our sample size is comparable to previous studies on this subject, the study sample is relatively small in terms of statistical power for the comparison between different Schatzker types. In addition, we were able to calculate fragment surface areas in terms of percentages, but not actual mm [2] (i.e., square units). This is a consequence of 2DCT fracture mapping, in which individual fractures are reduced and fitted into a standardized template in the axial plane. In this process, individual characteristics in terms of square units are lost, but overall patterns emerge. An important strength is that we examined the posteromedial fragment without exclusion of TPFs based on classification. Moreover, the inclusion of subjects from a level I and level III trauma center ensures that our sample is representative of a wide range of TPFs. A final strength is the modification of Barei's MAFA that adds to the clinical relevance of this paper and provides information on TPF fracture morphology that has not been described before.

In conclusion, our study shows that posteromedial fragments commonly occur not only in Schatzker type V and VI, but also in Schatzker type IV TPFs. We find that the morphology of these fragments is heterogeneous, but not significantly different among Schatzker types. The vast majority of posteromedial fragments (85%) presents with a fragment orientation smaller than 68°, and may therefore benefit from an additional medial or posterior surgical approach for fixation. Future analysis of posteromedial

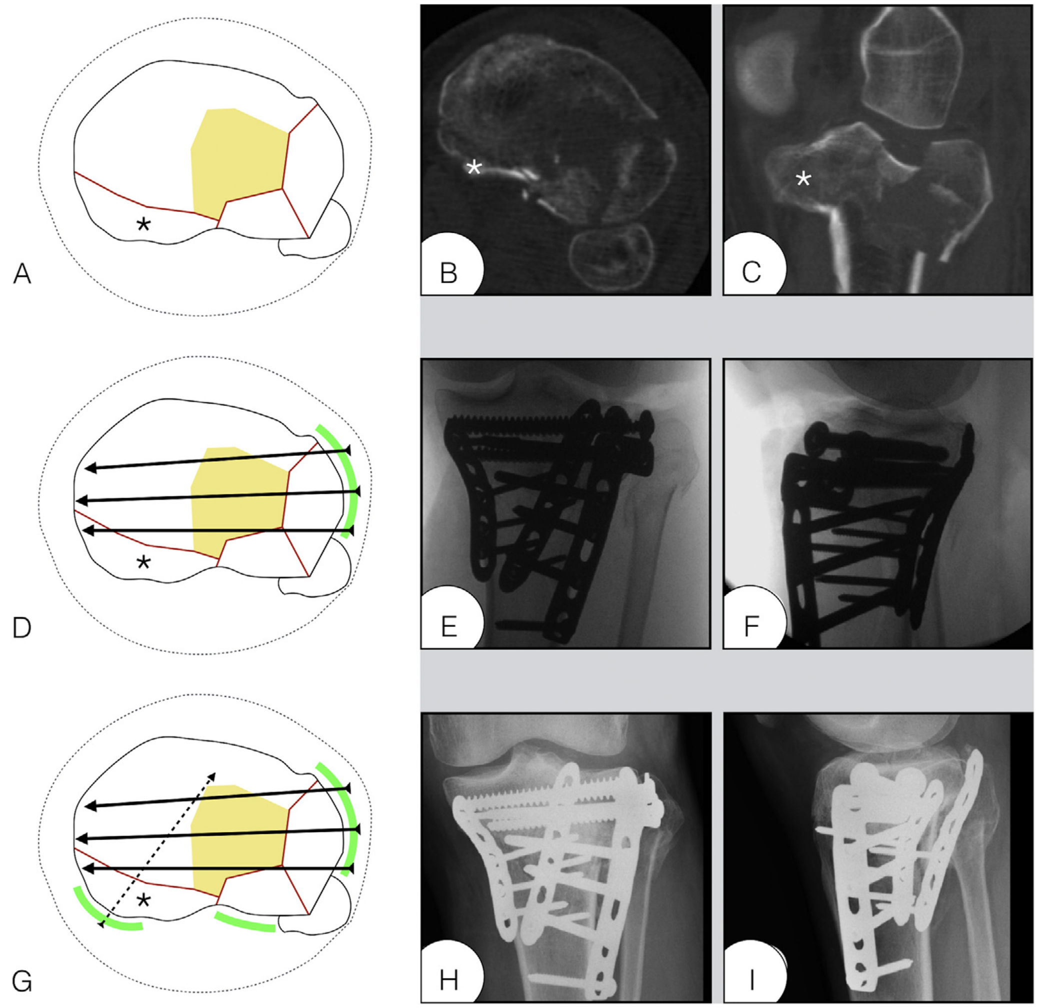

Fig. 8. A) Fracture map of the fracture depicted in B and C used for preoperative planning. B) Transverse and C) coronal CT scan images of a bicondylar tibial plateau fracture with a more displaced posteromedial fragment (*). Preoperative planning demonstrating that the posteromedial fragment (*) was not amendable for adequate fixation through an anterolateral plate (D). As a result, this fracture was treated with fragment specific fixation involving an anterolateral plate, a posteromedial plate, and a posterolateral plate, as illustrated in the intraoperative images (E and F) and final preoperative planning sketch (G). H and I) One year postoperative X-rays demonstrating maintenance of reduction after fracture healing.

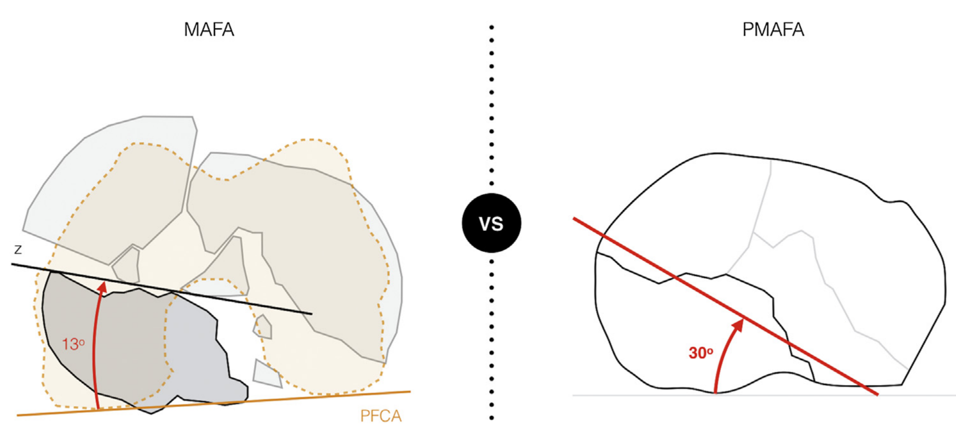

Fig. 9. Medial articular fracture angle (MAFA) versus posteromedial articular fracture angle (PMAFA) in the same tibial plateau fracture. This example is based on the CT example of Barei et al. (2008). Left panel: articular fracture angle as calculated by Barei et al. and Higgins et al. PFCA = posterior femoral condylar axis; z = line of "best fit" to replicate the major transchondral fracture line involving the medial tibial articular surface. The angle subtended by z and PFCA gives the MAFA, representing the pre-reduction orientation of the posteromedial fragment (= 13°). Right panel: fracture angle of the same fragment as calculated in the current study with the use of 2DCT fracture mapping (= 30°). Fracture mapping essentially results in a reconstruction of the tibial plateau fracture, comparable to the post-reduction (or pre-fixation) state of the fracture.

tibial plateau fragments with the use of quantitative three-dimensional computed tomography (Q3DCT) [30,31] might further enhance our understanding of the morphology of the posteromedial fragments and their relationship with fixed angle screws in current locking compression plate designs.

Conflicts of interest and source of funding

JND received an unrestricted research grant from the Marti-Keuning-Eckhardt foundation. For the remaining authors none were declared.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2018.10.029.

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