Posterior malleolar fractures

Diagnostic accuracy, morphology and clinical outcome

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QUANTIFICATION OF POST-OPE RATIVE POSTERIOR MALLEOLAR FRAGMENT REDUCTION USING THREE-DIMENSIONAL COMPUTED TOMOGRAPHY (Q3DCT) DETERMINES OUTCOME IN A PROSPECTIVE PILOT STUDY OF PATIENTS WITH ROTATIONAL TYPE ANKLE FRACTURES

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INTRODUCTION

Patients with rotational type ankle fractures that include a posterior malleolar (PM) fragment tend to have a poorer prognosis than ankle fractures without posterior involvement.1–7 Outcome of these fractures is related to the overall pattern of injury, fracture fragment size, and classic measures of residual fracture step-off and gap.2, 7–12

Classically, management of these PM fractures is guided by their size, that is, involved percentage of the complete articular surface of the tibial plafond.6, 12 However, determining the percentage of the articular surface on plain lateral radiographs has been shown unreliable. True prognostic value of fragment size as an outcome parameter remains unclear.2, 7–12, 16

In addition to fragment size, postoperative articular congruity in terms of step-off and gap is believed to be a strong predictor for clinical outcome.1, 2, 19–21 In general, orthopaedic trauma surgeons are trained that the presence of postoperative articular incongruity of > 2-mm step-off and > 2-mm talar shift correlates with early posttraumatic arthrosis and unsatisfactory functional outcomes.15, 19, 20

Besides step-off, fracture gap is another factor associated with articular congruity that one has to take into account for restoring the ankle joint.1 To date, one study on conservatively treated isolated fractures of the posterior malleolus showed that a gap at the fracture site had no impact on the clinical outcome after 20 years of follow-up.21

To date, there is a lack of evidence-based quantified cutoff points for acceptable articular step-off and gap size in ankle fractures, as they do emerge in other fractures.10, 22 Since the introduction of 2-mm displacement of the PM fragment in ankle fractures by Joy in 1974 and the paper of Jupiter’s ‘classic’ 2-mm step-off for distal radius fractures, the orthopaedic community continues to use these articles as reference standard.6, 10–21

Despite advanced imaging techniques, quantification of PM fragment size, step-off, and gap has not been analyzed clinically.22 In a previous study in this Journal, we revisited quantification of fragment size (defined as % of the complete articular surface), step-off (mm), gap (surface in mm²), and introduced a reliable and accurate measure of multidirectional 3D displacement.22

The objective of this pilot study was to assess the association between quantitative measures of postoperative reduction of PM fractures and patient- and physician-based outcome at 1 year after surgery. We hypothesized that posterior fragment size, residual postoperative step-off, gap, and 3D displacement following operative reduction correlate with functional and radiographic outcome scores.

MATERIALS AND METHODS

All patients in this pilot study were included in the prospective EF3X-trial, evaluating the added value of intraoperative use of 3D-fluoroscopy compared with 2D-fluoroscopy alone.24 Our institutional review board approved the study, in accordance with the Declaration of Helsinki. Dutch Trial Register NTR 1902.
Subjects
In this prospective pilot study, we included 31 patients with operatively treated rotational type ankle fractures including a PM fragment (OTA type 44). All patients were treated in the Academic Medical Center of Amsterdam, a Level-I-Trauma Center, between January 2010 and December 2013. A total number of 117 patients with rotational type ankle fractures (with and without PM fractures) were included in the EF3X-trial.58 Fifty-eight patients had a rotational type ankle fracture that included a PM fragment. Sixteen patients had postoperative computed tomography (CT) scans of insufficient quality for quantification of 3-dimensional CT (Q3DCT) modeling. Of the 42 remaining patients with complete good quality imaging data, 11 were lost to follow-up (26%), leaving 31 patients (74%) for analysis.

CT scans were obtained from all included patients within 7 days of the index procedure to quantify postoperative fracture reduction and fixation. CT scans were obtained with a maximal axial slice thickness of 1 mm according to the hospital protocol. Inclusion criteria were patients 18 years or older and radiographs of the ankle after 1-year follow-up. Exclusion criteria were polytrauma patients, the presence of a pilon fracture, and impaction of only the posteromedial tibial plafond not associated with a rotational type ankle fracture representing an axial load rather than rotational type injury.

Posterior fragments were classified according to OTA and Haraguchi classifications.55–27 The OTA/AO classification categorizes these fractures into 44A, 44B, and 44C. The Haraguchi classification categorizes fractures of the posterior malleolus as follows: type I: a triangular fragment involving the posterolateral corner of the tibial plafond, type II: extension of the fracture line to the anterior part of the medial malleolus, and type III: small, shell-shaped fragments at the posterior lip of the tibial plafond.20

Quantitative 3-Dimensional computed tomography (Q3DCT) modeling
To quantify fracture fragment size as percentage of articular surface, step-off (mm), total gap surface (mm²), and 3-dimensional multidirectional displacement of postoperative PM fragment reduction, we used Q3DCT modeling techniques as previously described.22, 26–28 In ankle fractures, this technique for quantification of step-off, gap, and 3D displacement of the reduced PM fragment has been found to be reliable in a separate study.22, 28

The creation of Q3DCT of post-op reduction involves the following steps: to create reconstructions, sagittal images of CT scans (DICOM files; Digital imaging and Communications in Medicine) were analyzed with an algorithm that identifies the outer margin of highest density (cortical or subchondral) bone using Matlab (version 8.0; Mathworks, Natick, MA). These outlines were then stacked using Rhinoceros (version 4.0; McNeel North America, Seattle, WA), creating a wire mesh representing the outer margin of the bone. This wire mesh model was then transformed into a polygon mesh, a hollow 3D model of the outer surface of the bone. Fracture fragments with the articular surface attached were then identified and isolated for analysis. After creating Q3DCT models of 31 distal tibias, these models were superimposed on a template of a full, unfractured tibia. This tibia was positioned in such a way that the tibial shaft was parallel to the y axis: the x axis represented the anteroposterior (AP) (or sagittal) plane and the z axis represented the mediolateral (or coronal) plane. After fitting the individual models to the template, fracture fragments with the articular surface attached were then identified and isolated for analysis. Three authors verified definitive fitting of the models to the template separately. A video to depict our Q3DCT modeling technique for PM fractures is available at http://www.traumaportal.org/posteriormalleolus.

Evaluation of Q3DCT
The articular surface area of the PM fragments and the remaining intact distal tibial plafond were measured (Figure 1). Surface area measurements were performed in Rhinoceros and are reported as a percentage of the articular surface of the complete tibial plafond. In case of multiple posterior fragments, the surface area of the separate fragments was combined. To determine the postoperative step-off, gap, and 3D displacement, the posterior fragment was virtually reduced to its anatomical position. Three authors verified this position separately until consensus on optimal reduction was reached. Postoperative step-off was determined as fragment placement on the Y-axis (DY) and given in millimeters (Figure 2). We calculated the gap surface measurement by filling out the articular surface of any visible recess between the tibial plafond and the posterior fragments with a calculable grid. The surface of this grid was then given in mm² (Figure 3). In case of multiple gaps, the accumulated surface area was calculated. 3D displacement was given as a vector of the combined displacements on the X-, Y-, and Z-axis (Figure 4) and calculated as follows:

$$3D\text{- displacement} (mm) = \sqrt{(\Delta x^2 + \Delta y^2 + \Delta z^2)}$$

FIGURE 1. Articular surface area of the PM fragment and the remaining intact distal tibial plafond.
MAIN OUTCOME

Patient-reported outcome measures
Patient-reported outcome measures were assessed using the Foot and Ankle Outcome Score (FAOS) pain and symptoms subscales and Short Form-36 (SF-36) quality of life questionnaire 1 year postoperatively.38, 39 For the FAOS, each subscale score ranges from 0 to 100, with higher scores indicating a better function or outcome. The SF-36 is a well-known and often used questionnaire to evaluate general health. Mental Component Score and Physical Component Score were calculated on a 0 (worst) to 100 (best) scale. A score of 50 is equal to the mean score for the general population.39

Secondary Outcome

Radiographic outcome measures
Radiographic measurements for early posttraumatic arthrosis were based on standard AP and lateral weight-bearing radiographs. The van Dijk ankle arthrosis score was used as the main outcome instrument as previously described in this Journal.35 The Kellgren and Lawrence score for osteoarthritis, which was developed for osteoarthritis of the knee with 5 categorical ratings, has significantly poorer interobserver reliability for scoring posttraumatic ankle arthritis.36 Radiographs were taken and evaluated using the van Dijk arthrosis score by 2 independent observers 1 year postoperatively.
Stage 0: Normal joint or subchondral sclerosis; stage 1: Osteophytes without joint space narrowing; stage 2: Joint space narrowing with or without osteophytes; stage 3: (Sub) total disappearance or deformation of the joint space.

Statistical analysis
Statistical analysis was performed by use of IBM SPSS Statistics for Macintosh, version 24.0 (IBM Corp, Armonk, NY). Baseline characteristics of study patients are summarized with frequencies and percentages for categorical variables and with means and SDs for continuous variables. Student t tests were performed to assess differences in patient-reported outcome measures between patients with and without surgically fixed malleolar fragments. The ordinal arthrosis score was compared by use of a Mann–Whitney U test. Pearson correlation coefficients were calculated to assess the association between the Q3DCT measurements and arthrosis score as well as patient reported outcome measures. A P value less than or equivalent to 0.05 was considered statistically significant. Index correlation coefficient was interpreted as follows: 0.00–0.19 ‘very weak,’ 0.20–0.39 ‘weak,’ 0.40–0.59 ‘moderate,’ 0.60–0.79 ‘strong,’ and 0.80–1.0 ‘very strong.’

RESULTS
Patient characteristics
Twelve (39%) of the 31 included patients were men; 19 were women (61%). Patients had an average age of 46 years (range 19–73). The left ankle was affected in 13 patients (42%). Fourteen (45%) posterior fragments were directly surgically fixed, 4 (13%) were reduced indirectly with a syndesmotic screw, and 13 (42%) patients had no fixation of the PM fragment at all. Twenty were injured because of a fall while walking, 8 because of a bicycle accident, and 3 because of other reasons. According to Haraguchi, the classification was as follows: type I: 17, type II: 7, and type III: 7. OTA classification revealed: 44A: 1 (44A: 1), 44B: 26 (44B1: 4, 44B2: 1, and 44B3: 21), and 44C: 4 (44C1: 1, 44C2: 2, and 44C3: 1) (see Table, Supplemental Digital Content 1, http://links.lww.com/JOT/A687).

Posterior malleolar fractures surgically fixed
Eighteen of the 31 (58%) patients were treated with fixation (direct or indirectly) of the posterior malleolus but did not significantly differ from the 13 patients without fixation (42%) in terms of early posttraumatic arthrosis, FAOS, and SF-36 scores (see Table, Supplemental Digital Content 2, http://links.lww.com/JOT/A688).

Eight of the 17 (47%) patients with a Haraguchi type I PM ankle fracture were treated with fixation of the PM fragment. Of the 8 patients with fixation, 4 (50%) patients were treated with an additional syndesmotic screw. The remaining 9 (53%) patients had no fixation of the PM fragment. Of these 9 patients, one had fixation of the ankle syndesmosis. All type I fractures had a fibula fracture (Weber B/C): All patients had a fibula fracture and were treated with a lag screw and/or standard one-third tubular plate (average 7 holes, range: 7–11).

In 3 of the 7 (43%) patients with a Haraguchi type II PM ankle fracture, both fragments (posterolateral and posteromedial) were fixed, 2 with a separate antiglide plate and, in one case, 2 AP screws. One of these 2 patients had an additional syndesmotic screw. In 4 (57%) patients, only the posterolateral fragment was treated, and in one of these patients, an additional syndesmotic screw was placed. All patients had a fibula fracture and were treated with a lag screw and/or standard one-third tubular plate (average 6 holes, range: 5–7).

None of the 7 patients with a Haraguchi type III PM ankle fracture had direct fixation of the PM fragment. In 2 (29%) patients, the syndesmosis was treated with a syndesmotic screw. Seven (100%) patients had a fibula fracture (Weber B/C): 2 (29%) treated with a lag screw and 5 (71%) with a standard one-third tubular plate (average 4 holes, range 7–9) (see Table, Supplemental Digital Content 3, http://links.lww.com/JOT/A689).

MAIN OUTCOME
Patient- and physician-based outcome and correlation with postoperative quantification of fracture reduction
Postoperative articular step-off in millimeters
Residual postoperative step-off showed a mean of 0.6 mm (SD 0.8), ranging from 0 to 2.7 mm (Figure 2 and Table 1). Nine patients (29%) were considered to have a perfect anatomical reduction (0 mm step-off), 12 patients (39%) had residual incongruity of 0–1 mm, 8 patients (26%) had 1–2 mm, and 2 patients (6%) had 2–3 mm. Step-off was significantly correlated with FAOS symptoms (Correlation coefficients (CC) = 0.37, P = 0.05) and FAOS pain score (CC = 0.38, P = 0.04). No significant correlations were found for arthrosis or SF-36 scores.

Postoperative articular gap in square millimeters
Residual postoperative gap showed a mean of 12.6 mm² (SD 19.5), ranging from 0 to 68.8 mm² (Figure 3). Twelve patients (39%) were considered to have a perfect anatomical reduction (0 mm² gap), 11 patients (35%) had residual gap of 1–15 mm², 3 patients (10%) had 16–30 mm², 3 patients (10%) had 31–45 mm², and the remaining 2 patients (6%) had >45 mm². There was no significant correlation between the total gap surface and posttraumatic arthrosis, FAOS, or SF-36 scores.

Postoperative multidirectional displacement in millimeters
Residual postoperative multidirectional displacement showed a mean of 0.96 mm (SD 0.8), ranging from 0 to 2.8 mm (Figure 4). Four patients (13%) were considered to have a perfect anatomical reduction (0 mm), 14 (45%) patients had 3D displacement of 0–1 mm, 8 patients (26%) had 1–2 mm, and 5 patients (16%) had 2–3 mm. Overall, multidirectional displacement did not show any significant correlation with any of the outcome scores. Results are shown in Table 1.
SECONDARY OUTCOME

Radiographic outcome measures

Fracture fragment size in terms of percentage of the involved articular surface of the talus dome

3DCT measurements of PM fragments showed a mean articular surface of 12% (range 0.0%–36.0%) of the joint surface (Figure 1). Posterior fragment size was moderately correlated with arthrosis (CC 0.44, P = 0.01). No significant correlations were found for FAOS and SF-36 scores.

DISCUSSION AND CONCLUSIONS

The purpose of this study was to begin to understand the relevance of residual step-off and gap on patients’ outcome in rotational type ankle fractures with an associated PM fragment, using advanced (but also very labor intensive) contemporary Q3DCT measurements. Although many clinically related questions remain unanswered, we found that measurements—using state-of-the-art Q3DCT imaging—of residual step-off correlated significantly with worse FAOS pain and symptoms subscales, our main outcome measures. By contrast, residual gap after reduction of PM fractures associated with rotational type ankle fractures was not significantly associated with patient- and physician-based outcomes at 1-year follow-up.

The present pilot study should be interpreted in the light of strengths and limitations, including a limited prospective sample size treated by different respective surgeons. In addition, one could argue that CT scans do not account for true articular involvement, as cartilage is not shown. Therefore, measurements made with Q3DCT can differ from magnetic resonance imaging or cadaveric studies.23 Finally, the short-term follow-up should be taken into account when interpreting this study on patient- and physician-based outcomes at 1-year follow-up. One could argue that there is some evidence suggesting that satisfactory functional recovery in the short term does not decay over the following decade after surgery for unstable ankle fractures; however, we will continue to collect data on this patient cohort to report on longer-term follow-up in subsequent studies to improve our understanding of residual step-off and gap on functional outcome.

TABLE 1. Q3DCT Measurements of Fracture Reduction

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<tr>
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<th>FAOS</th>
<th>SF-36</th>
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<tr>
<td></td>
<td>Arthrosis</td>
<td>Symptoms</td>
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<tr>
<td></td>
<td>CC p-value</td>
<td>CC p-value</td>
</tr>
<tr>
<td>Posterior fragment size (%)</td>
<td>0.44 0.01</td>
<td>-0.13 0.50</td>
</tr>
<tr>
<td>Step-off (mm)</td>
<td>0.10 0.6</td>
<td>-0.37 0.05</td>
</tr>
<tr>
<td>Gap (mm)</td>
<td>0.15 0.42</td>
<td>0.03 0.89</td>
</tr>
<tr>
<td>Overall multi-directional displacement (mm)</td>
<td>0.18 0.33</td>
<td>-0.26 0.17</td>
</tr>
</tbody>
</table>

In addition, size, location, and displacement are not the only criteria for fixation and potential predictors of outcome. The anatomical reduction of the PM fragment should also recreate congruence of the incisura, as these fragments carry the insertion of the posterior syndesmosis. Q3DCT is a useful technique to quantify the latter as well but was beyond the scope of the current study.

In long-term studies analyzing relations with patients’ functional outcome, size of the PM fragment has been the leading argument for surgically addressing the fragment directly.11,41,47 To date, fracture fragment size has been measured on plain lateral radiographs, which have shown to be unreliable (interobserver reliability) and inaccurate (diagnostic performance characteristics: sensibility, sensitivity, and accuracy).6,45 Only Evers et al applied CT scans to correlate size of the fragment with posttraumatic arthrosis. The authors concluded that fragments sized > 25% predicted the occurrence of posttraumatic arthrosis after 2.5 years.46 In accordance with Evers et al, this current study shows a correlation between fragment size— as percentage of the joint surface—and arthrosis after 1-year follow-up.

By contrast, according to a recent systematic review, the incidence of posttraumatic arthrosis was not associated with the size of the PM fragment quantified in terms of percentage of the articular surface but with the presence of fracture dislocation at injury, articular surface congruity, and residual talus subluxation.7 This is in line with our findings according to step-off but contrary in terms of fragment size.

Development of posttraumatic arthrosis is most likely to be multifactorial, including cartilage injury, degrees of comminution and impaction, age, functional status of the patient, and ligamentous damage.13 Drijfhout van Hooff et al showed that radiographic signs of posttraumatic arthrosis occurred more frequently when PM fragments showed a postoperative step-off of 2 mm or more as measured on plain radiographs. Joy et al established this for ankle fractures in 1974 and was applied by Knirk and Jupiter’s landmark paper for distal radius fractures.15,48

Perhaps, the biggest limitation of adapting these 2-mm measures is the fact that they rely on dated imaging technologies. With the advent of more sophisticated imaging techniques, the limitations of plain radiographs have come to light.44,49 Two-dimensional CT (2DCT) allows for more thorough evaluation, although surgeons may overestimate true articular involvement when evaluating CT images. In addition, articular incongruity often involves 3D displacement in multiple planes, which may not be acknowledged on conventional 2DCT. Kern and Anderson13 were the first to describe step-off in 3D that evaluated the articular surface of the ankle joint. Unfortunately, the authors did not report — nor did other authors — on clinical outcomes compared with state-of-the-art 3D measurements.

Our findings are in line with Donken et al according to fracture gap. They concluded that there was no correlation between the size of the gap and the clinical result of the patient.7 This can be caused by the fact that a gap is not caused by displacement of the whole PM fragment but more so by local impaction of the articular surface nevertheless, this conclusion was made for ‘isolated’ PM fractures, and measurements were again made on plain lateral radiographs.

In conclusion, in ankle fractures involving the posterior malleolus, residual intra-articular step-off as measured on Q3DCT significantly correlates with patient-reported pain and symptoms.
The scope of this study was to begin to understand the clinical relevance of residual postoperative articular step-off and gap in rotational type ankle fractures; however, many more clinically related questions remain that require further prospective studies in larger numbers. When these studies are undertaken, we recommend the use of postoperative Q3DCT measurements to further improve our understanding of intra-articular fracture reduction and (3D) quality of syndesmotic reduction to ultimately advise on which fragments to fix to improve our patients’ outcomes.

REFERENCES
