Injury, Int. J. Care Injured 50 (2019) 1392–1397

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Posterior malleolar fracture morphology determines outcome in rotational type ankle fractures

R.P. Blom[a,b,e,*], D.T. Meijer[a,c], R-J.O. de Muinck Keizer[c], S.A.S. Stufkens[a,b,e], I.N. Sierevelt[d], T. Schepers[c], G.M.M.J. Kerkhoffs[a,b,e,f], J.C. Goslings[g], J.N. Doornberg[a,h]

[a] Department of Orthopaedic Surgery, Amsterdam UMC, location AMC. University of Amsterdam. Amsterdam, the Netherlands
[b] Amsterdam Movement Sciences, Amsterdam, the Netherlands
[c] Trauma Unit, Department of Surgery, Amsterdam UMC, location AMC, Amsterdam, the Netherlands
[d] Specialized Centre of Orthopedic Research and Education (SCORE). Amsterdam, the Netherlands
[e] Academic Center for Evidence-based Sports medicine (ACES)
[f] Amsterdam Collaboration for Health and Safety in Sports (ACHSS), Amsterdam UMC IOC Research Center, Amsterdam, the Netherlands
[g] Trauma Unit, Department of Surgery, Onze Lieve Vrouwe Gasthuis (OLVG), Amsterdam, the Netherlands
[h] Department of Orthopaedics and Trauma Surgery, Flinders Medical Centre and Flinders University. Adelaide, South Australia, Australia

ARTICLE INFO

Article history:
Accepted 2 June 2019

Keywords:
Posterior malleolar fractures
Fragment size
Computed tomography
Fracture morphology
Clinical outcome

ABSTRACT

Introduction: Rotational type ankle fractures with a concomitant fracture of the posterior malleolus are associated with a poorer clinical outcome as compared to ankle fractures without. However, clinical implications of posterior malleolar (PM) fracture morphology and pattern have yet to be established. Many studies on this subject report on fragment size, rather than fracture morphology based on computed tomography (CT). The overall purpose of the current study was to elucidate the correlation of PM fracture morphology and functional outcome, assessed with CT imaging and not with –unreliable- plain radiographs.

Methods: Between January 2010 and May 2014, 194 patients with an operatively (ORIF) treated ankle fracture, were prospectively included in the randomized clinical EF3X-trial at our Level-I trauma center. The current study retrospectively included 73 patients with rotational type ankle fractures and concomitant fractures of the posterior malleolus. According to the CT-based Haraguchi fracture morphology, all patients were divided into three groups: 20 Type I (large posterolateral-oblique), 21 Type II (transverse medial-extension) and 32 Type III (small-shell fragment). At 12 weeks, 1 year and 2 years postoperatively the Foot and Ankle Outcome Scores (FAOS) and SF-36 scores were obtained, with the FAOS domain scores at two years postoperative as primary study outcome. Statistical analysis included a multivariate regression and secondary a mixed model analysis.

Results: Haraguchi Type II PM ankle fractures demonstrated significantly poorer outcome scores at two years follow-up compared to Haraguchi Types I and III. Mean FAOS domain scores at two years follow-up showed to be significantly worse in Haraguchi Type II as compared to Type III, respectively: Symptoms 48.2 versus 61.7 ($p = 0.03$), Pain 58.5 versus 84.4 ($p < 0.01$), Activities of Daily Living (ADL) 64.1 versus 90.5 ($p < 0.01$).

Conclusion: Posterior malleolar ankle fractures with medial extension of the fracture line (i.e. Haraguchi Type II) are associated with significantly poorer functional outcomes. The current dogma to fix PM fractures that involve at least 25–33% of the tibial plafond may be challenged, as posterior malleolar fracture pattern and morphology - rather than fragment size - seem to determine outcome.

Introduction

In 2006 Haraguchi et al. [1] published on posterior malleolar (PM) fracture pathoanatomy and challenged the historical concept that PM fractures should be stratified according to fragment size. The authors questioned the dogma that fragments involving at least 25–33% of the tibial plafond need to be fixed operatively [2].

* Corresponding author at: Amsterdam UMC, location AMC, Meibergdreef 9, 1105 AZ, the Netherlands.
E-mail address: r.p.blom@amc.uva.nl (R.P. Blom).

https://doi.org/10.1016/j.injury.2019.06.003
0020-1383/

Haraguchi et al. classified three PM fracture types: Type I, posterolateral-oblique; Type II, transverse medial-extension; and Type III, small-shell fragment [1] (Fig. 1). However, since their publication there have been no prospective cohort studies to correlate Haraguchi's concept on CT-based fracture morphology –rather than fragment size– to clinical outcome [3,4]. Many studies to date lack computed tomography (CT) for accurate analysis of fracture morphology [5–16]. Despite the fact that the two most recent current concept reviews advise to use CT to guide treatment [3,4], the most recent systematic review and clinical series on PM fractures still applies the classical concept of fragment size based on – unreliable – lateral radiographs [17,18].

Although some authors still debate the size of the PM fragment that requires fixation [4,19–21], we concur with the recent review articles [3,4]: PM fragment morphology may be more important than size [22]. Similarly, over a decade ago, O'Driscoll et al. described for coronoid fractures that fracture morphology –and the associated overall elbow fracture pattern– are more important than fragment size to determine fracture fixation strategy [23].

Multiple studies reveal that ankle fractures with a concomitant PM fracture may be associated with a poorer clinical outcome, as compared to patients without [4,7,12,19,24–26].

The overall purpose of the current study was to elucidate the correlation of PM fracture morphology and functional outcome, assessed with CT and not with plain lateral radiographs as in previous studies [22,27].

The primary aim of this study was to evaluate if PM ankle fractures that extend into the medial malleolus (Haraguchi Type II) are associated with poorer clinical outcomes as compared to the spectrum of posterolateral oblique (Types I and III) PM ankle fractures.

Patients and methods

Our Institutional Review Board (IRB) approved for the use of anonymized CT images of operatively treated ankle fractures from the prospective randomized clinical EF3X-trial [28], (Beerekamp, 2011 #6429) in accordance to the Declaration of Helsinki.

Subjects

Between January 2010 and May 2014, 194 patients with an operatively treated ankle fracture, were prospectively included in the randomized clinical EF3X-trial at our Level-I trauma center [28]. Two authors not involved in any patient care (first and senior authors: RPB and JND) evaluated all anonymous CT scans that were obtained out of the prospective randomized EF3X-trial to include patients for the current study. Inclusion criteria of the current study were intra-articular rotational type ankle fracture with a concomitant fracture of the posterior malleolus, i.e. AO/OTA Fracture Classifications; 44-A3, 44-B3, 44-C1/2 [29], patients aged eighteen years or older. 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.

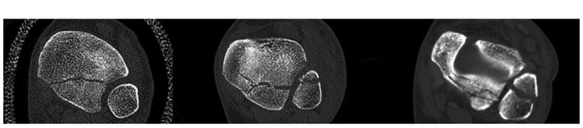

Fig. 1. Axial computed tomography (CT) images of the three different posterior malleolar ankle fractures according to the fracture classification system of Haraguchi et al. On the left a Haraguchi Type I fracture with a triangular fragment involving the posterolateral corner of the tibial plafond. In the middle a Haraguchi Type II fracture with extension of the fracture line into the anterior part of the medial malleolus, which results in a posterolateral and a posteromedial fragment. On the right a Haraguchi Type III fracture with a small shell-shaped fragment at the posterior lip of the tibial plafond.

The current study included 73 of the total 194 patients from the EF3X-trial, all suffered from a rotational type intra-articular ankle fracture with a concomitant fracture of the posterior malleolus. Interestingly, eleven patients were excluded because they did not fulfill the inclusion criteria: the posterolateral part of the posterior malleolus was intact and therefore these patients could not be stratified according to the Haraguchi classification and were beyond the scope of the current study.

All patients were divided into three groups by two observers registrar and fellow (first and senior authors: RPB and JND) according to an assessment of the CT scans based on the classification criteria defined by Haraguchi et al. [1] Disagreement was resolved by a third independent observer foot and ankle specialist (senior author: SAS).

Patient reported outcome measures

The primary study outcome: functional outcome, was evaluated according to the Foot and Ankle Outcome Score (FAOS) [30] at two years postoperatively. The Dutch translation of the FAOS questionnaire has been validated for use in the Netherlands [30]. Each domain score ranges from 0 to 100, with higher scores indicating a better outcome. The 36-Item Short Form Health Survey (SF-36) was used to determine patient-perceived health-related quality of life (QoL), with a higher score indicating a better quality of life. Patients were asked to fill in the questionnaires during follow-up visits at 12 weeks, 1 year and 2 years after the operative treatment. Secondary study outcomes were the 12-week and 1-year postoperative FAOS scores; and 12-week, 1-year and 2-year postoperative SF-36 scores. During the study patients had to provide data from at least two of three different follow-up moments.

Data analysis

SPSS version 23.0 software (SPSS Inc. Chicago, Illinois) was used for data analysis. After normally distributed data were ensured, continuous variables were reported using means and standard deviations (SD). Count variables were described by using frequencies with accompanying proportions.

Analysis of the primary study outcome was performed using multivariate regression analysis to identify differences in FAOS scores between the three groups. Adjustment for potential confounders (gender and age at surgery) was performed.

Due to the repeated data structure of the study design (12 weeks, 1 year and 2 years postoperatively) and missing data (12 weeks: 95%, 1 year: 80% and 2 years: 100% follow-up), a mixed model analysis was performed to investigate the differences between the groups in the secondary outcomes *during* the two years follow-up. Adjustment for potential confounders was performed and variance-covariance structure "Compound Symmetry" was used to model the correlation between the repeated measurements. A p-value <0.05 was considered statistically significant.

Demographics

The total study group of 73 patients included thirty males (41%). The mean age at the time of surgery was 48.0 years (SD 17.1). Group 1 (i.e. Type I: large posterolateral-oblique PM fractures) consisted of twenty patients; mean age was 49.9 years (SD 14.8) and ten (50%) were male. Group 2 (i.e. Type II: transverse medial-extension PM fractures) consisted of twenty-one patients; mean age was 47.9 years (SD 17.1) and three (14%) were male. Group 3 (i.e. Type III: small-shell PM fragment) consisted of thirty-two patients; mean age was 46.1 years (SD 11.6) and seventeen (53%) were male.

Table 1
Surgical Technique.

	Haraguchi Type I	Haraguchi Type II (N = 21)		Haraguchi Type III
	(N = 20)	*Posterolateral fragment*	*Posteromedial fragment*	(N = 32)
Direct Fixation *(no. [%] of patients)*	8 (40)	5 (24)	2 (10)	1 (3)
Antiglide plate	2 (10)	3 (14)	1 (5)	0
AP screw	2 (10)	1 (5)	0	0
PA screw	2 (10)	0	0	0
Normal plate	1 (5)	1 (5)	0	1 (3)
K-Wire	1 (5)	0	0	0
Additional syndesmotic screw	3 (15)	2 (10)	2 (10)	0
Single lag screw	0	0	1 (5)	0
Both fragments	–	6 (29)*		–
Non-Direct Fixation *(no. [%] of patients)*	6 (30)	1 (5)		20 (63)
Single syndesmotic fixation	3 (15)	0		15 (47)
Two syndesmotic screws	3 (15)	1 (5)		5 (16)
No fixation at all *(no. [%] of patients)*	6 (30)	7 (33)		11 (34)
Fibula fixation *(no. [%] of patients)*				
One-third tubular plate	20 (100)	19 (90)		27 (84)

* Each fragment treated with a separate antiglide plate.

Surgical technique (Table 1)

Patients were treated according to the general principles of the AO (Arbeidsgemeinschaft für Osteosynthesefragen) [31] by Trauma and Orthopaedic Trauma surgeons according to surgeons' preferred techniques. A total of eight respective surgeons were involved in patients' care at our Level-I trauma center.

Eight of the twenty (40%) patients with a Haraguchi Type I PM ankle fracture were treated with direct fixation of the PM fragment. Of the eight patients with fixation, three (7.5%) patients were treated with an additional syndesmotic screw. The remaining twelve (60%) patients had no fixation of the PM fragment. But of these twelve patients, six had fixation of the ankle syndesmosis. All Type I fractures also had a fibula fracture (Weber B/C): all treated with a lag screw and standard one-third tubular plates (average 7 holes, range: 5–9).

In six of the twenty-one (29%) patients with a Haraguchi Type II PM ankle fracture both fragments (posterolateral and posteromedial) were directly fixed, each fragment with a separate antiglide plate. In five (24%) patients only the posterolateral fragment was operatively fixed and in two of these patients an additional syndesmotic screw was placed. In two (10%) patients only the posteromedial fragment was directly fixed. In one (5%) patient only two syndesmotic screws were placed. In the remaining seven (33%) patients there was no fixation of the syndesmosis nor PM fragments. Nineteen (90%) patients also had a fibula fracture (Weber B/C): all treated with a lag screw and standard one-third tubular plates (average 7 holes, range: 5–9).

One of the thirty-two (3%) patients with a Haraguchi Type III PM ankle fracture had direct fixation of the PM fragment. In twenty (63%) patients the syndesmosis was treated with a syndesmotic screw(s). Twenty-seven (84%) patients also had a fibula fracture (Weber B/C): all treated with a lag screw and standard one-third tubular plates (average: 7 holes, range: 5–9).

Since there were a high number of surgeons involved in the care of these patients, the postoperative rehabilitation protocol was up to surgeons' surgical preferences. However, all patients were immobilized and non-weightbearing in a short-leg cast for six weeks. After six weeks, all patients visited a physiotherapist to start with range of motion exercises and (partial) weightbearing.

Results

Primary study outcome (Table 2)

For every single FAOS domain score, patients with a Haraguchi Type II PM fracture had significant lower outcome scores two years after surgery compared to Haraguchi Type III PM fractures. Two years postoperatively the FAOS domain scores Symptoms and Activities of Daily Living were significantly lower in Haraguchi Type II compared to Haraguchi Type I fractures. The remaining three FAOS domains (respectively: Pain, Sports and Quality of Life) did not show a significant difference between Type II and Type I PM ankle fractures after two years follow-up.

Secondary study outcomes (Table 3)

Patients with Haraguchi Type II PM ankle fractures showed significantly lower SF-36 domain scores at two year postoperative compared to Haraguchi Type III fractures: 71.7 (95% CI: 59.3–84.0) versus 85.7 (95% CI: 78.6–92.9) for Physical Functioning and 65.0 (95% CI: 42.9–87.1) versus 90.7 (95% CI: 80.8–100) for the Role of Physical Related Problems ($p = 0.03$ and $p = 0.02$, respectively). At two years follow-up there were no significant differences in SF-36 domain scores between Haraguchi Type II and Type I fractures.

Except the Symptoms domain, all the FAOS domain scores at two years after surgery were significantly lower in Haraguchi Type II compared to Haraguchi Type III. After one year follow-up the

Table 2
Primary Outcome: FAOS domain scores at two-year follow-up.

	Haraguchi Type I	Haraguchi Type II	Haraguchi Type III	Haraguchi Type II vs. I	Haraguchi Type II vs. III
FAOS	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	P Value	P Value
Symptoms	64.3 (56.5-72.1)	48.2 (39.6-56.8)	61.7 (54.8-68.5)	**0.02**	**0.03**
Pain	74.8 (60.6-89.0)	58.5 (45.1-71.9)	84.4 (76.5-92.3)	0.06	**<0.01**
Activities of Daily Living	80.9 (68.4-93.4)	64.1 (50.1-78.2)	90.5 (85.3-95.6)	**0.03**	**0.00**
Sports	50.7 (30.6-70.8)	45.6 (29.4-61.7)	71.2 (59.9-82.5)	0.65	**0.01**
Quality of Life	62.9 (49.3-76.5)	51.4 (39.6-63.1)	73.3 (65.2-81.5)	0.15	**<0.01**

Data presented as means and 95% confidence intervals. Significant differences i.e. p values <0.05 are presented in bold digits.

Table 3
Secondary Outcome: SF-36 domain scores at two-years follow-up.

	Haraguchi Type I	Haraguchi Type II	Haraguchi Type III	Haraguchi Type II vs. I	Haraguchi Type II vs. III
SF-36	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	P Value	P Value
Physical Functioning	75.3 (66.4-84.2)	71.7 (59.3-84.0)	85.7 (78.6-92.9)	0.59	**0.03**
Role of Physical Problems	58.8 (39.6-78.1)	65.0 (42.9-87.1)	90.7 (80.8-100)	0.60	**0.02**
Bodily Pain	73.0 (60.2-85.7)	70.2 (58.7-81.6)	80.2 (71.2-89.1)	0.73	0.17
General Health Perceptions	63.0 (50.9-75.1)	78.9 (70.6-87.2)	69.9 (60.8-79.0)	0.05	0.19
Physical Component Scale	48.6 (42.8-54.3)	46.9 (42.3-51.5)	52.5 (49.0-56.0)	0.63	0.07
Vitality	62.5 (52.8-72.3)	65.0 (57.8-72.2)	64.6 (53.1-76.1)	0.76	0.96
Social Functioning	78.7 (64.9-92.5)	80.5 (69.3-91.6)	82.9 (72.5-93.2)	0.84	0.76
Role of Emotional Problems	52.9 (27.9-78.0)	80.0 (57.1-100)	77.8 (62.3-93.3)	0.08	0.87
Mental Health	69.2 (60.1-78.3)	81.3 (74.0-88.5)	72.7 (60.8-84.6)	0.15	0.26
Mental Component Scale	42.7 (35.3-50.1)	51.2 (45.8-56.6)	47.1 (40.3-53.8)	0.11	0.39

Data presented as means and 95% confidence intervals. Significant differences i.e. p values <0.05 are presented in bold digits.

Table 4
FAOS domain scores: Differences of the mean *at* and *during* two-years follow-up.

	Haraguchi Type	Haraguchi Type	Difference in mean *at* two-year follow-up	P Value	Difference in mean *during* two years of follow-up	P Value
FAOS			Mean (95% CI)		Mean (95% CI)	
Symptoms	I	II	14.6 (2.8-26.3)	**0.02**	5.5 (-2.2-13.3)	0.16
	III		11.8 (1.3-22.3)	**0.03**	4.6 (-2.4-11.6)	0.20
Pain	I	II	16.8 (-0.33-34.0)	0.05	11.8 (2.0-25.5)	0.09
	III		26.6 (11.4-41.7)	**0.01**	13.4 (1.0-25.8)	**0.04**
Activities of Daily Living	I	II	16.2 (0.9-31.5)	**0.04**	11.8 (-0.7-24.3)	0.06
	III		25.7 (12.1-39.3)	<**0.01**	15.9 (4.7-27.2)	<**0.01**
Sports	I	II	3.7 (-19.2-26.6)	0.74	7.7 (-10.3-25.7)	0.40
	III		24.1 (3.7-44.6)	**0.02**	15.4 (-0.8-31.7)	0.06
Quality of Life	I	II	10.7 (-5.5-27.0)	0.19	8.1 (-5.4-21.6)	0.23
	III		21.1 (6.5-35.6)	<**0.01**	10.9 (-1.3-23.1)	0.08

Data presented as means and 95% confidence intervals. Significant differences (i.e. p values <0.05) are presented in bold digits.

FAOS domain Symptoms showed a significantly lower score in Haraguchi Type II compared to Haraguchi Type I. At 12 weeks follow-up there were no significant differences in FAOS domain scores between the three groups.

Mixed model approach (Table 4)

Table 4 shows data of the mixed model analysis, 'difference in mean *during* two years of follow-up'. After adjustment for potential confounders, the FAOS domains Pain and Activities in Daily Living of the Haraguchi Type II group showed significant lower outcome scores as compared to the Haraguchi Type III group. Significant differences during two years of follow-up between Haraguchi Type II and Haraguchi Type I ankle fractures were not found.

Discussion

Haraguchi et al. [1] challenged the dogma to evaluate PM ankle fractures based on fragment size and advised to stratify PM fracture pathoanatomy according to fragment morphology. To the best of our knowledge, there have not been any studies to date to correlate PM fracture pathoanatomy [22] to clinical outcome [3,4,32] as many studies lack CT data to qualify PM fracture morphology [5–10,12,14–16,24,26,33–35]. Therefore, the primary aim of the present study was to evaluate if PM ankle fractures that extend into the medial malleolus (Haraguchi Type II) were associated with poorer clinical outcomes as compared to the spectrum of posterolateral oblique (Types I and III) PM ankle fractures. We found that patients with Haraguchi Type II fractures had significant lower outcome scores at two years of follow-up compared to the Types I and III. Similarly, O'Driscoll et al. changed our perspective that coronoid fracture morphology – and the associated overall elbow fracture pattern – are more important than coronoid fracture size to determine fracture fixation strategy [23]. Likewise, we feel that this current CT-based study contributes to our understanding of the clinical implications of PM fracture pathoanatomy and associated patient- and physician based functional outcome: fragments with posterolateral to posteromedial extension into the medial malleolus (i.e. Type II) are associated with poorer functional results.

The outcomes of this present cohort study should be interpreted in the light of several limitations including: eight different General Trauma- and Orthopaedic Trauma surgeons decided on PM fragment fixation according to their discretion without a standardized protocol to address these posterior malleolar ankle fractures. Although this may influenced clinical outcome (unfortunately the numbers of surgeons and fixation strategies were too low for sound statistical sub-analysis), it does correspond to actual daily practice allowing us to evaluate the current general understanding and respective surgical strategies of a heterogeneous group of surgeons for PM fractures in a cohort study. Strengths of the current study include: 1) heterogeneity of the patients with rotational type ankle fractures that signifies daily practice with a broad range of Haraguchi fracture types represented in this cohort (twenty Type I, twenty-one Type II and thirty-two Type II); 2) CT images were used to stratify the posterior malleolar ankle fractures according to the fracture pathoanatomy described by Haraguchi et al. [1], and not as in previous studies on: fragment size and fracture pattern based on – unreliable - plain radiographs [27,36]. These measures (i.e. fragment size) as well as the amount of involved articular surface and postoperative intra-articular gap and step off were not included in the primary study question of this study –although interesting- and therefore subject of subsequent analysis.

It is generally accepted that patients with rotational type ankle fractures that involve the posterior malleolus have worse clinical outcome than patients without [4,7,12,19,24–26], but the size of a PM fragment that requires fixation has been subject of ongoing debate [4,19–21]. However, this debate seems outdated when treatment decisions should be based on fracture morphology and overall injury pattern [22], as with coronoid fractures. Indeed, the authors of the most current concept reviews advise CT imaging to quantify and characterize the fracture fragment [3,4]. Tenenbaum [3] and Irwin [4] go beyond the current dogma of 25–33% of articular involvement to guide (direct) fixation, and advise to base treatment decision not on the fracture-fragment-size threshold, but merely on fragment pathoanatomy [1], articular congruity, articular impaction and syndesmotic stability. Unfortunately, as Tenenbaum [3] and Irwin [4] did report their state-of-the-art treatment algorithms for the respective PM fractures in their review articles, the authors did not report –nor did other authors– on variability in clinical outcomes of respective fracture patterns to date.

Another issue regarding fracture morphology is that we found it challenging to distinguish posterolateral oblique orientated fractures in the spectrum of Haraguchi Type III to Haraguchi Type I fractures: A recent Q3DCT-based study of our group on the pathoanatomy of posterior malleolar fractures revealed: 1) that there is a spectrum of posterolateral-oblique fracture lines ranging from small shell -Type III- avulsion fractures to larger -Type I- fragments; and 2) that there is a separate group of fragments with posterolateral to posteromedial -Type II- transverse extension [22]. Overall, clinical studies to date do not address these concepts of pathoanatomy, fixation algorithms based on CT-based fracture pattern and associated clinical outcomes.

Although our understanding of the concepts of pathoanatomy of PM fracture patterns is currently evolving, the majority of clinical studies to date still rely on plain lateral radiographs [27,22], which makes direct comparison of the outcomes of the current study difficult: Verhage et al. [37] concluded in their series of 78 patients with a PM ankle fracture, that involvement of the medial malleolus leads to worse functional outcome, persistent pain and development of early ankle osteoarthritis. An explanation could be that some of these fractures were indeed Haraguchi Type II posterolateral fractures with extension into the posterior colliculus of the medial malleolus as well.

Evers et al. [20] performed a CT-based study to analyze outcome of trimalleolar ankle fractures. The authors did not stratify according to the Haraguchi classification, as they used the classification of Bartonicek [38]. Although using CT, they did correlate their clinical outcomes to respective fracture types based on pathoanatomy, but again on fragment size only: fragments that involved less than 25% of the total tibial plafond that were not fixed, had a worse outcome. We found in our CT-based pathoanatomy study that Haraguchi type II fractures on average involve 19% of the tibial articular surface (in concordance with Evers' <25%). However, it remains unclear if these patients with worse clinical outcome in the Verhage [37] and Evers' [20] studies truly represent the subgroup of Haraguchi Type II fractures, but these patients did represent the groups performing below average in these series.

Suggested reasons for poorer clinical outcomes in Haraguchi Type II ankle fractures are: 1) poor judgment of fracture morphology due to plain radiographs [36] as well as failure to identify the impacted fragments on the medial side and therefore insufficient understanding of the overall fracture pattern; 2) the fact that the deep deltoid ligament is attached to the posterior colliculus of the medial malleolus that is fractured in Haraguchi Type II fractures, representing a more unstable fracture type; 3) the lack of direct fixation of the posteromedial fragment (eight out of twenty-one patients) as was found on postoperative CT scans of the patients representing the Haraguchi Type II group. Unfortunately, a subgroup analysis of (directly) fixed *versus* non-operatively fixed Haraguchi Type II fractures is not statistically sound due to low numbers; and 4) Type II fractures may represent a subgroup of higher impact injuries with a higher incidence of associated bony injuries (impaction and/or comminution) to the talar dome or to the tibial plafond. Although our CT database allows this evaluation, this was beyond the scope of this manuscript and will be addressed in a separate study.

In conclusion, the FAOS domain scores in Haraguchi Type II compared to Types I and III PM ankle fractures demonstrated significantly poor clinical outcome after two years of follow-up. These findings should alert surgeons for the medial extension of the fracture line in Haraguchi Type II ankle fractures, as it seems to be under recognized and therefore the posteromedial fragment may be undertreated. Therefore, we agree with Tenenbaum [3] and Irwin [4] to undertake CT imaging when a PM ankle fracture is expected. In addition to accurate evaluation of fracture pattern and fragment size [39], the patient may benefit from the elucidation of associated bony injuries or chondral impaction to the talar dome or the tibial plafond in order to guide treatment and manage expectations. A separate medial approach to the posterior malleolar fragment could lead to a better restoration of the functional anatomy as well as direct stabilization of the deep deltoid ligament ultimately leading to a better functional outcome. We recommend that patients with rotational type ankle fractures that include a PM fracture should be further evaluated in prospective studies with a standardized protocol that include pre- and postoperative CT qualification in order to improve our understanding of the poorer clinical outcomes of this subgroup of patients.

Conflicts of interest and source of funding

Diederik T. Meijer and Job N. Doornberg were supported with an unrestricted research grant from the Marti-Keuning-Eckhardt Foundation. For the remaining authors none were declared. No funding was received in direct support of this study.

Author contributions

This study represents a great deal of effort in obtaining complete objective- and subjective outcome data, and manually rendering all computed tomography scans for quantification of three-dimensional models. All authors have participated in a material way to at least two of the five elements below:

- Study design: RPB, DTM, RJOdMK, SAS, GMMJK, JCG, JND
- Gathered data: EF3X-trial study group, RPB, DTM, RJOdMK, INS
- Analyzed data: RPB, DTM, RJOdMK, INS, SAS, JND
- Initial draft: RPB, JND
- Ensured accuracy of data: EF3X-trial study group, RPB, DTM, RJOdMK, SAS, TS, GMMJK, JCG, JND.

Conflicts of interest statement

Diederik T. Meijer and Job N. Doornberg were supported with an unrestricted research grant from the Marti-Keuning-Eckhardt Foundation. For the remaining authors none were declared. No funding was received in direct support of this study.

References

[1] Haraguchi N, Haruyama H, Toga H, Kato F. Pathoanatomy of posterior malleolar fractures of the ankle. J Bone Joint Surg Am 2006;88:1085–92.

[2] Nelson MCaJ NV. The treatment of trimalleolar fractures of the ankle. SurgGynecol Obstet 1940;7:.
[3] Tenenbaum S, Shazar N, Bruck N, Bariteau J. Posterior malleolus fractures. Orthop Clin North Am 2017;48:81–9.
[4] Irwin TA, Lien J, Kadakia AR. Posterior malleolus fracture. J Am Acad Orthop Surg 2013;21:32–40.
[5] De Vries JS, Wijgman AJ, Sierevelt IN, Schaap GR. Long-term results of ankle fractures with a posterior malleolar fragment. J Foot Ankle Surg 2005;44:.
[6] Donken CC, Goorden AJ, Verhofstad MH, Edwards MJ, van Laarhoven CJ. The outcome at 20 years of conservatively treated' isolated' posterior malleolar fractures of the ankle: a case series. J Bone Joint Surg Br 2011;93:1621–5.
[7] Broos PL, Bisschop AP. Operative treatment of ankle fractures in adults: correlation between types of fracture and final results. Injury 1991;22:403–6.
[8] Forberger J, Sabandal PV, Dietrich M, Gralla J, Lattmann T, Platz A. Posterolateral approach to the displaced posterior malleolus: functional outcome and local morbidity. Foot Ankle Int 2009;30:309–14.
[9] Harper MC, Hardin G. Posterior malleolar fractures of the ankle associated with external rotation-abduction injuries. Results with and without internal fixation. J Bone Joint Surg Am 1988;70:1348–56.
[10] Jaskulka RA, Ittner G, Schedl R. Fractures of the posterior tibial margin: their role in the prognosis of malleolar fractures. J Trauma 1989;29:1565–70.
[11] Klammer G, Kadakia AR, Joos DA, Seybold JD, Espinosa N. Posterior pilon fractures: a retrospective case series and proposed classification system. Foot Ankle Int 2013;34:189–99.
[12] Langenhuijsen JF, Heetveld MJ, Ultee JM, Steller EP, Butzelaar RM. Results of ankle fractures with involvement of the posterior tibial margin. J Trauma 2002;53:55–60.
[13] Neumaier Probst E, Maas R, Meenen NM. Isolated fracture of the posterolateral tibial lip (Volkmann's triangle). Acta Radiol 1997;38:359–62.
[14] Weber M. Trimalleolar fractures with impaction of the posteromedial tibial plafond: implications for talar stability. Foot Ankle Int 2004;25:716–27.
[15] Wang L, Shi ZM, Zhang CQ, Zeng BF. Trimalleolar fracture with involvement of the entire posterior plafond. Foot Ankle Int 2011;32:774–81.
[16] Xu HL, Li X, Zhang DY, Fu ZG, Wang TB, Zhang PX, et al. A retrospective study of posterior malleolus fractures. Int Orthop 2012;36:1929–36.
[17] Veltman ES, Halma JJ, de Gast A. Longterm outcome of 886 posterior malleolar fractures: A systematic review of the literature. Foot Ankle Surg 2016;22:73–7.
[18] Vidovic D, Elabjer E, Muskardin IVA, Milosevic M, Bekic M, Bakota B. Posterior fragment in ankle fractures: anteroposterior vs posteroanterior fixation. Injury 2017;48(Suppl 5):S65–9.
[19] Odak S, Ahluwalia R, Unnikrishnan P, Hennessy M, Platt S. Management of posterior malleolar fractures: a systematic review. J Foot Ankle Surg 2016;55:140–5.
[20] Evers J, Barz L, Wahnert D, Gruneweller N, Raschke MJ, Ochman S. Size matters: The influence of the posterior fragment on patient outcomes in trimalleolar ankle fractures. Injury 2015;46(Suppl 4):S109–13.
[21] van den Bekerom MP, Haverkamp D, Kloen P. Biomechanical and clinical evaluation of posterior malleolar fractures. A systematic review of the literature. J Trauma 2009;66:279–84.
[22] Mangnus L, Meijer DT, Stufkens SA, Mellema JJ, Steller EP, Kerkhoffs GM, et al. Posterior malleolar fracture patterns. J Orthop Trauma 2015;29:428–35.
[23] O'Driscoll SW, Jupiter JB, Cohen MS, Ring D, McKee MD. Difficult elbow fractures: pearls and pitfalls. Instr Course Lect 2003;52:113–34.
[24] Tejwani NC, Pahk B, Egol KA. Effect of posterior malleolus fracture on outcome after unstable ankle fracture. J Trauma 2010;69:666–9.
[25] Lindsjo U. Classification of ankle fractures: the Lauge-Hansen or AO system? Clin Orthop Relat Res 1985;12–6.
[26] McDaniel WJ, Wilson FC. Trimalleolar fractures of the ankle. An end result study. Clin Orthop Relat Res 1977;122:45.
[27] Meijer DT, Doornberg JN, Sierevelt IN, Mallee WH, van Dijk CN, et al. Guesstimation of posterior malleolar fractures on lateral plain radiographs. Injury 2015;46:2024–9.
[28] Beerekamp MS, Ubbink DT, Maas M, Luitse JS, Kloen P, Blokhuis TJ, et al. Fracture surgery of the extremities with the intra-operative use of 3D-RX: a randomized multicenter trial (EF3X-trial). BMC Musculoskelet Disord 2011;12:151.
[29] Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 2007;21:S1–133.
[30] Sierevelt IN, Beimers L, van Bergen CJ, Haverkamp D, Terwee CB, Kerkhoffs GM. Validation of the dutch language version of the foot and ankle outcome score. Knee Surg Sports Traumatol Arthrosc 2015;23:2413–9.
[31] Müller ME, Allgower M, Schneider R, Willeneger H. Manual of internal fixation. Techniques recommended by the AO-ASIF group. Berlin: Springer-Verlag; 1991.
[32] Levack AE, Warner SJ, Gausden EB, Helfet DL, Lorich DG. Comparing functional outcomes after injury-specific fixation of posterior malleolar fractures and equivalent ligamentous injuries in rotational ankle fractures. J Orthop Trauma 2018;32:e123–8.
[33] Abdelgawad AA, Kadous A, Kanlic E. Posterolateral approach for treatment of posterior malleolus fracture of the ankle. J Foot Ankle Surg 2011;50:607–11.
[34] Berkes MB, Little MT, Lazaro LE, Sculco PK, Cymerman RM, Daigl M, et al. Malleolar fractures and their ligamentous injury equivalents have similar outcomes in supination-external rotation type IV fractures of the ankle treated by anatomical internal fixation. J Bone Joint Surg Br 2012;94:1567–72.
[35] Mingo-Robinet J, Lopez-Duran L, Galeote JE, Martinez-Cervell C. Ankle fractures with posterior malleolar fragment: management and results. J Foot Ankle Surg 2011;50:141–5.
[36] Ferries JS, DeCoster TA, Firoozbakhsh KK, Garcia JF, Miller RA. Plain radiographic interpretation in trimalleolar ankle fractures poorly assesses posterior fragment size. J Orthop Trauma 1994;8:328–31.
[37] Verhage SM, Schipper IB, Hoogendoorn JM. Long-term functional and radiographic outcomes in 243 operated ankle fractures. J Foot Ankle Res 2015;8:45.
[38] Bartonicek J, Rammelt S, Kostlivy K, Vanecek V, Klika D, Tresl I. Anatomy and classification of the posterior tibial fragment in ankle fractures. Arch Orthop Trauma Surg 2015;135:505–16.
[39] Meijer DT, de Muinck Keizer RJ, Doornberg JN, Sierevelt IN, et al. Diagnostic accuracy of 2-dimensional computed tomography for articular involvement and fracture pattern of posterior malleolar fractures. Foot Ankle Int 2016;37:75–82.