



Pathoanatomy of Maisonneuve fracture based on radiologic and CT examination

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Received: 15 August 2018 / Published online: 14 December 2018
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Abstract

Introduction Although Maisonneuve fracture (MF) is a well-known type of ankle fracture–dislocation, there is still a lack of information about the epidemiology and the extent of all associated injuries. The aim of study is to describe MF pathoanatomy on the basis of radiographs, CT scans and intraoperative findings.

Materials and methods The study comprised 54 adult patients. MF was defined as an ankle fracture–dislocation with a fracture of the fibula in its proximal quarter. Ankle radiographs and lower leg radiographs were obtained in all patients. Computed tomography (CT) examination was performed in 43 patients, of these in 34 patients in combination with 3D CT reconstructions. A total of 51 patients were treated operatively, and in 38 of these an open procedure was performed.

Results The fibular fracture—fibular head was involved in four cases, and the subcapital region of the proximal quarter of the fibula was affected in 50 cases. Fractures of the posterior malleolus were identified in 43 of 54 patients (80%). Injury to the deltoid ligament was recorded in 27 cases (50%), a fracture of the medial malleolus in 20 cases (37%) and medial structures were intact in 7 cases (13%). Position fibula in fibular notch—in 9 cases the position changed only minimally, in 11 cases the space between the tibia and the fibula was larger than 2 mm, in 20 cases widening of the tibiofibular space was associated with external rotation of the fibula, in 2 cases fibula was trapped behind the posterior tibial tubercle and in 1 case it was associated with a complete tibiofibular diastasis.

Conclusion MF is a variable injury, always associated with rupture of the anterior and interosseous tibiofibular ligaments. CT examination should be employed widely in MF, and MRI should be considered under special circumstances.

Keywords Ankle fracture · Maisonneuve fracture · Posterior malleolar fracture · Deltoid ligament injury

Introduction

A subcapital fracture of the fibula caused by external rotation mechanism and associated with an injury to the tibiofibular syndesmosis was described for the first time in

1840 on the basis of experiments by the French surgeon Maisonneuve [1]. The term Maisonneuve fracture (MF) was spread gradually, namely thanks to his fellow countrymen Quenu [2], Chaput [3], and Destot [4]. The first to publish a detailed description of this fracture, including radiographs, was Tanton [5], in 1916. Ashurst [6] introduced the term Maisonneuve fracture into the English literature in 1923.

Bonin, in his study published in 1950 [7], dealt in detail with MF and considered it to be a stable injury as, in his view, it was associated only with the injury to the anterior tibiofibular ligament and the medial structures of the ankle remained intact. In the German literature this eponym appeared as late as in the 1960s [8]. Unlike Bonin [7], Weber [8] in 1966 defined MF as an unstable injury, with the interosseous membrane torn up to the fracture level. In 1976, Pankovich [9] published a study considered as a fundamental work in this field until today, although it was based on only 12 cases.

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Although MF is a well-known type of ankle fracture–dislocation, there is still a lack of information about the epidemiology and the extent of all associated injuries. It is surprising that only a few studies have dealt with MF in detail (Table 1), mostly in the form of case series [9–43]. The aim of this study is to describe MF pathoanatomy on the basis of radiographs, CT scans and intraoperative findings in a sizeable number of patients.

Materials and methods

Patients treated for a Maisonneuve fracture (MF) in the period from January 2012 until March 2018 were included in the study cohort. The study comprised 54 adult patients (33 men, 21 women). MF was defined as an ankle fracture–dislocation with a fracture of the fibula in its proximal quarter. Exclusion criteria were ankle osteoarthritis, previous injuries or interventions at the ankle, and skeletal immaturity. Three cases of a double fibular fracture were also excluded.

Ankle radiographs in three projections (anteroposterior, mortise and lateral views) and lower leg radiographs in two projections (anteroposterior and lateral) were obtained in all patients. Computed tomography (CT) examination was performed in 43 patients, of these in 34 patients in combination with 3D CT reconstructions. Preoperative MRI was performed in four patients to assess the syndesmotic ligaments. A total of 51 patients were treated operatively, in 38 of these an open procedure was performed.

The following parameters were evaluated on the basis of radiographic, CT and intraoperative findings:

- age of the patients and their distribution over the age decades,

- anatomy of the fibular fracture and its visibility on radiographs,
- injuries to the medial structures (deltoid ligament, medial malleolus),
- presence and morphology of any posterior malleolar fracture,
- injury to the syndesmotic ligaments, including fracture of the tubercle of Tillaux–Chaput,
- position of the fibula in the tibial incisura at the time of injury,
- associated injuries to the ankle.

In a first review, radiographs and CT scans were assessed separately by each of the authors. In cases of disagreement the images in question were discussed jointly in a second review.

Results

Epidemiology

The study cohort included 33 men with a mean age of 46.5 years (range 19–78) and 21 women with a mean age of 50.9 years (range 26–75). The mean age of the whole cohort was 48.2 years. A majority of patients were in their fifth and sixth decades (Fig. 1). The age category up to 50 years was dominated by men (21:8). In patients older than 50 years, the male–female ratio was almost equal (12:13). The right side was affected in 36 and the left side in 18 cases.

Fibular fracture

Fibular fracture anatomy was assessed in 52 cases on the basis of radiographs, and in 4 cases in combination with

Table 1 Literature overview of the pathoanatomy of Maisonneuve fractures

Author	Year	<i>N</i>	<i>OP</i>	<i>M/F</i>	Age	<i>PM</i>	<i>MS</i>
Pankovich	1976	17	7	?	17–42	15	MM 3, DL 1, IN 13
Ammann	1981	37	37	23/14	36	13	MM 13, DL 20, IN 4
Sousa	1985	12	11	?	?	?	?
Merril	1993	9	1	?	?	4	MM 1, DL 8
Kolman	1999	19		11/8	37	?	MM 9, DL 10
Kirschner	1999	32	32	25/7	?	9	MM?, D6
Manyi	2000	12	12	9/3	38	?	MM 7, D 5
Babis	2000	26	26	16/10	25	20	MM 20, D 6
Sproule	2004	14	14	12/2	36	5	MM 1, D 13
Pelton	2010	12	4	12/2	28	9	MM 9, D 3
Authors	2018	54	51	33/21	48	41	MM 20, D 27, IN 7

N number of patients, *OP* number of operated patients, *M/F* male/female, *PM* fractures of the posterior malleolus, *MS* injuries to medial structures, *MM* medial malleolus, *DL* deltoid ligament, *IN* intact, ? not mentioned

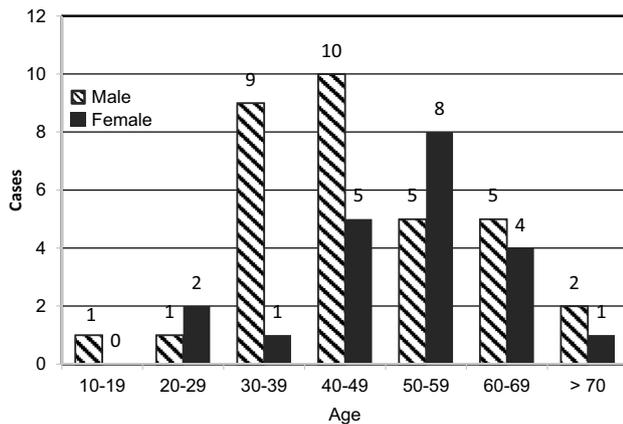


Fig. 1 Patient age distribution

3D CT reconstructions. The fibular head was involved in four cases, including two fractures and two fissures. The subcapital region of the proximal quarter of the fibula was affected in 50 cases, including 42 cases of a simple spiral fracture with varying displacement, 3 cases of a comminuted displaced fracture and 5 cases of a fissure without displacement (Fig. 2). In 14 cases (25%), the fibular fracture was not visible in the anteroposterior projection and was detected only in the lateral view.

Injuries to the medial structures

Injuries to the medial side of the ankle were assessed on the basis of radiographs in all 54 patients, CT scans in 43 patients, MRI scans in 4 patients and intraoperative findings in 51 patients. A lesion of the deltoid ligament was assumed with a medial clear space (MCS) of more than 4 mm shown on a radiograph or a CT scan. In case of an intact medial

malleolus and an MCS of less than 4 mm, a manual external rotation test was performed at the beginning of surgery. Injury to the deltoid ligament (DL) was recorded in 27 cases (50%). A fracture of the medial malleolus (MM) was present in 20 cases (37%); medial structures were intact in 7 cases (13%). Medial malleolar fractures were further classified with the use of CT scans and intraoperative findings. In only 2 cases was the anterior colliculus separated (Type I), in 5 cases the separated fragment carried the anterior colliculus and the intercollicular groove (Type II) and in 13 cases both colliculi were fractured (Type III) (Fig. 3).

Posterior malleolar fractures

Fractures of the posterior malleolus were identified with the use of radiographs in 43 of 54 patients (80%). The fragment shape was classified in 37 cases based on CT scans, according to the classification scheme developed by Bartoníček and Rammelt [44]. Type 1 (extracapsular fracture) was recorded in 5, type 2 (posterolateral) in 18, type 3 (two-part involving the medial malleolus) in 11 and type 4 (large triangular) in 3 cases.

Position of the fibula in the fibular notch

The position of the fibula in the fibular notch of the tibia was assessed in all 43 patients who underwent CT examination with the use of axial (transverse) sections 3–4 mm above the ankle joint space. A constant finding in this area was a higher density of the subchondral cancellous bone at the distal tibia close to the medial malleolus, due to the physiological undulation of the articular surface of the distal tibia (Fig. 4).

In 9 cases the position of the fibula changed only minimally, with the tibiofibular space measured at the center

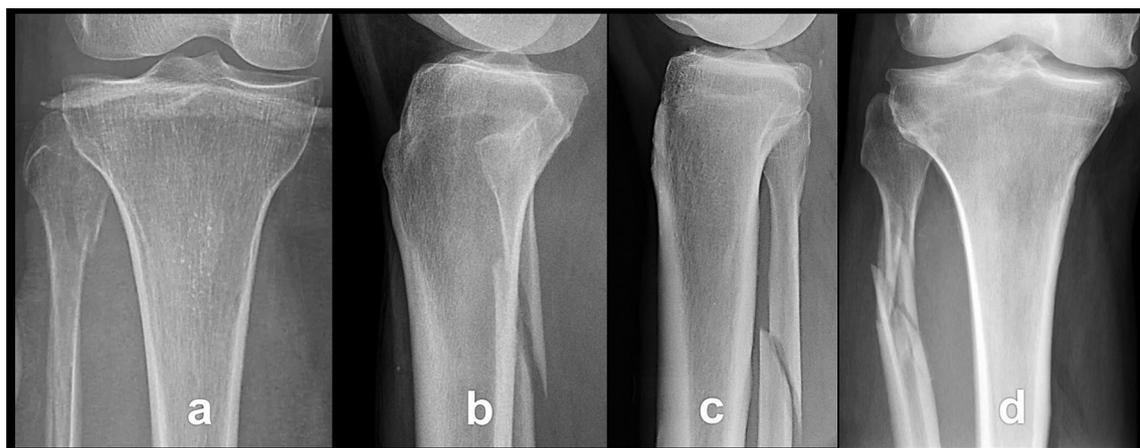


Fig. 2 Type of proximal fibular fractures. **a** Fracture of fibular head, **b** upper level of subcapital fracture, **c** lower level of subcapital fracture, **d** comminuted subcapital fracture

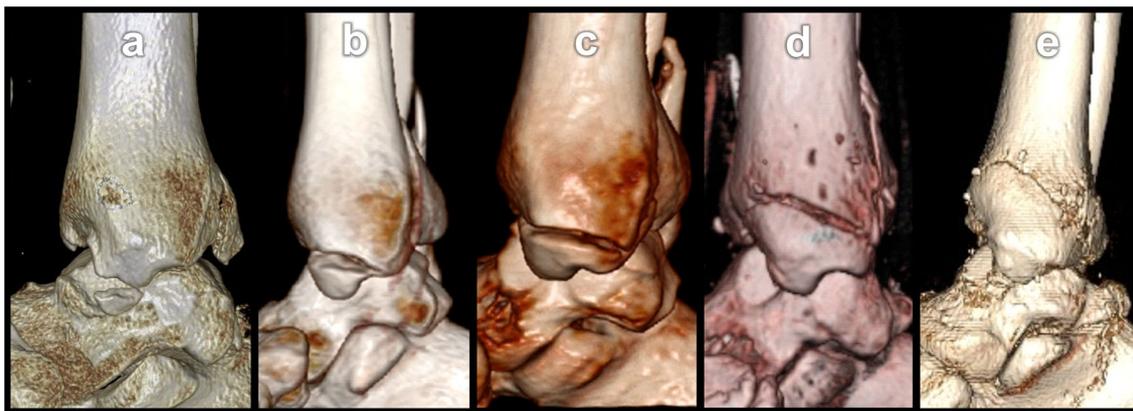


Fig. 3 Types of medial malleolar fractures. **a** Fracture of anterior colliculus (Type I), **b** fractures of anterior colliculus and intercollicular groove (Type II), **c** small bicollicular fragment, **d** large bicollicular fragment, **e** extra large bicollicular fragment. **c–e** Present Type III

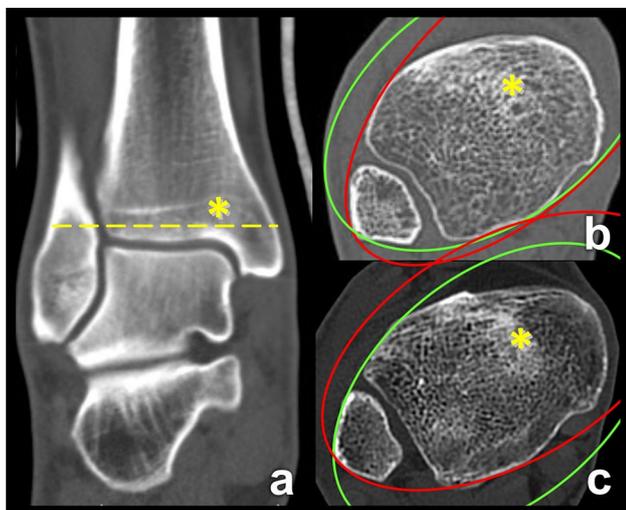


Fig. 4 Authors' method of evaluation of the position of the distal fibula within the tibial incisura (fibular notch). **a** Level of measurement, **b** concave incisura, **c** flat incisura, *area of higher density of the subchondral cancellous bone. The anterior aspect of the distal fibula must be in continuation with the anterior aspect of the distal tibia and the posterior aspect of the distal fibula must be in continuation with the posterior aspect of the distal tibia

of the incisura widened by less than 2 mm (Fig. 5a), in 11 cases the space between the tibia and the fibula was larger than 2 mm (Fig. 5b, c) and in 20 cases widening of the tibiofibular space was associated with external rotation of the fibula (Fig. 5d, e). In two cases of a Bosworth fracture–dislocation, the distal fibula was trapped behind the posterior tibial tubercle (Fig. 5f). One case was associated with a complete tibiofibular diastasis due to wedging of the talus between the distal tibia and fibula.

Syndesmotic injury

Injury to the syndesmotic ligaments was assessed in all 54 patients, based on radiographs, CT scans and intraoperative findings (visualization and hook test). On anteroposterior radiographs, rupture of the syndesmotic ligaments was indicated by a tibiofibular clear space of more than 4 mm in 30 cases (Fig. 6). On CT imaging, syndesmotic injury was documented by avulsion of the tubercle of Tillaux–Chaput in 9 cases, widening of the tibiofibular distance and external rotation of the distal fibula in 33 cases, dislocation of the distal fibula behind the posterior tubercle of distal tibia in 2 cases, and fractures of the posterior malleolus in 43 cases. Intraoperatively, rupture of the anterior tibiofibular ligament was found on direct inspection in all 38 cases of open reduction of the distal fibula.

Associated injuries

Associated injuries to the ankle joint were recorded in three cases, including one case of osteochondral fracture of the lateral part of the talar dome (Fig. 7), one case of osteochondral fracture of the posteromedial part of the talar dome and one case of compression of the lateral tibial plafond with involvement of the fibular notch of the tibia (Fig. 8).

Discussion

Maisonneuve fractures (MF) are a common variant of ankle fractures. Despite that fact, only few studies have provided a detailed analysis of the pathoanatomical features (Table 1) and, except for three [10, 19, 21], the cohorts under study were small with less than 20 cases. CT examination to identify individual lesions was used in none of them and MRI was used only in two studies, comprising 5 [17] and 12

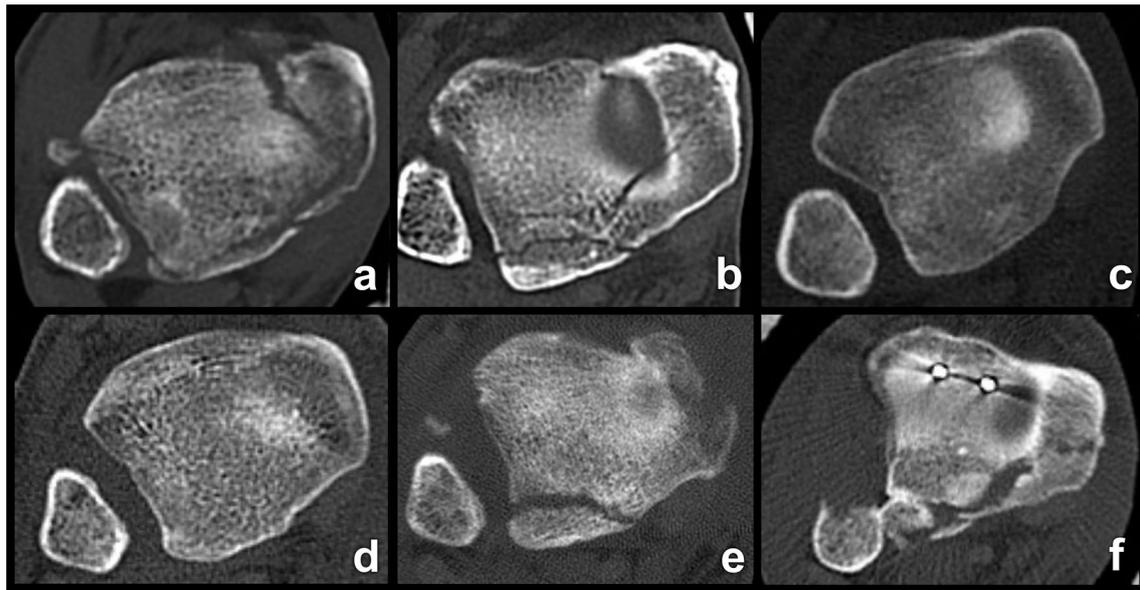


Fig. 5 Position of distal fibula within the incisura. **a, b** Minimal widening of the tibiofibular space, **c** widening of more than 2 mm, **d** widening and external rotation of the distal fibula, **e** marked external

rotation of the distal fibula, displacement of the distal fibula behind the posterior malleolus (Bosworth lesion)

Fig. 6 Relationship of the distal tibia and fibula. **a** “Normal” position, **b** widening of the tibiofibular clear space, **c** complete rupture of tibiofibular syndesmosis, **d** displacement of distal fibulae behind posterior malleolus (Bosworth lesion), **e** total tibiofibular diastasis



patients [22], respectively. We therefore analysed the patho-anatomy of Maisonneuve injuries with radiographs, CT, and intraoperative findings in 54 patients. To our knowledge, this represents the largest cohort of MF investigated so far and the first to systematically analyse the position of the distal fibula in the fibular notch, the proximal fibular fracture, and posterior and medial malleolar fracture, if present.

Some authors found a lower mean age of patients with MF, as compared to cohorts including all types of ankle fracture–dislocations (Table 1). By contrast, the mean age of 48 years of our 54 patients with MF equalled that of the group of 1325 patients with ankle fractures [45]. In a previous study, MF accounted for 3.5% (8 of 232) of all ankle fractures [46].

Fig. 7 Associated osteochondral fracture of the lateral talar dome. **a** Anteroposterior radiograph, **b** lateral radiograph, **c** axial CT scan, **d** sagittal CT scan



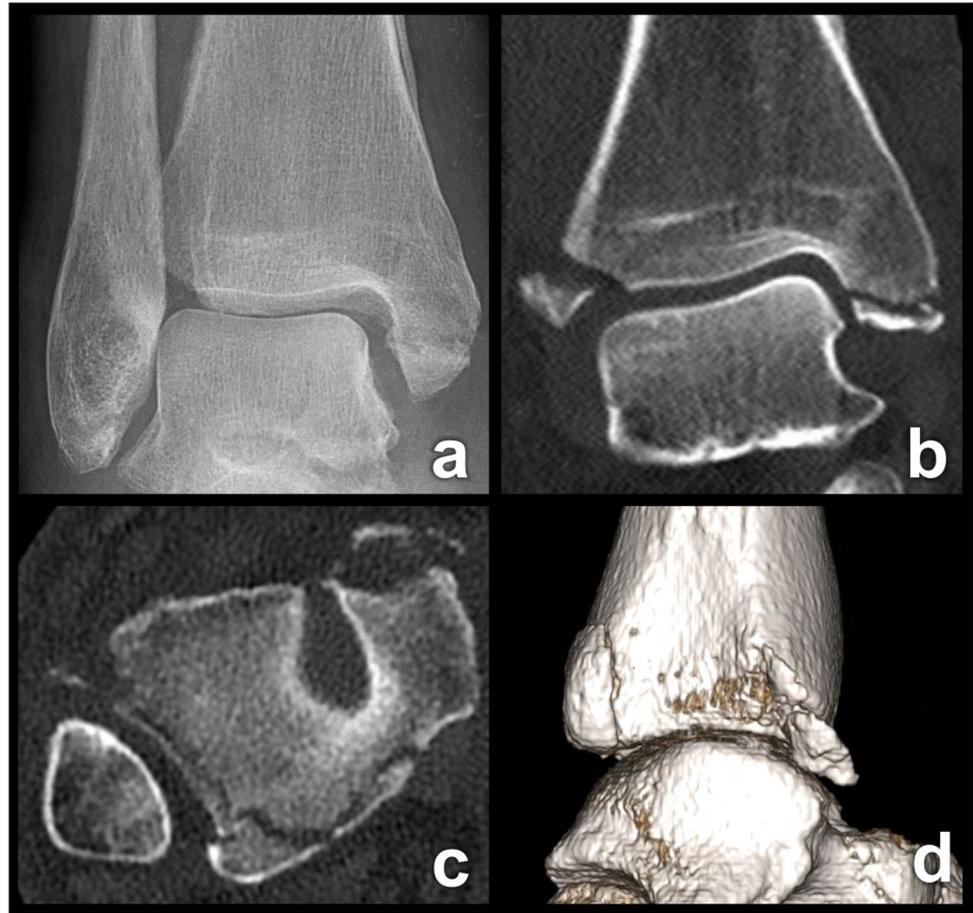
The basic feature of MF is a torsional subcapital fracture of the fibula, or a fracture of the fibular head, resulting from a rotational injury to the ankle. Some authors define MF as a fracture of the fibula in its middle third [33–35, 42], which is in our view a different fracture type. We did not encounter anterior dislocation of the fibular head, as has been described as an MF equivalent [24, 30, 31]. The issue of the so-called “distortion” of the tibiofibular joint has not yet been fully clarified. Pankovich [9] recorded 5 such cases without a fibular fracture in a group of 17 patients.

Very infrequently, subcapital fracture of the fibula may be associated with a fracture of the distal fibula (Weber B type or low Weber C type) [13, 23, 27, 29]. In terms of radiographic diagnosis, it should be noted that the fibular fracture was not visible in the anteroposterior view in 25% of our cases, but in lateral view, and in three cases it showed as a barely visible fissure that could easily be overlooked. Due to a combination of fractures in the distal and proximal parts of the fibula, the subcapital fracture is initially overlooked in most such cases [23, 27]. For this reason, it is always necessary to palpate the entire fibula, preferably prior to radiographic examination, and to check it for such a double lesion.

The presentation of injuries to the medial structures varies in the literature, as shown in Table 1. In our series, the medial structures were intact in seven cases, which is similar to the observations in other studies [31, 36]. This suggests that MF may be caused not only by a pronation-external rotation, but also by supination-external rotation mechanism, as discussed in detail below. Fractures of the anterior colliculus (Type I), or the anterior colliculus and intercollicular groove (Type II) of the medial malleolus (MM), may occur in the form of a combined osseoligamentous injury, associated with a partial, or complete, lesion of the deep (tibiotalar) portion of the deltoid ligament (DL). In a study employing MRI on acute MF, Morris et al. [17] detected rupture of the superficial part of the DL in all five analysed cases, complete rupture of the deep portion in three cases and partial deep rupture in one case. In one case, the deep portion of the DL remained intact. In summary, injuries to the medial structures may be complete, as in a bicollicular MM fracture, complete rupture of DL, fracture of the anterior colliculus with complete rupture of the deep portion of the DL; or partial, as in rupture of superficial part of DL, or fracture of the anterior colliculus of the MM.

Fractures of the posterior malleolus (PM) were present in 80% of the cases. CT classification was performed in 37

Fig. 8 Associated compression of the incisura. **a** Anteroposterior radiograph, **b** frontal CT scan, **c** axial CT scan, **d** 3D CT reconstruction with subtraction of the distal fibula, lateral view



patients, based on a previously published scheme [44]. Fractures of the posterior malleolus showed high variability and included different types of injury, most frequently types 2 and 3. This corresponds to the frequency of individual types reported previously [44]. Fractures of the PM were also described by other authors (Table 1) with a similar incidence [9, 21, 35]. While the posterior tibiofibular ligament (PTFL) was always intact in the arthroscopic study by Yoshimura et al. [30], Morris et al. [17] demonstrated complete rupture of the PTFL in three cases, partial rupture in one case and an intact ligament in one case. Injury to the posterior structures (i.e. PM fracture or rupture of the posterior syndesmosis) seem to be present in a high percentage of MF, which is in accordance with the proposed mechanism of injury to the tibiofibular syndesmosis [8, 9, 47].

The position of the distal fibula in the tibial incisura (fibular notch) is difficult to assess. We found assessment of the tibia–fibula relationship to be useful in axial CT sections 2–3 mm above the joint space, as the incisura is the deepest at this level and the distal tibia and fibula are in close relationship [48]. At this level, the anterior contour of the distal fibula is in continuity with the anterior contour of the distal tibia, and the same is seen posteriorly (Fig. 4).

Verification of injuries to all ligaments of the tibiofibular syndesmosis, including the interosseous membrane, is complex. We identified injury of the anterior tibiofibular ligament (ATFL), be it a rupture or avulsion of the anterior tibial (Tillaux–Chaput) tubercle, in all cases and consider it a constant finding in MF. Yoshimura et al. [30] arthroscopically verified injury of the ATFL in all four cases examined. Both Morris [17] and Manyi [22] found rupture of the ATFL in all their cases, always in combination with a lesion of the interosseous tibiofibular ligament.

According to the classical understanding [8, 47, 49], the interosseous membrane is always ruptured up to the level of the fibular fracture in case of MF. In a study employing MRI, Manyi [22] found that MF was associated with rupture of the membrane in all 12 patients, but only in its distal third, i.e. no more than 112 mm above the ankle joint space. Morris [17] detected rupture of the interosseous membrane by MRI in four of five patients examined.

Displacement of the distal fibula shown by CT was highly variable, from minimal widening of the tibiofibular space up to dislocation of the fibula from the incisura. Injury to the anterior tibiofibular ligament was always confirmed intraoperatively, even in cases of minimal displacement of the distal

fibula. By contrast, complete dislocation of the distal fibula posteriorly is a typical feature of a Bosworth fracture–dislocation [16, 50, 51].

Associated osteochondral lesions of the talar dome have been described, based on arthroscopic examination by Yoshimura [30], located posteromedially in all four cases. In our study, posteromedial osteochondral fracture of the talus was visible only on MRI and not on CT scans. Both the osteochondral fracture of the lateral part of the talar dome and compression of the subchondral bone in the lateral tibial plafond are novel findings that to the best of our knowledge have not been reported before in association with MF. Both findings point to a pronation mechanism. Arthroscopy is a valuable diagnostic tool for any syndesmotic injury including MF with associated chondral or osteochondral lesions. The amount of syndesmotic stability can be visualized with high sensitivity and specificity [30, 52, 53].

The pathomechanism of MF has been discussed by several authors [1–3, 8]. According to Lauge Hansen [50] and other authors, MF occurs in stage III of pronation-external rotation injuries. Stage I represents injury to the medial structures (medial malleolus or DL), stage II rupture of the ATFL and interosseous membrane, and stage III rupture of the PTFL or fracture of the posterior malleolus. This mechanism, however, does not explain cases with the medial structures left intact.

In contrast, Pankovich [9] describes the following five stages:

1. Rupture of the anterior tibiofibular ligament or avulsion fracture of one of its bone insertions, either one being associated with rupture of the interosseous ligament.
2. Fracture of the posterior tubercle or rupture of the posterior tibiofibular ligament.
3. Rupture of the anteromedial joint capsule or avulsion fracture of one of its bone insertions.
4. Fracture of the proximal part of the fibulae.
5. Rupture of the deltoid ligament or fracture of the medial malleolus.

This sequence corresponds to the supination-external rotation mechanism as proposed by Lauge–Hansen [50] and would explain cases of MF with the medial structures intact because they occur last in the sequence of injuries. The importance of the anteromedial part of the joint capsule remains unclear, both in terms of the sequence of injuries and its importance for stabilization, as it has no mechanical strength. It has probably been confused with the anterior portion of the DL which spreads from the anterior colliculus into the spring ligament and the navicular bone (tibionavicular part of DL).

A supination-external rotation mechanism would also explain injury to the anterior talofibular and calcaneofibular

ligaments as described by Morris et al. [17]. These authors found, in all five patients with MF whom they examined, injury to the anterior talofibular ligament, injury to the calcaneofibular ligament in three patients and injury to the posterior talofibular ligament in one patient.

Our study has shown the importance of CT examination for diagnosing the full extent of bony injuries in MF, particularly fractures of the Tillaux–Chaput tubercle, as none of those could be delineated clearly on plain radiographs. The same applies for fractures of the posterior malleolus that cannot be assessed reliably with plain radiographs with respect to size, fibular notch involvement and intercalary fragments [44, 54]. The ligamentous injury pattern is best assessed with the help of stress examination and MRI [52]. These allow assessment of the DL, the syndesmotic ligaments, including the interosseous membrane, and the fibular ligaments. MRI may also reveal occult lesions such as compression of the distal tibia in the fibular notch and osteochondral fracture of talus, as in this present series. With the present knowledge, we advocate the use of MRI in cases with an unclear mechanism of injury or when the latter does not match observed fracture pattern. It is further useful when accompanying injuries to the cartilage or tendons are suspected [52, 53].

Summary

The present study and literature review confirm that MF is a variable and often-complicated injury. It is always associated with rupture of the anterior and interosseous tibiofibular ligaments. The interosseous membrane is also almost always torn, but only in its distal third and not necessarily up to the level of the fibular fracture. The posterior tibiofibular ligament is not necessarily injured, but a fracture of the posterior malleolus occurs in 80% of cases. The incidence and extent of injury to the medial structures is highly variable. It may be absent, partial or complete, and display combinations of bony and ligamentous injuries. MF may be associated with injury to the lateral collateral ankle ligaments, osteochondral fracture of the talus or partial impression of the lateral tibial pilon. Because the amount of anterior and posterior bony avulsions cannot be determined reliably on plain radiographs, CT examination should be employed widely in MF, and MRI should be considered under special circumstances. The pattern of injury found in a substantial number of patients suggests that MF may be caused and not only by pronation-external rotation mechanism, but also by a supination-external rotation mechanism.

Acknowledgements This study was approved by the Institutional Ethics Committee. The authors wish to thank Prof. Chris Colton, MD,

FRCS and Ludmila Bébarová for their assistance in the preparation of the manuscript.

Funding This study was funded by grant of AZV-CR (Czech Agency for the Medical Research) Agentura pro zdravotnický výzkum České republiky 16-28458A: Trimalleolar ankle fractures - CT diagnostics of fractures of posterior tibial rim, their CT classification and operative treatment.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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