Journal of Clinical Orthopaedics and Trauma 36 (2023) 102086

Contents lists available at ScienceDirect

Journal of Clinical Orthopaedics and Trauma

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

The multi-ligament ankle fracture: Epidemiology, key anatomical findings and fixation strategies in unstable open injuries

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ARTICLE INFO

Article history:
Received 28 August 2022
Accepted 12 December 2022
Available online 17 December 2022

ABSTRACT

Background: Ankle fracture surgery has traditionally focussed on restoration of bony anatomy, with fixation of the malleoli and syndesmotic stabilisation where applicable. However, high energy open fracture-dislocations can also result in periosteal stripping of the stabilising capsuloligamentous attachments. As such, restoration of osseous anatomy alone may not result in sufficient articular stability.
Objectives: In this series from a level 1 trauma centre, we report a subset of highly unstable open ankle fractures with combined capsuloligamentous injuries, in which restoration of osseous anatomy did not result in a stable joint. Supplementary soft tissue reconstruction and other stabilisation techniques were required.
Methods: Retrospective case series of eligible patients from a level 1 trauma centre. Inclusion criteria were open ankle fractures with tibial extrusion (AO 44) and persistent instability post-bony fixation, age over 18 years and non-diabetic. Analysis of injury pattern, mechanism, pathological anatomy, soft tissue and orthopaedic reconstruction methods was performed.
Results: 16 patients were identified during the study period who met the eligibility criteria, out of 95 open ankle fractures treated between January 2017–December 2020. Most patients were under 65 (n = 13; 81.3%) and sustained combined or isolated injuries of the deltoid ligament, anterior capsule, lateral ligament complex (ATFL±CFL) and tibialis posterior retinaculum. The commonest injury pattern was tibial extrusion via a medial soft tissue defect with deltoid ligament and anteromedial capsule rupture. Associated syndesmotic instability and fixation was common (n = 10; 62.5%). Supplementary stabilisation methods to standard bony fixation included capsuloligamentous reconstruction or repair, "ORIF+" external fixation, or conversion to primary fusion or hindfoot nail. Six patients required either local or free flap soft tissue coverage.
Conclusions: A subset of up to 20% of open ankle fractures require supplementary fixation beyond anatomical restoration of the bony anatomy due to persistent ligamentous instability. They are associated with capsuloligamentous and syndesmotic disruption, more commonly affecting the medial structures. These rare injuries can be defined as multi-ligament ankle fractures. Surgeons should be aware of this subset and be able to recognise where supplementary stabilisation strategies are required.
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1. Introduction

Management of open ankle fractures presents unique challenges due to the complex nature of the talocrural articulation and its capsuloligamentous attachments, combined with a relatively thin and vulnerable soft tissue envelope. Successful early outcomes are dependent on restoration of ankle stability and adequate soft tissue coverage, in the absence of infection.[1,2] The accepted best practice for treatment of these severe injuries is via a combined orthoplastic approach, which has been formalised in the United Kingdom in the BOAST open fracture national guidelines.[3]

Stability of the ankle joint has been extensively researched and is dependent on intact bony and ligamentous anatomy.[4,5] As such,

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https://doi.org/10.1016/j.jcot.2022.102086
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restoration of osseous anatomy alone may not result in sufficient articular stability, especially in the context of the severe soft tissue and periosteal stripping seen in high energy open fracture-dislocations.

In this series from a level 1 trauma centre, we report a small subset of highly unstable open ankle fractures in which restoration of bony anatomy alone did not result in a stable articulation, therefore necessitating supplementary or alternate stabilisation strategies. The purpose of this review is to assess, identify and define the pathoanatomy and treatment, introduce the term and report the incidence of these infrequent injuries.

2. Methods

We performed a retrospective review of all open ankle fractures treated at a level-1 trauma centre between January 2017 and December 2020. Our trauma centre is situated in a major city urban environment and part of the regional trauma network receiving referrals from varied geographic and socioeconomic areas. Electronic patient records and clinical imaging were reviewed.

Inclusion criteria included all open ankle fractures with tibial extrusion (AO 44) and persistent articular instability post anatomical osseous fixation. Patients were all examined under image intensifier following fixation: external rotation test (to elucidate deltoid injury), anterior draw, syndesmosis stability, lateral stress test (Hook test or Cotton test), and talar tilt test for medial and lateral instability. We utilised the definition of ankle stability in ankle fractures as the ability to maintain the talus centralised under the tibia when held in a neutral position and undergoing physiological stress.[6]

Exclusion criteria were under 18 years of age, diabetes, polytrauma and history of local bone infection, and where non anatomical reconstruction was undertaken as the index procedure (e.g. spanning hindfoot nail). Data was recorded for a number of variables including demographics, injury pattern, surgical findings and fixation methods.

The quality of anatomic reduction was assessed using the criteria described by Pettrone.[7] To classify the fixation as satisfactory, the following four criteria had to be met: fracture separation of medial and lateral malleolus to be $\leq$ 1 mm and $\leq$ 2 mm respectively; to ensure deltoid ligament integrity, a medial clear space $\leq$ 3 mm; to ensure the restoration of the syndesmosis, a tibio-fibular space $\leq$ 5 mm, or tibio-fibular overlap $\geq$10 mm on AP or $\geq$ 1 mm on mortise view. The measurements were accomplished using the graphics package present on the hospital Picture Archiving and Communication System (Sectra AB, Linköping, Sweden). To minimize bias caused by the interobserver variability, all radiographs were observed by two authors (JW, RA) independently.

3. Data collection

The NHS Heath Research Authority decision tool deemed this work not to be classified as clinical research requiring formal ethical approval (http://www.hra-decisiontools.org.uk/research/). Local internal review and conformation of local audit office and approval were gained. The final data collection tool was devised and underwent internal review and was piloted.

3.1. Statistical analysis

The study was completed according to STROBE guidelines for observational studies.[8] Comparisons between group characteristics were made using a T − test and subsequent analysis was conducted using SPSS (v17) for personal computers. Statistical significance was defined as a p value of <0.05.

4. Results

4.1. Demographics

Between January 2017 and December 2021, 534 ankle fractures were treated at our level 1 trauma centre, 95 of these were open. Of these, 16 patients were identified that met the inclusion criteria for this study (16.8%). The mean age of patients at time of injury was 41.8 years (range 18–83), 13 patients (81.3%) were under 65, comprising 10 females and 6 males. Patients underwent an average of 1.9 surgeries during their primary admission.

4.2. Injury pattern

a) Injury Mechanism and Related Energy

The majority of patients (n = 12, 75%) had sustained high energy trauma (motor vehicle collision, cycle collision, horse riding accident, fall from >2 m; average age 34), and the four remaining patients sustained a low energy fall from standing height (average age 74.5). Orthopaedic and plastic surgical injury patterns and reconstruction are summarised in Table 1.

b) Fracture Classification and Associated Capsuloligamentous Injury

AO/OTA 44B and 44C fractures with tibial extrusion via a medial wound were the most common injury pattern (n = 10). There were two 44A type fractures, both with an open lateral wound. There were two 44C type injuries with tibia extrusion via an anterior wound. The remaining two patterns were a high energy 44C with a lateral wound, and a pure ankle (tibiotalar) dislocation with an open lateral wound.

Capsuloligamentous injury pattern was recorded for each case, with deltoid ligament (n = 12), anterior capsule (n = 10), and lateral ligament complex (n = 8) rupture most frequently encountered. Tibialis posterior retinaculum disruption with tendon dislocation was seen in four cases. Soft tissue coverage was achieved by primary closure in ten cases, the remaining six required free or local flaps.

Tibial extrusion via an open medial wound, associated with AO 44B and 44C fractures, was found to have anterior capsule disruption and deltoid ligament injuries (deep and superficial) in 12 patients, with tibialis posterior retinaculum rupture and tendon dislocation also seen in three of these patients. Open injuries with a lateral soft tissue defect (n = 4) were all associated with lateral ligament complex disruption, one with peroneus brevis rupture. The two injuries via an anterior wound were both high energy, complex fracture patterns with anterior capsule, lateral ligament and syndesmotic injuries.

4.3. Osseous fixation and assessment

Osseous fixation was achieved via plate and/or screw stabilisation of each individual malleolus as detailed in Table 1, with syndesmotic stabilisation achieved via screw or tight-rope fixation where indicated. Non-standard fixation methods included *trans*-tibial (fibula pro-tibia) screws (2) and conversion to hind-foot nail (1) or ankle fusion (1). In the 14 patients who underwent anatomical reduction via ORIF, utilising a Pettrone score of less than 1 to define an ankle that is not mal-reduced, 2 patients were found to be mal-reduced on the intra or immediate post-operative radiographs.

Following fixation, patients were examined for instability under anaesthetic. All patients were found to have persistent ankle

Table 1
Summarised cases see Table 2 for key to fixation, anatomical structures and injuries.

Case	Sex	Age at time of surgery	Number primary surgeries	Mechanism	Energy	Open Wound laterality	AO/OTA classification 44	Direction of Instability Post Bony Fixation	Bony fixation	Capsulo-ligamentous injury	Supplementary stabilisation/ repair	Plastics Reconstruction
1	F	37	3	Horse riding	High	Medial	B2	Multi-directional	FLP, SS, TKW	DL, AC, SL, LL	DL, AC, LL	Primary closure
2	M	54	1	Fall from standing	Low	Medial	C3	Anterior, medial	SS	DL, AC, SL, TP	DL, AC, TP	Primary closure
3	M	27	1	Fall >2 m	High	Lateral	A2	Anterior, lateral	MMS, MMP	LL	LL	Primary closure
4	M	37	1	MVA	High	Medial	C2	Multi-directional	FNLP, SS, MMP	DL, AC, SL, LL	AC	Free flap
5	F	83	2	Fall from standing	Low	Medial	C1	Anterior, medial	HFN	DL, SL, TP	HFN[b]	Primary closure
6	F	79	2	Fall from standing	Low	Medial	B2	Medial	FNLP, TTS	DL	TTS	Primary closure
7	M	21	2	Cyclist	High	Lateral	A3	Multi-directional	MMP, STR	DL, SL, LL	DL, LL	Free flap
8	M	18	3	MVA	High	Lateral	C2	Anterior, lateral	FNLP, SS, EF, TKW	DL, SL, LL, PB	EF, LL, PR	Free flap
9	F	82	2	Fall from standing	Low	Medial	B3	Anterior, medial	EF, AF	DL, AC, TP	AF[b]	F closure
10	M	65	2	Fall >2 m	High	Medial	B3	Medial	FNLP, PMP, MMS, SS	DL, AC	AC, EF	Local flap
11	F	27	2	Motorcycle	High	Lateral	[a]PD	Anterior, lateral	BS (in talus # only)	LL	LL, ER	Free flap
12	F	40	1	Cyclist	High	Medial	C3	Anterior, medial	SS	DL, AC, SL	DL, AC	Primary closure
13	F	18	1	Motorcycle	High	Anterior	C2	Anterior, lateral	TTS	AC, SL, LL	AC, LL	Primary closure
14	F	21	2	Sports Injury	High	Medial	C2	Anterior, medial	MMP	DL, AC, TP	DL, AC	Free flap
15	F	42	2	Fall from Horse	High	Medial	C3	Anterior, medial	FLP, MMS, SS	DL, AC, SL,	DL, AC, TP	Primary closure
16	F	18	3	Fall from Horse	High	Anterior	C3	Anterior	TTS	AC, SL, LL	LL, AC, TKW	Primary closure

[a] PD = pure dislocation.
[b] Non-ORIF.

Table 2
Key for abbreviations in Table 1.

Bony fixation		Capsuloligamentous structures/repair		Supplementary stabilisation	
FLP	fibula locking plate	AC	anterior capsule	EF	external fixator
FNLP	fibula non-locking plate	DL	deltoid ligament	SR	syndesmosis reconstruction
PMP	posterior malleolus plate	LL	lateral ligament	STF	subtalar fusion
MMS	medial malleolus screws	TP	tibialis posterior	HFN	hindfoot nail
MMP	medial malleolus plate	PR	peroneal retinaculum	TTS	transtibial screws
SS	syndesmosis screws	PB	peroneus brevis	POP	plaster of paris
TKW	temporary k-wires	ER	extensor retinaculum		
BS	Barouk screws	SL	Syndesmotic ligaments		
TTS	transtibial screws				
STR	syndesmosis tightrope				
AF	ankle fusion				

instability on stress testing following initial bony fixation. Instability was defined after examination under anaesthesia following fixation, with directional patterns including anteromedial (n = 6), anterolateral (n = 4), multidirectional (n = 3), medial (n = 2) and lateral (n = 1).

Supplementary soft tissue stabilisation was utilised in isolation or in combination in all patients as detailed in Table 1. The most frequent soft tissues interventions were anterior capsule repair (n = 9), lateral ligament repair (n = 7), and deltoid ligament repair (n = 6). Additional bony procedures included reapplication of external fixator (n = 3), hindfoot nail (n = 1), trans tibial (fibula protibia) screws (n = 2) and conversion to primary fusion (n = 1) in cases in which soft tissue reconstruction still did not provide adequate stability.

5. Discussion

Open ankle fractures are an uncommon and complex injury pattern associated with significant morbidity related to wound complications, soft tissue coverage and infection.[1,2] A less well-described feature of open ankle fractures is the mechanical implications of high energy disruption of the stabilising soft tissues around the joint. Our series describes a small subset of patients in which the extent of soft tissue injury resulted in persistent instability following anatomical fracture reduction and fixation, mandating supplementary or alternate strategies to address.

5.1. Early assessment and identification of combined injuries

Unfortunately, a fracture dislocation with associated capsuloligamentous disruption is not easily predictable prior to surgical exploration. We advocate a systematic assessment of all structures at time of initial surgery, with a low threshold for capsuloligamentous reconstruction or supplementary stabilisation. In keeping with the Gustillio Anderson Classification for open injury assessment, this should be undertaken at the time of debridement. Post fixation stress examination should be performed and considered mandatory. This follows British Orthopaedic Association (BOA) advocated combined ortho-plastics approach to standardise the management of open fractures across the UK. Initial debridement should be performed concurrently by orthopaedic and plastic surgeons within 24 h of injury, with definitive soft tissue coverage within 72 h.[3] We believe ligamentous stabilisers must also form part of the assessment at the primary debridement and definitive management and be considered during index ankle fracture fixation surgery, not just the bony restraints.

5.2. Classification of instability in ankle fractures

There have been a large number of classifications systems for ankle fractures introduced over the years, including Percival Pott's malleolar system in 1758,[9] Danis-Weber's simple fibula-based classification in 1948,[10,11] and Lauge-Hansen's more complex rotational mechanism-based classification of 1950.[12] More recently the AO system has gained popularity, especially in the field of research, which we have utilised. With regard to open fractures, the most commonly used is the ubiquitous Gustilo-Anderson classification of soft tissue injury.[13] As there is no specific open ankle fracture classification, a combination of the two is generally utilised in the literature.

These classification systems do not address issues with stability. We therefore define stability in this context as the ability to maintain the talus centralised under the tibia when held in a neutral position and undergoing physiological stress (i.e. simulated weight-bearing in theatre). For the purposes of this review, a multi-ligamentous open ankle fracture is defined as a complete tear of a combination of the ATFL/CFL complex, deltoid ligament, tibialis posterior disruption/subluxation and capsular disruption, which is also associated with an ankle fracture/dislocation and/or a syndesmosis injury, and led to instability on examination under anaesthetic once osseous stability has been undertaken.

Lambert et al. defined the roles of ligamentous structures in the 5 planes of instability: sagittal plane translation and rotation (controlled by ATFL and superficial deltoid), frontal plane translation and rotation (controlled by fibula, AITFL, PITFL, IOL, posterior deep deltoid, anterior deep deltoid, superficial deltoid, tibiocalcaneal ligament) and horizontal plane rotation (medial malleolus, CFL, PTFL in dorsiflexion).[6] ATFL restricts with the foot in plantar flexion (posterior malleolus, medial malleolus, fibular, ATFL, AITFL, PITFL, anterior deep deltoid, posterior deep deltoid), the secondary restraints being the capsule and extrinsic muscles.

We found these restraints were identifiable at the time of primary debridement surgery and allowed us to classify injuries with their prospective instability pattern following definitive osseous stabilisation. The commonest injury pattern was a medial open wound with deltoid injury. However, the combination of anterior and medial instability was most frequent and observed with an anterior capsular avulsion and combined with syndesmotic and deltoid ligament injury. Further medial structure injuries included the bed of tibialis posterior, where anterior shift and medial translational instability was noted after osseous fixation. The latter is quite a common feature in this series and indicative of the energy responsible for the injury and may be responsible for a post traumatic flat foot deformity.

5.3. Treatment strategies

'Traditional' orthopaedic ankle fracture surgery focusses on restoration of the medial and lateral malleoli and syndesmotic stabilisation, and in recent years the stabilising role of posterior malleolar reduction and fixation has been widely accepted.[14,15] The role of capsulo-ligamentous repair or reconstruction is however less well understood in the context of ankle fractures but should be considered as part of a multi-ligamentous ankle injury akin to those seen in the knee.[16]

The concept of multi-ligamentous knee injuries encompasses a large variety of presenting combinations, including a wide range of ligament and intra-articular injury patterns. However, the literature lacks adequately sized prospective comparative patient-reported outcome studies to guide clinical decision making and much the same is true of ankle injuries. The decisions of operative versus non-operative management, timing of surgery, repair versus reconstruction, use of allograft versus auto-graft, choice of which ligaments to treat, and rehabilitation protocols remain at best controversial or unknown.

Currently, there are limited numbers of reports in the literature on capsular and ligamentous repair or reconstruction in ankle fractures, and none specifically in open injuries in these acute pathologies. The majority relate to deltoid ligament repair or reconstruction in the context of SER ankle fractures, which has long been a contentious issue.[17] Ren et al. report good outcomes in a series of 15 patients undergoing deltoid and anteromedial capsular repair in SER 4 ankle fractures.[18] Ye and colleagues report utilising a combination of bioabsorbable implants and external fixation in 16 patients with satisfactory outcome, after recognising the inherently unstable nature of open fracture dislocations.[19] Debnath et al. report a case series of 8 'floating ankles' of which some were treated with a combination in internal and external fixation.[20] There are a small number of case reports of 'pure' open ankle dislocation, i.e. without an associated fracture. One was treated with lateral ligament, capsular repair and external fixator in an open dislocation,[21] and two further cases from a single report were treated with capsular repair and cast immobilisation.[22] The importance of superficial deltoid a stabiliser for repair is highlighted by its roles a sagittal plane stabiliser and also its repair along with those strands that augment the spring ligament and prevent a post traumatic flat foot.

This series adds to the limited existing literature by highlighting the associated capsuloligamentous injuries and defining the concept of the multi-ligamentous open ankle fracture dislocation and the potentially destabilising implications of these findings. Although the injury pattern or extent are not necessarily predictable, a surgeon needs to be aware of these possibilities in assessing these injuries. Injuries with medial tibial extrusion appear to be particularly susceptible to ligamentous injuries and possibly persistent instability, and these injuries are associated with a significant number of syndesmotic injuries which require stabilisation. Combined ligamentous and capsular repair was often required and achieved using anchors akin to the Gould modification of the lateral ligament repair for stabilisation.

Medial injuries particularly associated to the deltoid are concerning as they have been linked with the development of pes planus, due to instability of the tibialis posterior. It has been recognised that the medial deltoid is intimately related to the spring ligament and thus injuries in this complex can lead to post traumatic pes planus as well as ankle instability. The implications of not addressing these injuries is long-term instability and reduction in

PROMS. In unreconstructable injuries in frail patients the option of primary fusion, hindfoot nail or total contact cast may be considered as a primary fixation strategy as early functional weight bearing maybe essential for the patient.[23]

6. Limitations

The limitations of this study are the limited number of patients, retrospective nature of data collection and lack of functional outcomes. Future studies require larger prospective collaborative series which may allow classification of specifically open ankle fracture patterns and associated soft tissue injuries. Further research into the destabilising effects of associated capsuloligamentous disruption in ankle fractures and viable treatment modalities would be of great value, as this area of injury is possibly underestimated.

7. Conclusion

Open ankle fracture dislocations are, by definition, associated with significant soft tissue disruption. The destabilising effect of the periosteal stripping of capsuloligamentous attachments leads to ligamentous failure around the ankle and is often associated with syndesmotic disruption.

We advocate a high index of suspicion, systematic examination of soft tissue structures and intraoperative stress testing at the time of debridement and following surgical fixation. Surgeons should be aware of the risk of persistent ankle instability following bony fixation and consider the various supplementary strategies described here and available to achieve this.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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