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Trauma to the medial ray of the foot: A classification of patterns of injury and their management

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ABSTRACT

Aims: Fractures and dislocations of the midfoot are relatively uncommon but can be life changing injuries. Within the literature, there has been scant specific reference to the identification and management of medial ray injuries in midfoot trauma. Moreover, it is appreciated that these injuries are associated with poor outcomes. We aim to clearly define these injury characteristics and demonstrate fixation techniques.

Patients and methods: A retrospective review of the case notes and imaging was conducted for operatively treated midfoot injuries between January 2013 and January 2018.

Results: 161 patients were identified, 31 of these with imaging and operative diagnosis suggestive of medial ray injury. Studying these 31 injuries revealed five patterns of injury.

Conclusion: When treating midfoot trauma, it is important to fully understand the injury pattern as this dictates the principles and techniques of fixation. Identification and knowledge of these five injury patterns will aid surgeons in future management of these injuries and may improve treatment outcomes.

Introduction

Fractures and fracture-dislocations of the midfoot are uncommon. Injuries involving the tarso-metatarsal joint (TMTJ) [Lisfranc's joint] occur more frequently than injuries involving the mid-tarsal joint (MTJ) [Chopart joint]. Injuries to the TMTJ occur in 1.8 per 100,000 of the population. Isolated navicular and cuboid fractures are marginally less common each with a reported incidence of 1.7 per 100,000 with Chopart injuries being rarer still [1,2]. A precise incidence of MTJ injuries remains unclear from the literature. Moreover, within the literature, these injuries are often considered in isolation with scant reference to an appreciation of any injuries which may have occurred concomitantly [2–4]. In a recent paper classifying navicular fractures, Petrie et al. noted a small, but significant, group of combined TMTJ/MTJ injuries caused by longitudinally directed forces that rendered instability to the medial ray [5].

Within the literature, there are no fixed definitions of the sagittal subdivisions of the foot termed "first ray", "medial ray" or "medial column". Universally, the first metatarsal is common to all descriptions of the medial or first ray with some authors also including the medial cuneiform and others acknowledging the contribution of the naviculo-cuneiform joint (NCJ). Equally, some authors define the medial column of the foot as comprising the navicular, the three cuneiforms, their respective metatarsals and phalanges and consider the column to articulate with the talus. Quite often, the two terms "medial ray" and "medial column" are used interchangeably with no definition of the component anatomic structures. For the purpose of this study, the term "medial ray" is used and is comprised of the first metatarsal, medial cuneiform, the navicular and the head of the talus. The rationale for this is that, together with the hallux, these bony structures comprise the medial longitudinal arch of the foot which together provide the stable platform for the propulsive phase of gait.

The purpose of this study is to describe injuries to the medial ray of the foot in detail and suggest principles of management based on the patterns and characteristics of the injury. This study is unique as these injuries have not been examined any detail before and there is no reference to their specific management principles in the literature.

Patients and methods

Our institution is a tertiary referral teaching hospital and the Major Trauma Centre serving a population of approximately 1.8 million. A retrospective review of the case notes and ORMIS (Oracle, USA) operating department management system was

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conducted for cases between January 2013 and January 2018. The database was searched using the keywords “midfoot”, “Lisfranc”, “tarso-metatarsal”, “cuneiform”, “navicular” and “talus”. The cases identified from this search were then further cross-referenced with the HSS CRIS Radiology Information System (Healthcare Software Solutions Ltd, Mansfield, United Kingdom). The imaging for all operative cases was reviewed looking for radiological evidence of disruption to the first TMTJ, avulsion of the Lisfranc ligament, fracture of the medial cuneiform, medial inter-cuneiform joint diastasis, medial naviculo-cuneiform dislocation, navicular fracture, talo-navicular (TNJ) dislocation and fracture of the head of the talus. Any concomitant injuries that involved the lateral structures of the midfoot were noted. Injuries were classified as either high or low energy according to the same criteria defined in the paper regarding Lisfranc injuries by Renninger et al. [2]: High energy injuries were classed as those sustained in road traffic accidents, direct crushing or a fall from greater than 4 feet in height. Low energy trauma was defined as occurring during athletic activity, torsional trauma at ground level or a fall from less than 4 feet in height.

For those injuries requiring surgical treatment, the operation notes and post-operative images were reviewed to assess how the surgeon had stabilised the medial ray and the surgeon’s appreciation of the original injury pattern.

Results

We identified 161 patients with our search criteria. We excluded 118 patients who had other midfoot injuries, including 67 TMTJ fracture dislocations injuries (Fig. 1). Any injury that resulted in primary amputation was also excluded. This led to a final study group of 31 cases (31/157 [19.7%]) with medial ray injuries.

The injury characteristics for this group revealed that 48.7% were male with an average age of 41 years (range 17–73). The majority of our cohort were ASA (American Society of Anesthesiologists) 1 29/31 (93.5%). One patient had Type 2 diabetes without complications, one patient suffered from alcoholism and one patient had multiple cardiac co-morbidities. Most of these injuries were closed (29/31 [93.5%]) and deemed to have occurred as low energy injuries (athletic injury, torsional injury, fall <4 feet height) 19/31 (61.3%).

All patients were managed operatively with plain radiographs and CT scans available in all but two patients pre-operatively. The two patients without pre-operative plain film images were taken to theatre for damage limitation surgery as part of major trauma, but had CT imaging.

Intra-operative fluoroscopy was available for all patients and all patients had at least one post-operative radiograph. Open reduction and internal fixation was performed in 28/31 (90.3%) of cases as the index surgical procedure. In the remainder, one case had temporary external fixation with subsequent conversion to internal fixation, one case was managed with combined internal and external fixation and one case was managed with external fixation alone as definitive treatment. There was one case of primary fusion of the affected 2 & 3 TMTJs. As part of their initial treatment, two patients required plastic surgical intervention with vacuum-assisted dressings prior to definitive split skin grafting.

Five basic patterns of injury were identified as shown in Fig. 2. Common to all patterns of injury was the avulsion of the Lisfranc ligament. In each pattern of injury, the presence/ absence of concurrent lateral injury was noted (Table 1). Where the injuring force disrupts the 1st TMTJ, rendering the medial ray unstable at this joint (Line A), as well as disruption of the Lisfranc ligament, the energy of injury always caused a heterogenous pattern of fractures

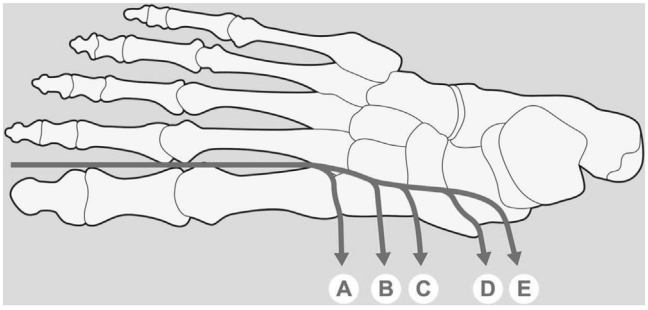

Fig. 2. Locations of energy exit from the medial column.

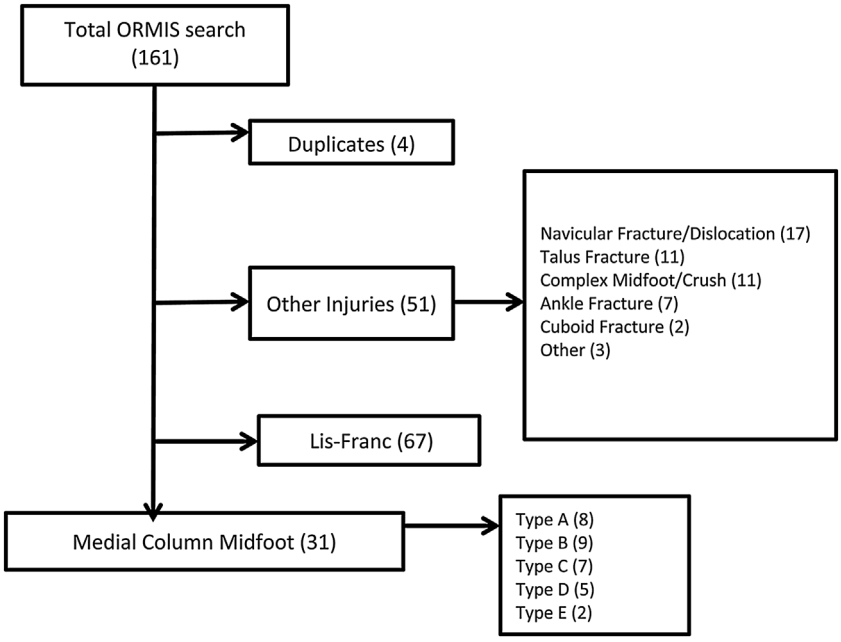

Fig. 1. Exclusions from initial search.

Table 1
Medial ray injury type, associated lateral injuries and energy of injury.

Medial ray injury	Number	No lateral injury	Base 2nd metatarsal fracture /2nd TMTJ subluxation/Middle cuneiform fracture	Base 3rd metatarsal fracture/ 3rd TMTJ subluxation/Lateral cuneiform fracture	Fracture dislocation of 4 &5 TMTJ	Cuboid fracture/ Anterior process fracture of calcaneus	Number of high energy injuries	Percentage of cases of high energy injury
A	8	0	7	3	0	0	0	0
B	9	4	4	2	1	0	3	33
C	7	6	1	0	0	0	1	14
D	5	2	1	1	2	1	4	80
E	2	0	1	1	0	2	2	100
Total	31	12	14	7	3	3	10	

and dislocations to the second and third TMTJs [8/31, 25.8%]. In the second group, the energy of the injury caused a fracture of the medial cuneiform (Line B, Figs. 1 & 4) [9/31, 29%]. Within this group of patients, a third sustained their trauma as a result of high energy trauma and more than three quarters of them were associated with concomitant lateral ray injuries. In the third group, the energy of injury propagated longitudinally along the inter-cuneiform joint and exited through the medial NCJ (Line C, Figs. 1 and 5) [7/31, 22.6%] but largely, these injuries were as a result of low energy mechanisms of injury. The fourth group was characterised by the longitudinal propagation of energy via a sagittal-plane fracture line through the navicular and subsequent exit of the energy medially through the TNJ (Line D, Figs. 1 and 6) [5/31, 16.1%]. Within this group of injuries, 80% were as a consequence of high energy trauma. In the final injury pattern to the medial ray, the longitudinal propagation of high energy led to a dorsal or dorsomedial avulsion of the head of the talus (Line E, Figs. 1 & 7) [2/31, 6.5%] and was associated with trauma to the lateral column. In Figs. 3–7, the key characteristics from the imaging are highlighted together with examples of internal fixation to address the areas of instability.

Discussion

Inherent to the function of the medial ray is the requirement for it to be of sufficient length and stability. In the normal foot, the medial ray carries 40% body weight during stance phase [6]. Additionally, the Achilles tendon requires a stable medial ray of sufficient working length to act as a lever arm whilst in the propulsive phase of gait. Dependent upon the definition of the medial ray, its stability will be affected by the joints it consists of and the statics and dynamics of supporting soft tissue structures such as the plantar fascia and the musculo-tendinous units of tibialis anterior, peroneus longus and tibialis posterior. In a seminal cadaveric study of 100 feet, Wanivenhaus and Pretterklieber [7] found that sagittal plane and coronal plane motion of the first TMTJ was negligible in most individuals. In addition, rotational motion through this joint could only be detected once the plantar capsular ligaments of the joint were sectioned. In the case of injury to the ligaments of this joint, it is clear that this will render the medial ray unstable and dysfunctional [6].

Two key papers from experienced trauma units emphasise the need to restore and maintain the length and alignment of the medial ray and its relationship with the lateral column [8,9]. Shortening of the medial ray, through malreduction, can lead to a cavus foot shape [8]. Instability of the medial ray may be due to plantar widening of the first TMTJ, ligamentous insufficiency between the medial and middle cuneiforms or with capsular disruption of the NCJ. In turn this leads to flattening of the medial longitudinal arch and can be addressed by the surgeon appreciating the need to stabilise these areas with appropriate screw or plate fixation [9]. Restoration of correct column length, alignment and achieving stability is associated with better outcomes following these injuries [9]. Therefore, we believe that it is important for the treating surgeon to consider where the energy of injury exits on the medial ray by obtaining CT imaging and scrutinizing these images.

It is appreciated that fractures and fracture-dislocations of the midfoot are uncommon with TMTJ injuries occurring in 1 in 55,000 [9]. This means that medial ray injuries that involve both the TMTJ and MTJ complexes are likely to be even less common. It is possible to extrapolate an estimate of their frequency by carefully analyzing the paper by Richter et al. [9]. This paper reported 155 midfoot injuries over a 25-year period and indicated that injuries to the MTJ occur half as often as injuries to the TMTJ, suggesting an incidence of 1 in 110,000. Furthermore, there appears to be a similar incidence of combined midfoot trauma to both levels of joints (1 in 110,000) meaning that injuries that only affect the medial ray will occur even less frequently implying an incidence of <1 in 100,000 [9]. Additionally, they note that combined injuries to the TMTJ and MTJ were associated with greater post-traumatic radiographic evidence of arthrosis and were associated with the worst outcomes of all foot injuries. They conclude that the key factor in optimizing outcome was re-establishing the relationship between the medial and lateral columns of the foot.

Previous classifications of injuries to the midfoot tended to distinguish between injuries affecting the TMTJ complex and the MTJ [3,4,8–12]. Common to all of these classification systems were

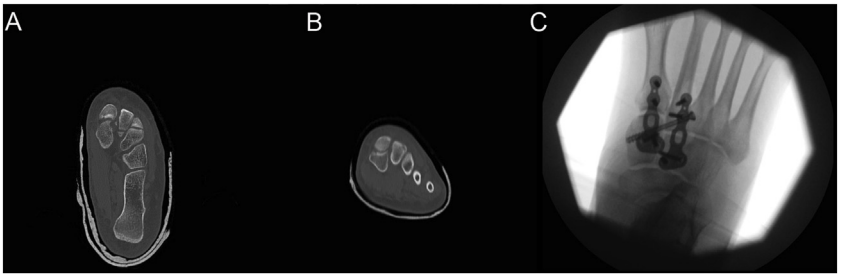

Fig. 3. Pre-operative coronal and axial CT images demonstrating a medial split-depression fracture of the first metatarsal base in conjunction with clear avulsion of the Lisfranc ligament (Type A). Intra-operative fluoroscopic images show restoration of the midfoot anatomy with lagged screw fixation addressing the avulsed Lisfranc ligament and bridge plating across the 1 & 2 TMTJs to restore stability of these joints.

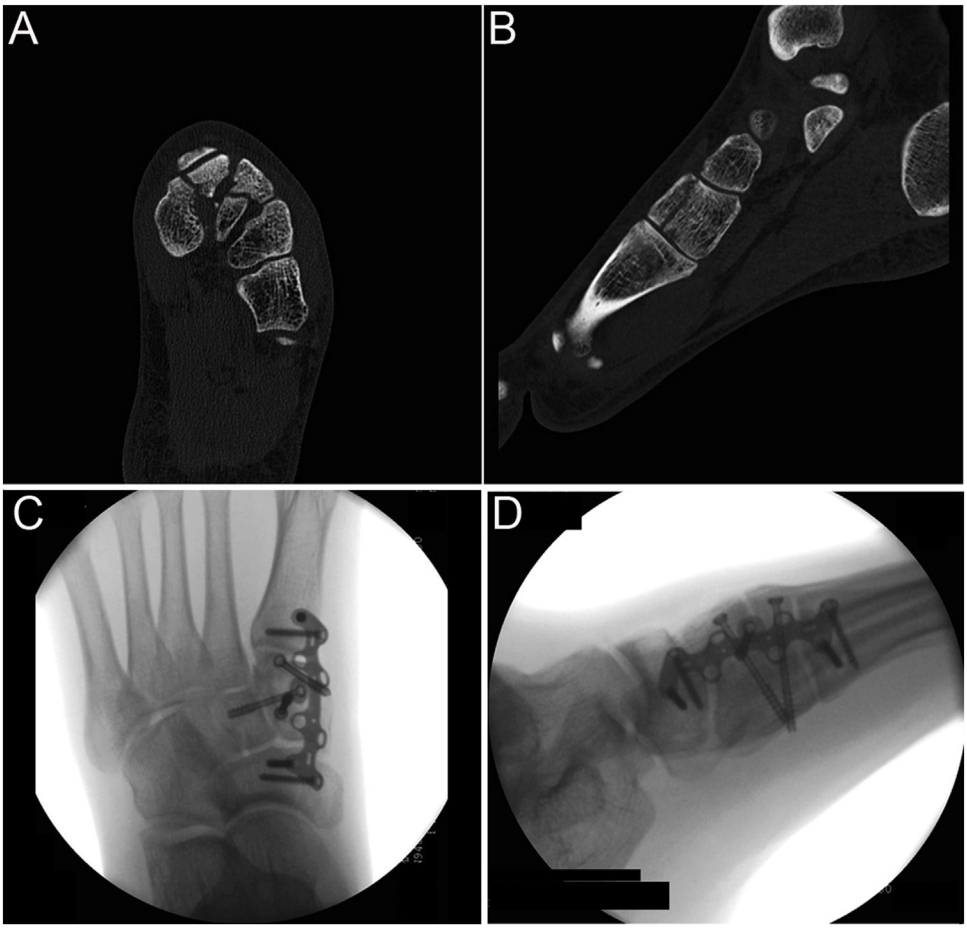

Fig. 4. Pre-operative CT images detailing an axial split fracture of the medial cuneiform (Type B) and intra-operative fluoroscopic images demonstrating lagged screw fixation of the fragments and neutralisation of the fixation by bridging from navicular to first metatarsal base.

that they were based upon plain radiographic findings and pertained only to high energy injuries. More frequent attempts have been proposed to classify Lisfranc injuries. The original classification of TMTJ injuries by Quenu and Kuss 10] spawned two further widely quoted classification systems by Hardcastle et al. and Myerson et al. [3,4]. Together, all three acknowledge the involvement of the medial ray [3,4,10] as does the more descriptive studies by Wilson 11] and Main & Jowett [12]. In both the Hardcastle [3] and Myerson [4] studies, injury occurred to the medial ray in every one of their groups. However, because these were descriptive classifications that focused on partial or complete involvement of the forefoot and the direction of displacement, the injury to the medial ray is not further analysed. There is no explicit recognition in either of these seminal studies about how to specifically manage the medial ray injury and therefore there is no correlation with outcome. In many studies, any proximal propagation of the energy of injury beyond the Lisfranc ligament still meant that these injuries were regarded as "Lisfranc joint complex" injuries [3,4,8,11]. None of the previous classifications before the present study allude to injury involving the head of the talus (Type E).

Conversely, the navicular fracture classification proposed by Sangeorzan, does not consider concomitant injuries to the TMTJ complex [13]. More recent studies looking at midfoot injuries have involved CT imaging techniques. In a proposed classification of operatively treated fractures of the navicular, Schmid et al. focused solely on the effects of the fracture on the talonavicular joint and did not describe any longitudinal lines of injury more distally through the TMTJ complex [14]. The advent of CT imaging has meant that more subtle injuries to the midfoot can be appreciated, especially those involving lower energy mechanisms of injury. Renninger et al. found that two thirds of their study group of midfoot injuries had low energy injuries with the medial ray equally likely to be affected (medial cuneiform fracture, inter-cuneiform instability and naviculo-cuneiform instability) as in those with high energy injury [2]. In a recent paper providing a comprehensive classification system for fractures of the navicular, Petrie et al. apportioned a separate category of injury to those fractures associated with TMTJ disruption [5]. This group accounted for 1% of navicular fractures but warranted surgical intervention to stabilize the medial ray in every case. This work suggests that there is an additional sub-group of injuries to the medial column of the foot which if not correctly understood could mean an underestimation of the extent of injury and lead to mismanagement and potentially poorer outcomes.

Moreover, in the era in which these studies were conducted, with the lack of access to CT scan assessment, the nuances of the injury severity were readily inadvertently overlooked. It is also likely that the increased use of CT has led to accurate diagnosis of those injuries occurring with lower energy and skewing the relative proportions of high to low energy midfoot injuries. As a result, what are now appreciated as low energy injuries to the midfoot may not have been considered. It is clear from subsequent literature that any injuries involving the medial ray, albeit from high or low energy trauma are associated with poorer outcomes [9,15]. There injuries can be under appreciated from plain radiography but CT scans clearly demonstrate the extent of the injury with various combinations of ligamentous/capsular

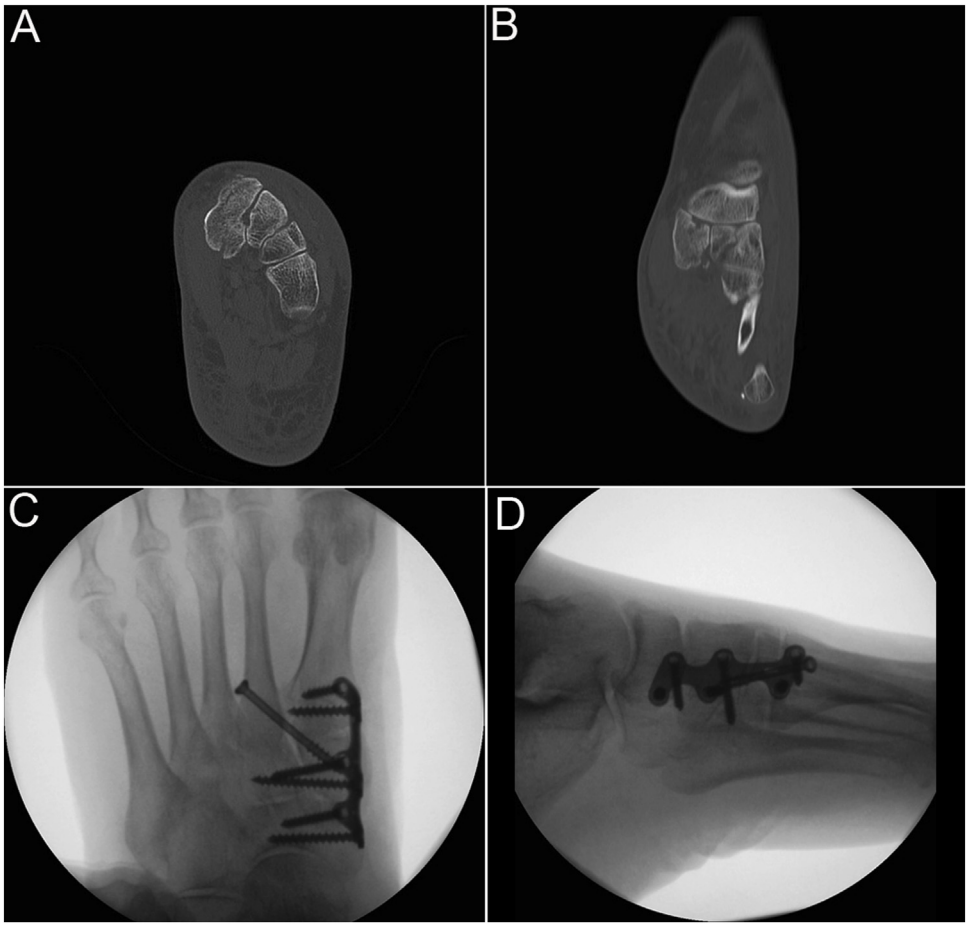

Fig. 5. Pre-operative coronal and axial CT images demonstrating a fracture-dislocation of the medial naviculo-cuneiform joint (Type C). Intra-operative fluoroscopic images demonstrate reduction and hold of the avulsed Lisfranc ligament and bridge plating of the dislocation of the NCJ.

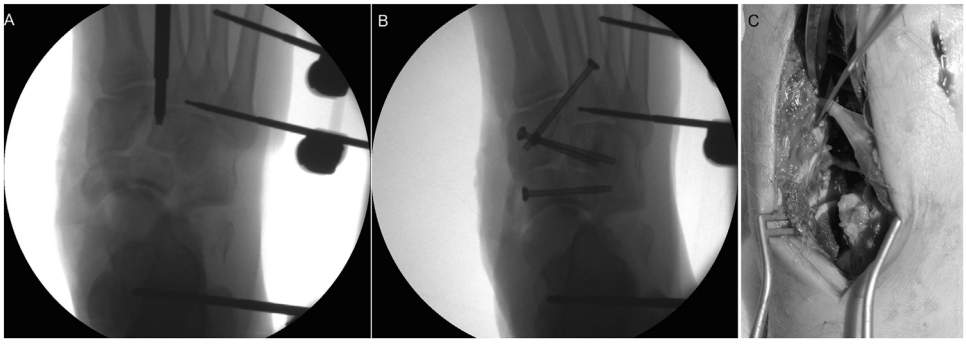

Fig. 6. Intra-operative photograph and fluoroscopic imaging demonstrating the instability of the medial ray (Type D). The sagittal plane fracture of the navicular is clearly visible and the open laminar spreader demonstrates the diastasis across the inter-cuneiform joint and across the ruptured Lisfranc ligament. The same features are visible on the fluoroscopic view where the end of the screwdriver is positioned in the diastasis. Fixation proceeded proximally to distally, sequentially addressing the sagittal split in the navicular and then the diastasis with appropriately placed screw fixation. The external fixator was to restore lateral column length intra-operatively.

avulsion fragments, fracture lines in various planes and diastasis of the affected joints seen.

The present study focuses on the importance of identifying injuries to the medial ray in midfoot trauma in order to try and avoid the known poor outcomes secondary to medial ray instability or malunion. The present study classifies injuries according to the exiting line of trauma energy at clear anatomic levels namely: the first TMTJ, through the medial cuneiform, the medial NCJ, through the body of the navicular and exiting through the TNJ and finally through the medial aspect of the head of the talus. Although diagrammatically referred to in other studies [3–59], this has never been previously assessed. Although no outcome data are included in the study, the present study is unique in aiding the planning of sufficient stabilisation of each line of trauma energy by bridging the unstable segment. Having ascertained the level of injury, this can guide the surgeon to plan incisions for surgical approach bearing in mind concurrent lateral injuries to the TMTJ and Chopart joints.

In this study, the lines of energy exiting through the first TMTJ are as a result of low energy trauma and are invariably associated

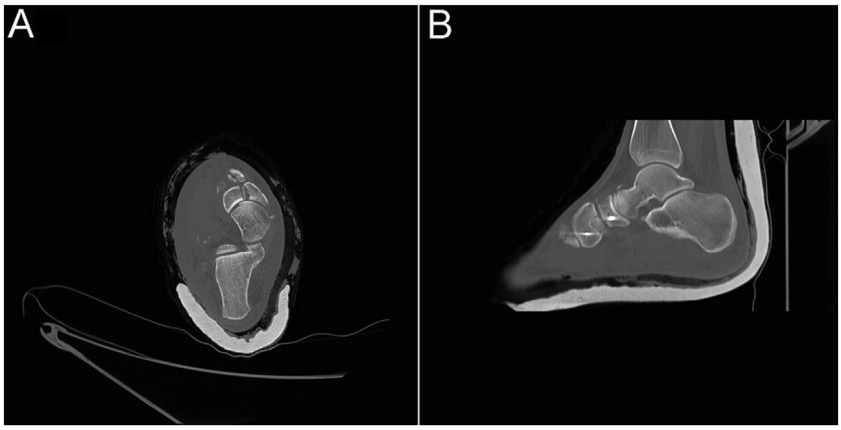

Fig. 7. Pre-operative CT images demonstrating impaction of the head of the talus in a high-energy injury requiring temporizing external fixation (Type E). In these cases, it may be necessary to bridge onto the neck of the talus.

with injuries to the second and third rays (Type A). Radiologically, it is important to identify plantar or medial avulsion fracture fragments from the CT scan if there is not obvious first TMTJ subluxation. As well as addressing the diastasis caused by rupture of the Lisfranc ligament, it is important to look for and address first TMTJ instability with appropriate fixation (Fig. 3). In those medial ray injuries where the line of traumatic energy has fractured the medial cuneiform (Type B), more energy has been imparted to the midfoot. These injuries are often isolated to the medial ray. In order to stabilise them, lagged screws may hold simple fracture planes, but the ray may need further stabilization by fixing across the first TMTJ, ICJ or NCJ by screws or bridge plating. In Type C injury patterns, the line of energy principally exits through the NCJ but may also create splits and/or depressed fracturing to the medial cuneiform. Because the Lisfranc ligament and inter-cuneiform ligaments are ruptured, the medial ray needs appropriate stabilisation with hardware preventing the medial ray from subluxating (Fig. 5). In both the Type D and Type E injuries, these consistently occur as a result of high energy trauma. In both groups the proximal propagation of traumatic energy creates a sagittal split of the navicular that needs addressing with a lagged screw. Bridging of the talonavicular joint may need to be considered with a bridge plate or medial external fixation. In the event of trans-articular bridge plating, this plate will need to be removed after bony union in order to restore TNJ function. In both of these groups, there is a high chance of injury to the lateral column of the foot that will also require adequate reduction and stabilisation.

The drawbacks of this descriptive study are principally that it is a retrospective operative study, and this accounts for the absence of non-operatively managed medial ray injuries. In addition, it may reflect expert opinion in managing severe foot injuries in a tertiary referral major trauma centre and may not represent the experience in smaller trauma units. Another drawback in the present study is that no attempt has been made to comment upon outcomes, although the authors believe that it is already accepted that medial ray injuries are associated with poor recovery of function [9,15].

In the modern era with greater access to, and use of CT, it is imperative to understand how the medial ray can be injured in order to plan accurate surgical reconstruction of the midfoot. We believe that the present study is unique in analysing in greater depth the patterns of injury to the medial ray. By pre-emptively identifying where the energy of injury exits on the medial ray from the CT imaging, these areas can be assessed intra-operatively with fluoroscopic-assisted examination and direct visualization of the joints. Under direct vision, haemarthroses and capsular rents can easily be identified. In this way, potential medial ray instability can be treated with robust fixation techniques using plates and screws or spanning external fixation techniques across each unstable segment. Likewise, potentially unnecessary exploration of uninjured joints may be avoided. Achieving accurate restoration of foot anatomy with sturdy fixation techniques increases the chance of improved outcomes.

Conflict of interest

None.

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