Acta Biomed 2020; Vol. 91, Supplement 4: 36-46 DOI: 10.23750/abm.v91i4-S.9724

Review

Central metatarsal fractures: a review and current concepts

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Summary. Central metatarsal fractures (CMF) are common injuries. More frequently fractures are those of the fifth metatarsal, followed by CMF and therefore by the first metatarsal. Third metatarsal is injured most frequently than the others and up to 63% is associated with second or fourth metatarsal fractures and up to 28% with both. Anatomy and metatarsal kinematics merits attention due to its influence on function, injuries and treatment options. Diagnosis is based on the history of trauma and clinical examination, relating with instrumental exams. Fractures with less than 10° of angulation and 3-4 mm of translation in any plane are typically treated conservatively, while operative treatment is generally reserved for fractures out if these values. Intramedullary fixation with K-wires seem to be the most common and valid surgical treatment in simple fractures. Spiral fractures should be treated by interfragmentary screws, which positioning may result difficult due to the adjacent metatarsals. Therefore, an alternative approach is an osteosynthesis with a dorsal plate. Multiple metatarsal fractures often occur in the contiguous bones, so clinicians will also have to carefully inspect metatarsals and adjacent joints such as Lisfranc articulation. The clinical and functional outcomes are often influenced by the pattern of fractures and patient conditions and are reported in the literature up to 39% of poor results. (www.actabiomedica.it)

Introduction

Metatarsal fractures (MF) represent about 88% of all fractures involving foot and ankle, amounting up to 35% of all foot fractures and up to 7% of all skeletal injuries.[1-4] Older female gender is the most affected, with a female to male ratio of 2:1 in general population, while males appear more commonly affected in athletes.[1, 4-6]

These types of lesions have been frequently reported in second through fifth decade of life[4], but children also appear to be affected, accounting up to 61% of all fractures of the foot[7] and occurring in the fifth (41%) and the first (19%) by anatomical exposure.[7]

MF can be cause by an isolated injury, associated with other metatarsals fractures or Lisfranc joint injuries. Both direct and indirect traumas can lead to a MF but, generally, are the result of low-energy trauma;[4] however, high-energy crush injuries may occur quite frequently, involving soft tissues[2] and resulting up to 1% of all metatarsal open lesions.[5]

Other type of injury as stress fractures can occur in metatarsals, most commonly in the second but also in the third and fifth. They are usually reported in women with osteoporosis and people with repetitive stress injuries, ballet dancers and military recruits.[8]

MF can occur at any level of the metatarsal bone and there is no specific classification.[9] Proximal metaphyseal and central metatarsal base fractures are sometimes associated with Lisfranc injuries. Shaft fractures are usually oblique and they should be examined for shortening, angulation and displacement.[4, 10-12]

Metatarsals can be divided in 3 groups: first, central and fifth metatarsal. The second, third, and fourth metatarsals are distinct as central metatarsals (CM).[3]

More frequently fractures are those of the fifth metatarsal, followed by CMF and therefore by the first metatarsal. Several studies state that, among central metatarsals third metatarsal is injured most frequently than the others and up to 63% is associated with second or fourth metatarsal fractures and up to 28% with both.[4]

Although fractures of the first and fifth metatarsals are generally isolated fractures, multiple metatarsal fractures often occur in the contiguous bones, so clinicians will also have to carefully inspect metatarsals and adjacent joints such as Lisfranc.[4]

Central metatarsal fractures (CMF) are caused more frequently by direct trauma and less frequently by indirect torsional trauma. The central metatarsal bases articulate with the tarsal bones so diagnosis and management of this type of fractures may result difficult.[13]

Anatomy

The metatarsals constitute the skeleton of the foot adjoining the mid to forefoot regions positioned between tarsus and phalanges. All metatarsals include a base, shaft, and distal extremity or head. They are prismoid in shape, tapered distally and wider at the base. The base articulates with the tarsal bones and is wedge-shaped, the shaft is curved dorsally and has a rough surface for ligament insertion. The head has a convex articular surface which extends inferiorly more than superiorly, the plantar surface is ploughed by two articular eminences for the transit of flexor tendons.[14]

The second metatarsal is the longest among metatarsal bones with the base that has five joint facets and is grooved between the three cuneiform bones. The third and fourth metatarsals articulate with adjacent metatarsal and tarsal bones.[15]

Within the human foot metatarsal blood supply shows significant anatomic variation in first[16] and fifth ray[17], while the central metatarsals are generally vascularized by the plantar metatarsal artery that divides near the metatarsal heads into a medial and a lateral branch.[18] The primary nutrient artery of the CM come in laterally, more or less 3.1 cm from the distal joint cartilage.[19]

The CM have important ligamentous structures that connect each bone to their adjacent ones. The base of each central metatarsal enclose 3 ligaments (plantar, central, dorsal) that support and stabilize each respective metatarsal and the adjacent metatarsal, except between the base of the first and second metatarsal bases where there is a lack of connection. The Lisfranc ligament bestrides plantarly from the second metatarsal to the medial cuneiform to give stability. The dorsal and plantar interossei muscles, which provide metatarsophalangeal stabilization, originate mainly from these metatarsals, so that the extensor and the long flexor can have a correct muscle action.[20]

However, these muscles can also represent as a deforming force in case of metatarsal fractures. There is an increased motion through the tarso-metatarsal joints, having a peak in the fourth and fifth tarso-metatarsal joints. The adaptability to the ground by the metatarsal heads is allowed by the increase in movement in the sagittal plane in these central metatarsals. The tarso-metatarsal joints of the second and third ray are relatively hardy to this sagittal motion, and therefore, stress fractures are more common in the second and third metatarsals than in the remaining metatarsals.[9]

Biomechanics

Metatarsal kinematics merits attention due to its influence on function, injuries and treatment options. The metatarsal bone plays an important role in terms of posture and gait cycle. The first ray carries twice the load of each of the lesser ones during the stance phase of step giving it special biomechanical features. The joints at the basal extremity of the metatarsals concur to extension of the longitudinal arch during push-off phase.[21] Equally, position of the metatarsals and orientation of the joint facets determine distal arch rotation in relation to foot supination and pronation.[22] Kinematics of the foot can be affected by various factors such as age, pathological process and BMI.[23]

Anyhow, latest studies have provided significant information on the mechanical functioning of the foot during normal and pathological phases. The most significant evolution has been made with the multi-segment kinematic model. Several studies based on normal patients confirmed these multi-segmental concepts, specially highlighting the dynamic relationship between the various segments during forefoot-hindfoot motion and arch elevation and drooping.[24]

Shereff reviewed pathological consequences of altered forefoot biomechanics.[25] During stance phase of the gait, CM support the same weight each other, metatarsal displaced fracture may change in a not plantigrade foot. Plantar dislocation of the distal fragment lead to overload that may bring an unmanageable plantar keratosis. Dorsal dislocation of the distal fragment decreases load on the respective metatarsal but this produces an overload metatarsalgia on the nearby metatarsal heads. Lateral dislocation of the fragment produces a mechanical conflict on the adjacent metatarsal or the formation of a possible interdigital neuroma. Finally, medial dislocation of the distal fragment of the first metatarsal or lateral dislocation of the fifth metatarsal produces a bone prominence that may cause problem wearing shoes.[26]

Stress fractures

CM are resistant to the sagittal motion, so stress fractures are more frequent in this site in professional athletes, military personnel and ballet dancers representing up to 23% of all stress fractures. Rarely stress fractures occur to the first and fifth metatarsals.[27-29]

Several studies showed that most of the second metatarsal stress fractures occur in the diaphysis or in the neck and in dancers these fractures may affect the base.[30-31]

Stress fractures are usually caused by recurrent traumas, low energy external forces, unintentional muscles contraction and bone weakness.[32] High longitudinal arch of the foot, leg length discrepancy and forefoot varus appear to be some of biomechanical factors associated with this type of fractures.[33] A long second metatarsal and an overly mobile first ray may contribute to an excessive repetitive load on the second metatarsal.[34]

On the other side a short first metatarsal produced abnormal overloading stress along the second metatarsal, particularly patients with a length of the first metatarsal 80% compared to the second metatarsal were more prone to fracture.[28, 35] Achilles contracture increases plantar pressure and the risk of stress fractures.[36] Ringham et al. demonstrated that excessive external rotation of the hip can produces a hyperpronation of the foot and this condition may increase the risk of stress fractures to the lower limb.[37]

It is therefore acceptable to observe that there is a complex articular interaction affected by metatarsal orientation, topography and kinematics. These ascertainment are not only relative to the trauma and orthopaedic surgeon but also maybe important for the rehabilitation therapist.[9]

Aetiology

CMF occur with either indirect or direct trauma.4, 38 Seldom crush injuries, typically occur within industrial workplaces, may cause this type of fractures, often associated with soft-tissue injury;4 instead, stress fractures commonly occur with a sustained and acute increase in the activity's intensity and are frequently related with endocrine or metabolic deficiency.39

It is important for the second and third metatarsal fractures to assess the intra-articular involvement or concomitant lesions such as Lisfranc's fracture. Furthermore, given the relatively limited soft-tissue structure around the metatarsals, assessment of possible suffering or defects communicating with the fracture site is highly recommended.[20]

Lindholm et al. showed that displaced CMF were uncommon due to the rigidity of the ligaments between metatarsals. Authors noted that diaphyseal metatarsal fractures rarely became displaced when interosseous and lumbrical muscles and ligaments insertion were intact. However, neck fractures could displace because of the action of flexor tendons that exert a force and dislocate the metatarsal head proximal or plantar.[26]

Although studies have reported an association between valgus deformity of the hindfoot and osteoporosis with fractures of the second metatarsal, none of these conditions explain the reason for the increased incidence of fractures in the non-proximal region of the metatarsal.[40-42] Boden et al. demonstrated that the healing of a proximal fracture is generally longer than the non-proximal fracture and presents high risk of complications.[43-44]

Clinical evaluation and diagnosis

Diagnosis of CMF is based on the history of lesion mechanism, clinical examination and X-ray. Most commonly the lesion mechanism is a consequence of a fall from standing height or twisting injury with a stationary forefoot.[4] It is important to identify risk factors such as a corticosteroid use, amenorrhea and osteoporosis in case of suspicious of stress fractures; patients affected from these type of fractures usually present a history of pain in the forefoot.[27]

The clinical presentation of these fractures is characterized by swelling, pain and inability to weight bearing; bony deformity is subtle, unless there are concomitant Lisfranc joint injury, serial metatarsal fractures or attendant proximal/distal injuries.[45]

The initial clinical assessment reveals bruising, pain on palpation and pain exacerbation on forefoot weight bearing[46]; in case of open fracture, evaluation for neurovascular status is essential.

Clinical assessment of metatarsal fractures must include examination of the proximal and distal joints.[47] Another important sign to investigate in case of crush trauma and suspicious of Lisfranc injuries is plantar hematoma in the midfoot.[48]

Standard diagnostic X-rays should comprise antero-posterior, lateral and oblique (45°) views of the foot.[45] However, if associated fractures such as V metatarsal are suspected, it is recommended an additional fifth metatarsal base view obtained with an antero-posterior X-ray of the ankle which comprise the proximal part of the fifth metatarsal. Up to 23% of fifth metatarsal avulsion resulting not visible on the routine three views.[49] In case of doubt, optional radiographs are recommended for diagnosis such as contralateral foot view specially in paediatric patients.[45]

Moreover, it is important to identify accessory bones in the region to rule out avulsed fragments, such as os vesalianum, os peroneum, os inter-metatarseum and os cuneometatarsal.[50]

In some cases, stress fractures could not be evident on initial plain radiographs; these latest normally demonstrate evidence of radiolinear lucency and/or periosteal reaction in a time comprise between two and six weeks.[51] It is therefore appropriate to repeat the radiographs at 10 to 15 days may show evidence of resorption gap at the fracture site.[30]

Although they are occasionally utilized, magnetic resonance imaging (MRI) and nuclear medicine bone scan (NM Bone Scan) are seldom required in diagnostic study;[52] particularly, MRI is only recommended in occult fracture with clinical history or suspected stress fractures,[30] and is widely accepted as gold standard for the early diagnosis of metatarsal stress fractures with T1-weighted images that demonstrate decreased medullary signal with bone stress reaction and fracture delineation.[53]

Banal et al studied the use of ultrasound (US) in the early diagnosis of these fractures and demonstrated satisfactory level of diagnostic reliability with 83% sensitivity and 76% specificity, in addition to its low duration of execution, cost and immediate availability.[53]

When multiple and serial metatarsal fractures are present, they require a computerized tomography (CT) scan to ascertain the intra-articular involvement, comminution and integrity of the Lisfranc joint. A significant proportion of metatarsal fractures may be missed on initial radiographs and in case of polytrauma with complex foot and ankle injury a CT scan is indicated. A thorough evaluation built on an understanding of the injury mechanism and careful clinical examination matched with the standard three views foot X-rays remains fundamental in CMF diagnosis.[54]

Classification

CMF are classified topographically in relation to the location of the fracture site: base, diaphysis, neck and head.; however, these metatarsals have no specific classification, differently from fifth metatarsal fractures.[9] The AO classification divided these fractures in: type (A) extra-articular fracture, type (B) intra-articular fractures, type (C) dislocated fracture and type (D) pure metatarsal dislocation, the latest also called "floating metatarsal". Each of these types is in turn subdivided into proximal metaphyses, diaphyses and distal metaphyses.[55]

Management

The goal of the treatment is to obtain a correct healing of the fracture maintaining the metatarsal parabola, the sagittal position of the metatarsal heads and bone-to-bone contact in order to preserve a functional forefoot. The stability of the CMs is kept by the anatomical position and soft tissue which limits the displacement in multiple metatarsal fractures because these usually displace in unison and maintain their respective anatomical relationships, thus resulting in a decreased risk of subsequent complications.[45]

All undisplaced metatarsal fractures, including stress fractures, may be treated conservatively. The amount of the displacement of the CMF can influence the choice of the treatment and it is also correlated with the outcome of patients. Indeed, in their study Cakir et al. recorded that a displacement of more than 2 mm in any direction was associated with a poorer outcome.[1] The values of displacement or angulation that influence the choice of treatment (operative or non-operative) are still debated, although there is consensus that fractures with less then 10° of angulation and 3-4 mm of translation in any plane require a non-operative treatment.[2,56-59] Moreover, a conservative treatment can be implemented in case of CMT with a frontal plane displacement without shortening.[60]

A distal traction from the finger may be useful for the reduction in case of displaced fractures of the CMF. However, sometimes maintaining the reduction with external manoeuvres could be difficult and should be require proceeding with open reduction, and eventually using a percutaneous pinning.[2] Careful consideration should be given to the base metatarsal fracture that could be associated to a concurrent Lisfanc injury and may often require surgery.

In case of stress fractures, it is important to investigate the reason of their occurrence. Stress fractures in professional athletes have to be treated according to the functional requirement of the patient to avoid prolonged time of immobilization. Stress fractures of the metatarsal shaft or neck can be treated with a short-leg cast, cast boot or a stiff-soled shoe, with healing in 6 to 8 weeks. Moreover, in patients who have high risk for impaired stress fracture healing, Raghavan et al. demonstrated that Teriparatide may be useful in the clinical setting to accelerate the healing.[61]

Conservative treatment

Non-operative treatment frequently includes immobilization for 3-6 weeks with pain relief in the days

Figure 1. Clinical case of a 27 years old female affected by an undisplaced fracture at the base of the II, III and IV left metatarsals. a-b: AP and oblique X-ray after a crushing trauma; c-d: X-rays at 2-month FU after a conservative treatment with a good consolidation at the fracture site

immediately following the fracture.[1,9,62] In our clinical practice we usually perform a functional taping for 6 weeks (with a renewal of the taping after 3 weeks) wearing a talus shoe and weightbearing as tolerated (Figure 1).

Rammelt et al. described several non-operative treatments that include: taping plus a rigid sole with non-weightbearing of the metatarsal heads, a short leg walking cast, and a non-weightbearing cast for 3 weeks followed by walking cast for another 3 weeks.[45] Moreover, Sammarco and Conti proposed a non-weightbearing cast for 2 to 3 weeks followed by a walking cast for other 3 weeks.[63]

Zenios et al. conducted a prospective randomized study on 50 patients with acute metatarsal fractures treated with cast (n = 25) or taping (n = 25). The authors showed no substantial long-term (3 months) differences in pain score, mid-foot circumference, analgesic requirements, independent mobility and radiological union. However, patients treated with taping showed a significantly better AOFAS (American Orthopaedic Foot and Ankle Society) mid-foot scores ($p < 0.05$).[64]

The conservative treatment requires regular follow-up with serial x-rays (1st, 4th and 6th weeks) to prevent subsequent displacement of the fragments and follow the evolution of the fracture over time.

Surgical treatment

According to the literature, the reduction of any fracture with displacement of more than 3-4 mm and angulation of more than 10° is reccomended.[58] A close reduction or a mini-invasive reduction through a small incision is the preferred method. Indeed, open reduction may be associated with high risk of devascularization and wound complications. However, the classic open reduction followed by internal fixation is indicated when closed reduction and correct alignment cannot be maintained.

Surgery is required for the treatment of the acute, displaced, unstable, or multiple central metatarsal fractures. Intramedullary fixation with K-wires is considered today the gold standard treatment.[45]

There are different techniques to perform the pinning such as retrograde, antegrade and antegrade/retrograde.

Usually, retrograde intramedullary fixation with K-wire represents the most common approach to treat simple central metatarsal fractures. In this technique, K-wire should be inserted through the metatarsal head or the base of the respective proximal phalanx.[2, 45, 60] (Figure 2).

Instead of retrograde stabilization with K wire it is possible to stabilize the neck fracture with reabsorbable pin that has the advantage not to block the MTF joint requiring no hardware removal (Figure 3).

Baumfeld et al. demonstrated that percutaneous antegrade surgical treatment is a valid alternative to retrograde technique, with a lower incidence of complications such as risk of infection or chondral damage in the MTFJ caused by plantar position and crossing of the wire through the proximal phalanx base.[65] Also Kim et al. showed good results using closed antegrade intramedullary pinning for the reduction and fixation of metatarsal neck fractures. Full weightbearing is allowed 6 weeks after surgery, and the K-wire is usually removed between 6 to 8 weeks. [66-67]

Zarei et al. proposed an antegrade/retrograde technique. The K-wire is introduced in an antegrade configuration, proximal to the fracture, into the medullary canal, then the K-wire is drilled through the metatarsal head while its' edge exited from the plantar skin of the foot. Finally, the K-wire is introduced in a retrograde configuration to the proximal segment.[68]

Other surgical approaches for the treatment of neck and head fractures have been proposed. Regarding metatarsal neck fractures, Donahue et al. described a technique whereby the pin is introduced transversely from the fifth metatarsal as a lateral buttress for the other metatarsal neck.[69]

Verzin et al. proposed a modification of the Kapandji technique where the K-wire is introduced from distal and lateral to proximal and medial to carry out a buttress for the metatarsal head.[70] In case of multiple metatarsal fractures which require an open approach, Ozer et al. proposed transverse incision to reduce the risk of devascularization due to longitudinal incisions at each metatarsal.[71]

Spiral fractures should be treated by inter-fragmentary screws, which placement may result difficult

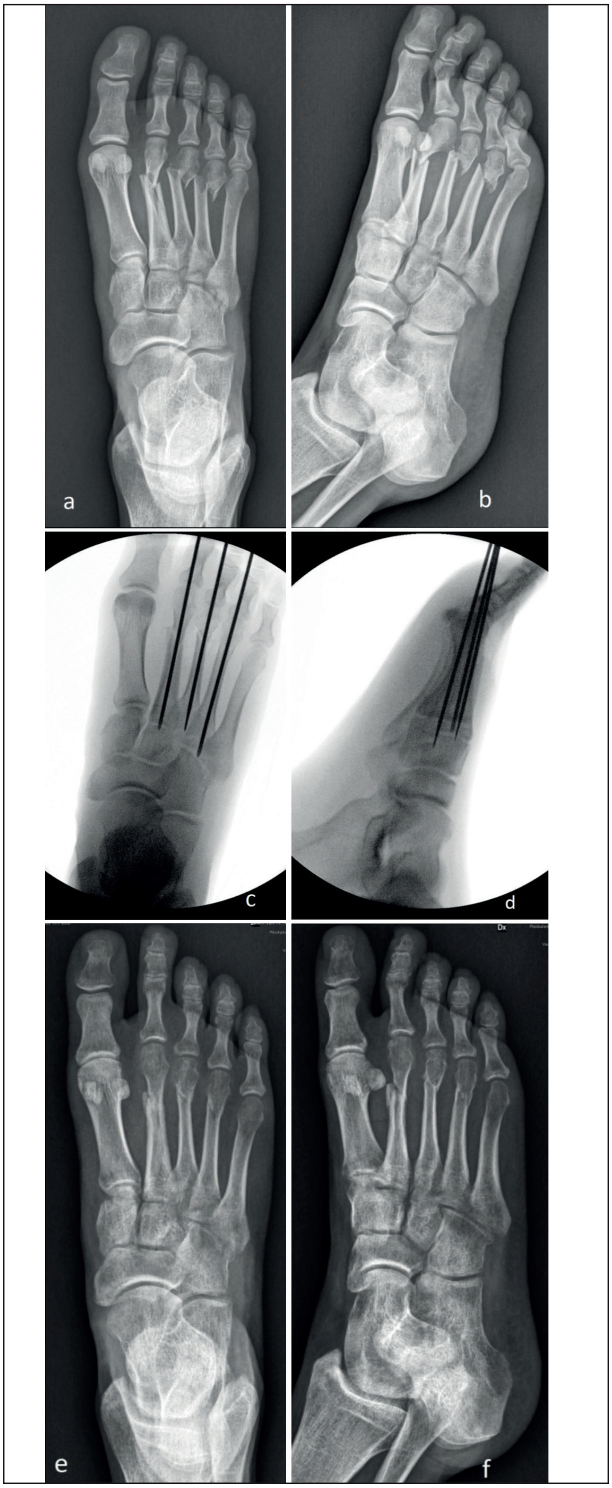

Figure 2. Clinical case of a 22 years old male affected by CMFs following a car accident. a-b: AP and oblique X-ray of multiple neck fractures of the right central metatarsals; c-d. intraoperative x-ray after reduction and fixation with K-wires; e-f. X-ray 2 months after surgery.

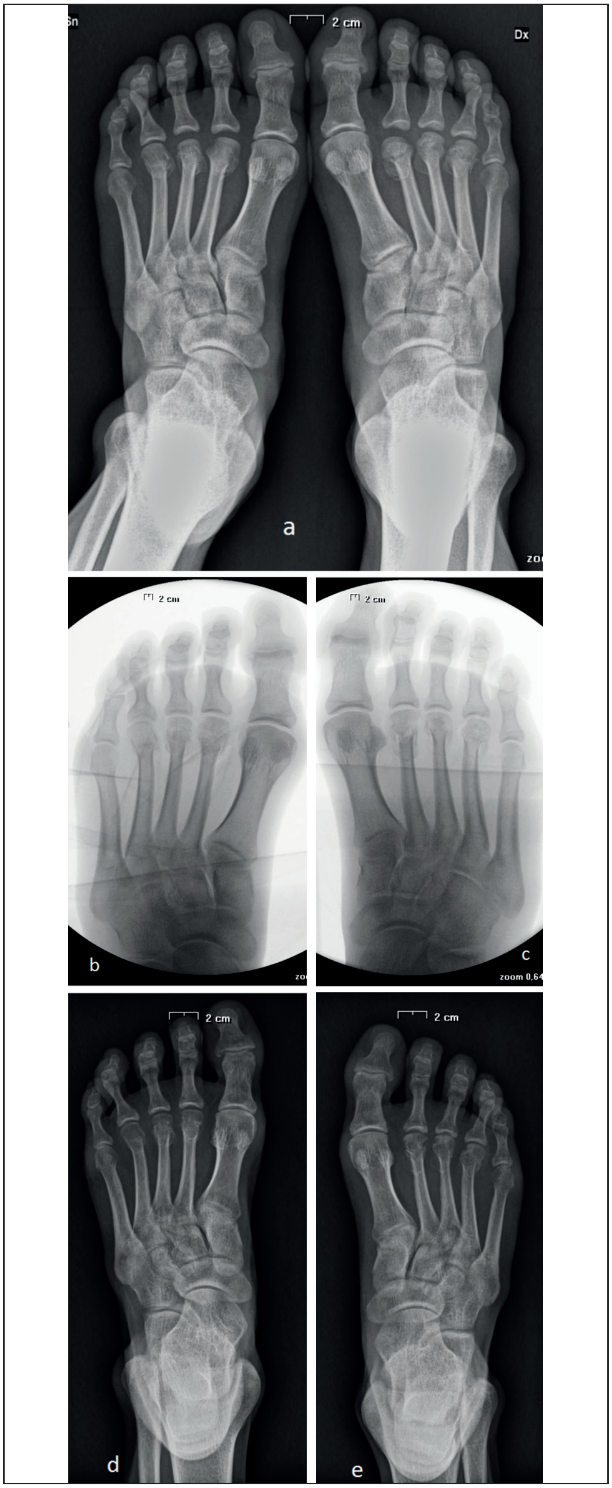

Figure 3. Clinical case of a 27 years old male affected by bilateral CMFs following a car accident. a-b: AP and oblique X-ray of multiple neck fractures of the central metatarsals bilateral; c-d. intraoperative x-ray after reduction and fixation with reabsorbable pin of the II, III and IV metatarsals bilaterally; e-f. X-ray 3 months after surgery.

due to the adjacent metatarsals. Therefore, an alternative approach could be an osteosynthesis with a dorsal plate. In comminuted metatarsal shaft fractures, as a result of high energy trauma, a bridge plate may be used to stabilize the fracture and avoid interfering with healing biology. Alternatively, external fixation is useful for stabilizing these fractures and this construct should be parallel to the metatarsal axis in order to prevent sagittal plane alignment and metatarsal malunion or non-union.[3]

Open fractures of the central metatarsals require a management according with Gustilo and Anderson protocols. These should be treated with wound irrigation and debridement, antibiotics, and skeletal stabilization with internal constructs or external fixation depending on soft tissue conditions.[3, 72]

Outcomes

In the literature there is a lack of studies in which functional and radiographic results of CMFs treatment are reported. Sánchez Alepuz et al. report the evolution and final results of 57 patients with CMF treated conservatively (36 cases) and operatively in 21 cases. Fractures were classified according to their-anatomic localization and whether they were closed (44 cases) or open (13 cases).[13] The functional results obtained according to the clinical criteria (pain when walking, pain intensity, type of shoes habitually used, post-fracture plantar hyperkeratosis, and deformities of the first toe) were: 39% poor results, 30% fair, and 32% good results (32%). Using the same criteria, of the open fractures: 64% poor results, 17% fair, and 17% good results.

Metatarsalgia was the most important long-term symptom in 56.8% of the patients. Pain was related to alterations of the residual metatarsal shaft displacement, Morton's neuroma (2 patients), metatarsophalangeal arthrosis (4 patients), and osteomyelitis (1 patient).[13]

The most frequent complication after non-operative treatment of CMF includes metatarsalgia secondary to mal-union or residual deformity and metatarsal parabola disruption. A delayed union may be observed, conversely non-union is uncommon thanks to the vascularization that promotes the healing and usually it occurs as a result of a long-standing stress fracture and not in case of acute injuries.[2]

When healing of a stress fracture is prolonged over time, surgery should be considered. Sarimo et al. have applied successfully the drilling technique to treat delayed union stress fracture on the base of second and third metatarsals to stimulate healing.[73]

A plantarly displaced fracture on the sagittal plane is correlated with a worse outcome causing painful callosities, mechanical metatarsalgia, and neuroma formation for the altered weight distribution on the metatarsal heads. Furthermore, the dorsal angulated fractures can cause dorsal soft tissue irritation. Conversely, a transverse plane mal-alignment is better tolerated but can cause irritation during gait and can cause post-traumatic valgus or varus deformities resulting in early degenerative osteoarthritis.[45, 60]

Healing could be affected by patient's initial condition and Cakir et al. showed that diabetes mellitus, overweight and female gender can impact negatively outcomes;[1] however, healing is often not necessarily caused by open or acute trauma. Murphy et al. showed that delayed union as a result of CMF is usually associated to non-traumatic factor (smoking, poor nutrition, systemic illnesses, and immune compromise).[74]

Conclusions

CMF are common injuries. The understanding of the injury mechanism and clinical evaluation matched with the standard three views foot X-rays remains fundamental in CMF diagnosis. MRI and CT scan are used respectively in stress fracture and patients with multiple, articular fractures. The conservative treatment by taping, cast or brace first without weightbearing for 3 weeks and then weightbearing for another 3 weeks is indicated in undisplaced fractures but requires regular follow-up with serial x-rays to prevent subsequent displacement of the fragments and follow the evolution of the fracture over time. Today, surgery represent the gold standard treatment for displaced, articular and multiple fractures with good outcomes. First attempt should be a closed reduction and pinning and if fails a mini-open reduction and pinning is indicated. The clinical and functional outcomes are often influenced by the pattern of fractures and patient conditions.

Treating, operatively or non-operatively the central metatarsal fracture we should always keep in mind complications at follow-up as metatarsalgia secondary to mal-union or residual deformity and metatarsal parabola disruption.

Conflict of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

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Received: 10 April 2020
Accepted: 10 May 2020
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