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Fifth metatarsal fractures: an update on management, complications, and outcomes

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- Even though fifth metatarsal fractures represent one of the most common injuries of the lower limb, there is no consensus regarding their classification and treatment, while the term 'Jones' fracture has been used inconsistently in the literature.
- In the vast majority of patients, Zone 1 fractures are treated non-operatively with good outcomes.
- Treatment of Zone 2 and 3 fractures remains controversial and should be individualized according to the patient's needs and the 'personality' of the fracture.
- If treated operatively, anatomic reduction and intramedullary fixation with a single screw, with or without biologic augmentation, remains the 'gold standard' of management; recent reports however report good outcomes with open reduction and internal fixation with specifically designed plating systems.
- Common surgical complications include hardware failure or irritation of the soft tissues, refracture, non-union, sural nerve injury, and chronic pain.
- Patients should be informed of the different treatment options and be part of the decision process, especially where time for recovery and returning to previous activities is of essence, such as in the case of high-performance, elite athletes.

Keywords
- fifth metatarsal
- fracture
- treatment
- review

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Introduction

Metatarsal fractures represent the most common injury of the foot, accounting for approximately 5–6% of all the fractures encountered in the primary care setting, with about 45–70% of these injuries involving the fifth metatarsal (1). Their incidence has been reported as high as 1.8 per 1000 person-years, with patients most frequently presenting between 20 and 50 years of age (2). Noteworthy, the majority of young patients are males, whereas older patients are females (3). In elite athletes (4), a 5-year review from a single National Football League (NFL) team demonstrated an incidence of 3.42% (5). Besides football, other sports with an increased risk of suffering these fractures include soccer, basketball, and track and field athletes (4, 6). Sir Robert Jones was the first who described the metaphyseal–diaphyseal (within 0.75 inches from the base) fifth metatarsal fracture in four patients in Liverpool in 1902, with himself sustaining the same injury while dancing (7). Nowadays, the term 'Jones fracture' defines just one type of the fifth metatarsal fracture, that is a 'Zone 2' injury, and there are several misconceptions and controversies regarding the terminology and treatment of these injuries. The purpose of the herein study is to provide an update in regard to the evaluation, management, and outcomes of these important and frequent injuries.

Relevant anatomy

Several specific anatomical considerations are crucial in assessing the healing potential and therefore the management of these injuries. Four structures attach on the fifth metatarsal base, dorsally; peroneus brevis attaches at the tubercle, peroneus tertius at the metaphyseal–diaphyseal junction, and abductor digiti minimi and the lateral band of the plantar fascia on the plantar-lateral aspect (8) (Fig. 1). In addition, the proximal part of the fifth metatarsal is relatively fixed by strong ligaments attaching to the cuboid and other metatarsals, whereas its shaft remains mobile. It is

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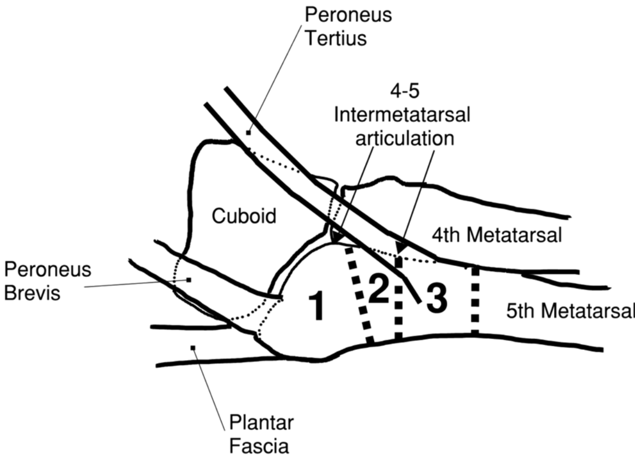

Figure 1
Schematic drawing showing the pertinent anatomy of the fifth metatarsal including Zones 1, 2, and 3. Zone 1 involves the tuberosity, Zone 2 the 4–5 intermetatarsal articulation (arrows), and Zone 3 is within 1.5 cm of the proximal metaphysis. (Obtained with permission from George D. Chloros, MD.)

these features that account for the increased propensity of delayed union/non-union in the metaphyseal–diaphyseal junction, and additionally, the stresses exerted at the mobile metatarsal head, which are directed to the base, using the metaphyseal–diaphyseal junction as a fulcrum (8). Additionally, two sesamoid bones, the *os peroneum* (inside the peroneus longus tendon) and *os vesalianum* (just proximal to the fifth metatarsal base), should be differentiated from fractures, having a smooth contour (9). Most importantly, there is a watershed area at the metaphysis–diaphysis junction between the proximal metaphyseal blood supply and the diaphyseal part of the bone supplied by the nutrient artery which is greatly responsible for the highest risk of delayed union/non-union of these fractures (10, 11) (Fig. 2). Finally, the sural nerve is very close to the entry point for intramedullary screw fixation and should be identified and protected during reconstructive procedures (12).

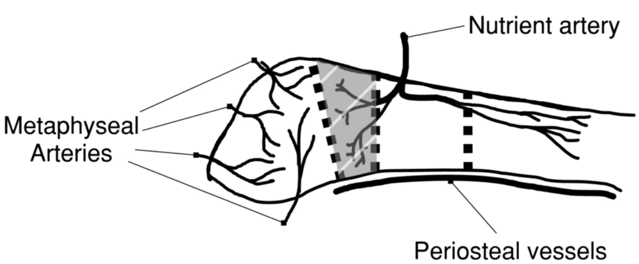

Figure 2
Vascular supply of the fifth metatarsal showing the watershed area in Zone 2 (gray). (Obtained with permission from George D. Chloros, MD.)

Biomechanics and predisposing factors

Kavanagh *et al.* in a force platform analysis demonstrated that a vertical or medial lateral force is often required for a fracture to occur (13). Inversion injuries are responsible for tuberosity avulsion fractures (14), where peroneus brevis is already contracted during stance phase and has the potential of pulling the tuberosity fragment when the plantarly flexed foot is subjected to an inversion stress; the firm attachment of the lateral band of plantar aponeurosis, on the other hand, is implicated for fractures distally to the tuberosity (15, 16, 17, 18). Furthermore, Gu used a three-dimensional model to study stress loads on the metatarsals during landing, reporting that one of the peak stress points was in the proximal fifth metatarsal. When he changed the angle of landing, he noticed that the lateral metatarsal stress surged during inversion (19). A weak toe-grip strength may also predispose a fifth metatarsal fracture by decreasing the dynamic balance ability which may lead to overloading of the lateral side of the foot (20). Athletes who encounter a Jones fracture apply increased forces at the base of the fifth metatarsal during common sports activities (21).

There are many predisposing biomechanical factors which can shift weight to the lateral foot and cause a Zone 2 or Zone 3 fifth metatarsal fracture. In a cadaveric study, Aronow *et al.* demonstrated that isolated gastrocnemius or triceps surae contractures transmit weight-bearing forces from the hindfoot to the midfoot and forefoot (22). Congenital bone malstructure such as plantar malunion of fifth metatarsal or dorsal malunion of any of the first four metatarsals can also provoke relative plantarflexion of fifth metatarsal's head and cause a shear force carried by the fifth metatarsal. Obese patients are more prone to Zone 3 fractures due to secondary biomechanical and metabolic consequences of excessive adipose tissue (23). A recent radiographic analysis of 51 NFL players showed that a long, straight, narrow fifth metatarsal possesses a greater risk for Jones fracture (24). Tibia vara, varus hindfoot (25), forefoot adduction (26), genu varum heel (14), and metatarsus adductus (27) have also been associated with increased load to the lateral column.

Classification

Over the years, numerous classification schemes have been created, the first one reported by Stewart in 1960 based on the fracture location and morphology (28). Type I is an extra-articular fracture between the metatarsal base and the diaphysis, type II an intra-articular fracture of the metatarsal base, type III an avulsion fracture of the base, type IV a comminuted fracture with intra-articular extension, and type V a partial avulsion of the metatarsal bone with or without a fracture. Fifteen years later, Dameron *et al.* observed differences in healing between fractures of fifth metatarsal tuberosity and fractures distal to the insertion of the peroneus brevis (29). Based on these findings, Lawrence and Botte later divided proximal fractures into three anatomic zones (14, 29, 30) (Fig. 1):

Zone 1: Tuberosity avulsion fractures with or without involvement of the tarsometatarsal articulation ('pseudojones' or 'tennis' fractures) – most common, accounting for more than 90% of the fifth metatarsal fractures (31). They usually occur as inversion injuries, secondary to the pull of the lateral band of plantar fascia and peroneus brevis tendon.

Zone 2: Fractures of the metaphyseal–/diaphyseal junction, which extend into the fourth–fifth intermetatarsal facet, distal to the articulation between cuboid and fifth metatarsal base ('Jones' fractures). They occur after indirect adduction force to the fifth metatarsal, distal to the tuberosity and along with ankle plantarflexion. This foot twisting creates a pulling force on the lateral band of the plantar fascia, with tension and strain on peroneus brevis tendon.

Zone 3: Proximal diaphyseal stress fractures, typically located distal to the Lisfranc joint and distal to the fourth–fifth intermetatarsal facet, that is in the proximal 1.5 cm of the metatarsal shaft. They occur from chronic repetitive stress in sports like running, soccer, and basketball or from certain biomechanical abnormalities such as the case of a cavovarus foot, varus tibia, and recent augmentation of weight-bearing activity. Microfractures of the lateral cortex are initiated by tensile forces; subsequently, the fracture propagates medially. Possible explanations for this process have been described, such as that muscle creates a localized force which prevails stress-bearing capacity of bone (32).

Fractures occurring at the regions distal to Zone 3 are termed as 'Dancer's fractures'. They are typically spiral fractures occurring from rotational forces to the axially loaded, plantarflexed foot. In addition, fractures of fifth metatarsal's head can be intra-articular or extra-articular. The injury comes after a direct force to the plantar, dorsal, or lateral foot, and the result is usually an extra-articular fracture which involves also the neck.

For delayed patient presentations, the classification which is most widely used nowadays was developed by Torg, who subdivided Dameron's Zones 2 and 3 (former Jones' and proximal diaphysis fracture) into three categories, according to radiological appearances and healing status (33, 34, 35). These three types need adjusted management strategies and help the physician to determine the age of the fracture at presentation:

Type I (acute): Fractures characterized by a narrow fracture line, no intramedullary sclerosis, minimal cortical hypertrophy, or periosteal reaction with no history of previous fracture (previous discomfort or even pain may be present).

Type II (delayed union): Increased fracture line width, involving both cortices, associated periosteal bone and intramedullary sclerosis, with a history of previous injury or fracture.

Type III (non-union): Eradication of the medullary canal by sclerotic bone, evidence of periosteal reaction and radiolucency, typically associated with a history of repetitive trauma and recurrent symptoms.

Clinical presentation

The patient's history and physical examination is extremely important to differentiate between an acute vs a stress fracture. Patients with acute fifth metatarsal fractures present with pain, localized swelling and tenderness, difficulty in walking or weight-bearing, and in some cases, ecchymosis. On the contrary, patients presenting with stress reactions or fractures complain about pain only during activity in the prodromal phase, with these symptoms commonly being present for several weeks (29, 36). Generally, patients are able to localize the pain to the area of the fracture, while foot inversion from 30 to 50° results in maximal strain and increased symptoms. Note that there is very limited mobility at the fracture site and therefore absence of crepitus or palpable gap.

Predisposing factors for stress fractures such as previous history of a stress fracture, recent intense (or change in) activity, osteopenia, and endocrinopathies (diabetes mellitus, hyperparathyroidism, nutrient deficiencies, amenorrhea, etc.) should be identified. Serum calcium, vitamin D, nutritional deficiencies, and history of menstrual cycle irregularity in females should be evaluated, as these can unveil metabolic bone pathologies. Finally, a comprehensive foot and ankle examination is of paramount importance, with the entire lower limb being evaluated for the presence of axial deformity, such as pes cavus or genu varum.

Investigations

For reducing radiation exposure, the Ottawa Foot Rules have been introduced, as an extension of the Ottawa Ankle Rules and indicate that the clinical assessment of every subtle ankle injury should encompass palpation of both malleoli, navicular bone, and base of the fifth metatarsal (37). A foot injury requires radiographic evaluation if the patient has pain in the midfoot and if any of the following is present, bony tenderness at the base of the fifth metatarsal, bony tenderness at the navicular, and inability to bear weight taking four steps both immediately and in the emergency room. The reported sensitivity and specificity of these rules are 100 and 70%, respectively (38).

Three standard, weight-bearing views are necessary, anteroposterior (AP), lateral, and 30- or 45-degree oblique view, with the latter being the most helpful for the anatomic classification. If the patient cannot tolerate pain with weight-bearing, mild supination can be added to the lateral view in order to minimize osseous overlap. Yet, as much as 77% of avulsion fractures (particularly those at the tip of the tuberosity) may be missed on standard foot radiographs (39), and a supplementary AP view of the ankle including the base of the proximal fifth metatarsal should be obtained (40).

It must be stressed that radiographic features of stress fractures are usually absent in the early stages. Well-differentiated linear lucencies usually appear 2–6 weeks after the original insult, with variable degree of periosteal reaction (41). MRI and technetium bone scan may guide the physician in equivocal cases in the early stages (42, 43). CT may be used to evaluate delayed union/non-union, confirm healing, or refracture. Dual energy X-ray absorptiometry (44) may be useful in cases of multiple refractures or recurring non-unions. Finally, a metabolic workup may be warranted, including screening of vitamin D levels (45, 46).

Management

Conservative or surgical treatment is decided based on the fracture type, associated injuries, and individual patient characteristics. There is a plethora of non-operative treatment modalities, including elastic bandage support, non-weight-bearing casting, a hard-soled shoe, short-leg walking casts, and a cam walker boot (47, 48, 49, 50, 51, 52). Various surgical techniques exist, with intramedullary screw fixation (6, 13, 36, 53, 54, 55, 56, 57, 58, 59) with or without bone grafting, tension band constructs (60), and low-profile plates (61, 62, 63, 64, 65, 66, 67).

In general, surgery is contraindicated in neuropathic feet, presence of vascular insufficiency, and local infection (68). However, diabetic patients with intact sensation and vascular supply are eligible for surgical management (69). When there is a secondary predisposing factor such as a limb axial deformity, for example pes cavovarus, this should also be addressed otherwise it will eventually lead to therapeutic failure (70).

Zone 1 – Non-displaced and displaced tuberosity avulsion fractures

Dameron (71) was the first to report clinical healing as high as 97% of tuberosity fractures, within weeks from injury; other teams have also reported equivalent results (30, 35, 72). There is a general agreement that all non-displaced or minimally displaced tuberosity avulsion fractures should be treated conservatively; a systematic review and meta-analysis demonstrated no significant difference in union and refracture rates between different conservative methods (73). Elastic wrapping and weight-bearing as tolerated for a period of 3 weeks is adequate (74) and a hard-sole shoe, short-leg cast, or cam walker boot can also be other options (51, 52, 75).

Historically, surgery was recommended for a displacement greater than 2 mm, or comminution in Zone 1 fractures and various operative interventions have been described (76, 77, 78, 79, 80, 81). A prospective study showed no benefit of immobilization vs symptomatic treatment for avulsion fractures of the base of the fifth metatarsal (48), while a recent systematic review opted for non-operative treatment, regardless of technique (82). Involvement of more than one-third of the cubometatarsal joint may require open reduction and screw fixation using tension band wiring or a small fragment screw (2.0–2.7 mm) (40, 83, 84); however, the latter is found to be superior (83). A distal ulna hook plate was used with good results for displaced tuberosity avulsion fractures (85). A recent study showed that clinical and radiologic outcomes of operative vs non-operative management of Zone 1 fractures are equivalent (78). In cases of delayed symptomatic presentation, excision of the involved proximal fragment is indicated (86). In our practice, it is very rare that we operatively treat Zone 1 fractures, either displaced or undisplaced. Even if the fracture does not ‘heal’ radiographically, a pain-free fibrous union may develop, hence making an operation unnecessary (Fig. 3). Poor outcomes are rare and may be attributed to either a painful fibrous union, joint incongruity, or entrapment of the sural nerve branch inside the callus (86).

Zone 2 – ‘Jones’ fractures

Optimal management of these fractures is controversial and treatment is individualized to patient’s needs and expectations. One of the problems is that the term ‘Jones fracture’ has been inconsistently used to include both Zone 2 and Zone 3 fractures (49, 87). In general, the ‘true Jones’ fractures should be treated with non-weight-bearing, as weight-bearing has been implicated in increased incidence of non-union (54), although there has also been a trend toward ‘functional treatment’ consisting of full weight-bearing accompanied by full range of motion (49, 50). Several authors have reported successful conservative treatment (50, 88, 89). However, because of the watershed area of the region, non-union rates of Zones 2 and 3 have been reported to be up to 21% after non-operative management (84, 90, 91, 92). Healing starts from a medial to lateral direction and callus is seen

Figure 3
Conservatively managed Zone 1 injury. (A) Injury anteroposterior, oblique, and lateral radiographs showing a Zone 1 injury. (B) At 6 weeks, the patient went into a fibrous painless union. (Obtained with permission from George D. Chloros, MD.)

Figure 4
(A) Pre-operative anteroposterior and oblique radiographs showing a Zone 3 injury. (B) Intra-operative fluoroscopic images showing placement of an intramedullary screw. (C) Post-operative anteroposterior and oblique radiographs at 3 months showing complete healing. (Obtained with permission from George D. Chloros, MD)

by 6–8 weeks. Where there is absence of callus within this period, a trial of pulsed electromagnetic field therapy may be used with a reported healing union time of 3 months, range 2–4 months (93). Portland recorded a 100% success in union after prompt screw fixation in 22 patients (94), while a randomized trial reported 44% of failure after cast treatment of acute Jones fracture vs operative treatment (95). Porter after utilizing a 4.5-mm (96) cannulated screw fixation in athletes showed a 100% union rate and no refractures, with a 7.5 week mean time for return to sports (97). Low *et al.* studied 86 athletes of NFL, showing a union rate of 94 vs 80% for operative and non-operative treatments, respectively (98). Several systematic reviews conclude that surgery results in shorter union times and lower number of delayed union or non-unions (80, 99, 100, 101).

Intramedullary screw fixation with or without grafting is being widely performed (6, 13, 36, 53, 54, 55, 56, 57, 58, 59) (Fig. 4). To avoid complications such as hardware failure (Fig. 5) and refracture (102), several studies have been conducted to assess the properties a screw should have to achieve reduction and compression at the fracture site. The diameter of the screw should be no less than 4.5 mm in order to obtain adequate compression across the fracture line, and the largest screw possible which will achieve maximal contact interface with the dense cortical bone should always be used (97, 103, 104, 105,

Figure 5
(A) Post-operative view of a relatively small, thin intramedullary screw. (B) A 2-month post-operative radiograph demonstrates hardware failure. (Obtained with permission from George D. Chloros, MD)

106). Radiographic studies confirmed that excessive screw length should be avoided by keeping screw length less than 68% of length of fifth metatarsal (104). Interestingly, there was no correlation between age, straight segment length, and canal diameter. There were differences noted (not statistically significant) between male and female coronal canal diameter (5.2–4.8 mm) and at the curvature of the fifth metatarsal (104). The surgeon should take this into consideration with their K-wire insertion.

Regarding the surgical technique for fresh fractures, the patient is placed supine on a radiolucent table with a bolster under the ipsilateral hip and a tourniquet is applied. The alignment of the fifth metatarsal is drawn with a marking pen and a 1 cm incision is made at the proximal aspect about 2–3 cm proximal to the base and parallel to the fifth metatarsal canal. Any small sural nerve branches are identified and retracted, and the interval between the peroneus brevis and the lateral band of the plantar fascia is identified and bluntly dissected down to the fifth metatarsal base. The entry point is crucial and is classically described as being 'high and inside', that is on the dorsal and medial aspect just medial and superior to the edge of the tuberosity. A guidewire is inserted and advanced into the canal past the fracture and thereafter the cannulated drill was passed over the guidewire to be on the fracture site several times in an attempt to break up the intramedullary sclerosis if present. Depending on the pre-operatively templated size, a smaller, for example a 5.5-mm, cannulated tap is initially used over the guidewire and based upon its clearance on fluoroscopy the appropriate size cannulated tap for example a 6.5 mm is finally used. The tap is removed, and finally an appropriate length solid screw is advanced into the canal to achieve excellent fracture compression, prevent bowing and plantar/lateral gapping. Cannulated screws are not preferred because of their lesser strength (107) and association with refractures and non-unions (108).

In cases of surgery on delayed/non-unions (Torg II and III types), the incision is from 0.5 cm proximal tuberosity to just distal to the fracture site, usually about 3 cm in total length. At the distal aspect of the incision the fracture site is exposed, cleared of all tissue, and the sclerosis taken down with a high-speed bur and 2.0 mm guidewires are used to make multiple drill holes in its proximal and distal aspect. The cannulated drill is passed several times at the fracture site in an attempt to break up the intramedullary sclerosis. Bone marrow aspirate concentrate, as well as autograft, is packed to the non-union site, and subsequently, a solid screw is passed as previously described. Final fluoroscopic images are obtained in multiple planes. Possible complications include refracture (102), sural nerve injury (12), malunion, delayed union/non-union, prominence of the screwhead, or chronic low level pain (109). Proper surgical technique and appropriate post-operative protocols are the keys to minimizing those complications. In athletes, relatively high refracture rates have been reported, up to 30% (6), and therefore alternative approaches may be adopted such as plate fixation (61, 62, 63, 64, 65, 66, 67). A cadaveric study from Duplantier showed promising results of plantar-lateral plate fixation, as plates could resist more the tension forces from fifth metatarsal and tolerate greater peak load to failure than intramedullary screws (110). In a recent study of plantar plate fixation in 38 athletes, there was a 10.5% rate of refracture and symptomatic hardware (111), however previous studies had shown no problems as far as union or refractures (63, 64, 67). This technique may be preferred in cases of a laterally bowed fifth metatarsal or comminuted fractures (112), however further clinical research is needed to better define its role.

In our practice, the treatment is individualized according to the patient's needs and expectations through an informed consent process. If non-operative treatment is decided, the patient is placed in a short-leg cast, non-weight-bearing for 6 weeks and thereafter they are transitioned to a cam walker boot with weight-bearing as pain allows. As soon as the patient is asymptomatic, physical therapy is initiated with gradual return to activity within 12 weeks is the typical scenario. In cases of stress fractures/reactions, non-weight-bearing is typically prolonged for 12 weeks, and the patient is followed-up closely both clinically and radiographically to determine whether the reaction has subsided, that is diminished sclerosis and re-establishment of the medullary cavity. In case the patient is an operative candidate, an intramedullary screw fixation is our usual standard of care as described above. Post-operatively, the patient is placed in a non-weight-bearing splint after 1 week and transitioned to a non-weight-bearing cast for another 3 weeks, and then progressively transitioned to partial weight-bearing in a removable boot with crutches for another 2 weeks as pain allows. At this point, the patient is allowed to do some level of activity, for example stationary bicycle or swimming. At 6 weeks, the healing is evaluated clinically and radiographically and if the fracture has healed then full weight-bearing is allowed with a gradual return to full activity. If the fracture has not healed, then a bone stimulator is recommended, and the patient will revert back to non-weight-bearing and the healing closely followed clinically and radiographically. In cases of delayed union or non-union, the patient routinely undergoes metabolic workup to correct any deficiencies and is subsequently treated operatively with a primary or revision intramedullary screw and bone grafting ± bone marrow aspirate concentrate as described above. For the competitive athlete, CT confirmation of union is warranted prior to return to full play.

Zone 3 – Proximal diaphyseal stress fractures

These fractures usually present late, as 'stress fractures'. If they are acute, a trial of non-weight-bearing cast vs operative treatment (87, 113) is discussed with the patient. However, the latter may be favored in a high-demand individual such as an elite athlete (87, 113). The treatment is similar to Zone 2 injuries (114) as described above.

Dancer's fracture – Diaphyseal spiral fracture

In general, non-operative treatment is preferred for these fractures and is quite effective leaving no sequela even in competitive athletes (115, 116). In a recent study, 33 patients were treated with a boot or a hard-sole shoe with a minimum of 10 months follow-up and showed excellent outcomes regardless of the degree of displacement, shortening, or rotation. There were 9% delayed unions, however, all patients ultimately united with an average time to union of 8.3 weeks. The hard-sole shoe showed superior outcomes compared to the boot. Of note, despite classically being associated with high-performance athletes, hence the name 'Dancer's fracture', a recent study showed increased incidence in females over the age of 40 and when low energy trauma is involved in that group they should be considered as early fragility fractures and warrant metabolic workup (3).

Complications

Although surgical outcomes are widely successful (6, 13, 36, 53, 54, 55, 56, 57, 58, 59, 80, 94, 97, 99, 100, 101, 106), possible complications include hardware failure (Fig. 5) and refracture (102), sural nerve injury (12), malunion, delayed union/non-union, prominence of the screwhead, chronic low level pain (109), and iatrogenic fractures (12, 36). Table 1 summarizes the causes of non-union following fifth Metatarsal fractures.

Refractures or non-unions may occur up to 12% of the intramedullary screw fixation cases (59, 100). However, the rate of refracture in elite athletes may be as high as 30% for intramedullary screw fixation (6) vs 10.5% for plate fixation (111), in recent studies. Table 2 summarizes the literature assessing the incidence of non-union and subsequent treatment strategy. Possible causes of failure may be technically related, for example inappropriate screw size/biology, failure to simultaneously address causative factors such as pes cavus, as well as secondary to inadequate post-operative protocols. In the past, symptomatic hardware has been reported in up to 30% of intramedullary screw fixation patients with a traditional screw, which is now rare with the use of fracture-specific screws (106) and the authors use them routinely (Fig. 4B). Headless screws are not recommended because of difficulty in removal (108). Plate removal has been reported in up to 31% of cases (111). It is important to note that removal of hardware may create stress risers and extreme caution is warranted especially in the case of athletes in which case it is recommended to occur only after retirement and in the meantime managed by shoe modification (117).

Conclusion

Fractures of the fifth metatarsal remain a challenging problem to treat, especially in competitive athletes. In recent years, these injuries have been more clearly reported as the 'true' Jones fractures have been better differentiated from the rest as far as treatment and outcomes are concerned.

The intra-osseous blood supply to the fifth metatarsals' greater tuberosity and proximal diaphysis differs. Fractures of the greater tuberosity both at a proximal and distal level have the propensity to heal given the numerous randomly distributed metaphyseal arteries. In contrast, fractures at the proximal metaphysis disrupt the nutrient artery, and hence create the so-called 'avascular region' (10). Considerations of fracture location and potential vascular compromise should therefore always be taken into account and considered in the treatment strategy.

The classification systems have evolved since the first described 'Jones' fractures in 1902 but despite this their remains a discrepancy in what is defined as a Jones fracture with some authors defining it as a fracture at the metaphyseal–diaphyseal junction and others at the proximal diaphysis. Therefore, we propose using a combination of Lawrence and Botte's classification (14) in conjunction with Torg's classification (35) to avoid any discrepancies when describing these fractures.

Table 1 **Non-union causes fifth metatarsal fractures** (74, 120, 121, 122, 123, 124).

Patient specific	Injury specific	Surgeon-specific factors	Medications
Smoking status Diabetic Peripheral vascular disease Vitamin D/calcium deficiency Hormonal deficiency (e.g. hypothyroidism) Increased age	Zone 2/Zone 3 fractures Open fractures	Small diameter screws (<4.5 mm)	NSAIDs Synthetic glucocorticoids Chemotherapy agents

NSAIDs, non-steroidal anti-inflammatory drugs.

Table 2 Failed non-union treatment causes and rates.

Reference	Patients, *n*	Patients (*n*) with non-unions (M:F)	Type of study	Injury pattern sustained	Treatment modality	Type of failure	Time to failure	**Other comments** (treatment of non-union)
Rettig *et al.* (84)	8	8	RCS	Jones fracture (not further classified)	Conservative management	Non-union	Unknown	Five non-unions shelled through lateral incision of peroneus brevis; One non union fragment was large and articulated cuboid; 2 non-unions healed with screw fixation
Holmes Jr *et al.* (93)	9 (5:4)	4 (1:3)	RCS	Jones fracture acute type (narrow fracture line) as per Torg	Treated conservatively in walking cast	Non-union	Mean duration of use of PEMF was 2.8 months.	Pulsed electromagnetic fields
Glasgow *et al.* (125)	11	3 (2:1)	CS	Jones fracture (not further classified)	Local bone graft	Refracture	10 months	Local graft, persistent canal stenosis
					Corticocancellous graft	Refracture	31 months	Short bone graft persistent canal sclerosis
					4.5 mm malleolar screw	Delayed union, screw deformation	10 weeks	None
Wright *et al.* (108)	6	6 (6:0)	RCS	Jones fracture acute type narrow fracture line) as per Torg	4.5 mm cannulated screw	Refracture	7 weeks	Limited activity
					5.0 mm cannulated screw	Refracture	11 weeks	6.0 mm solid screw
					4.5 mm cannulated screw	Refracture	8 weeks	6.5 mm Herbert screw
					4.5 mm cannulated screw	Refracture	12 weeks	Limited activity
					4.0 mm cannulated screw	Refracture	5.5 weeks	Bone grafting
					4.5 mm cannulated screw	Refracture	6 weeks	Limited activity
Larson *et al.* (126)	15	6	RCS	Jones fracture acute type (narrow fracture line) as per Torg	5.0 mm cannulated screw	Refracture	14 weeks	Inlay graft
					4.0 mm cannulated screw	Refracture	18 weeks	5.0 mm screw ICBG
					4.0 mm cannulated screw	Refracture	44 weeks	ICBG
					6.5 mm cannulated screw	Refracture	16 weeks	Sliding BG
					6.5 mm cannulated screw	Non-union	48 weeks	None
					4.5 mm cannulated screw	Non-union	20 weeks	Antibiotics 5.0 mm screw & ICBG
Mologne *et al.* (95)	37 (35:2)	6	RCT	Jones fracture acute type (narrow fracture line) as per Torg	18 patients cast 19 surgical group (4.5 mm malleolar screw)	Five non-unions and two refractures	N/A	**Non-union group** Three patients underwent fixation with 4.5 mm screw. Remaining two declined operation. **Refracture** One patient underwent fixation with 4.5 mm screw. One treated conservatively with walking cast boot.
Hunt *et al.* (91)	21	21 (16:5)	RCS	Jones fracture (Zone II Dameron)	5 patients non-operative treatment 16 patients previous surgical fixation	One non-union 5 patients symptomatic non-unions 16 patients non-unions/refracture	N/A	Bone graft and repeat fixation Eight patients, iliac crest cancellous bone graft. Eight patients, bone marrow aspirate and DBM. Four patients bone graft harvested from calcaneus. One patient, DBM alone One patient, no bone graft.
Ritchie *et al.* (127)	6	6	RCS	Jones fracture (Not further Classified	Six patients Treated non-operatively	Six patients symptomatic non-unions	Mean 12.2 months	Excision of avulsed fragment.
Panteli *et al.* (128)	41	7	RCS (abstract)	Isolated fifth metatarsal fracture (Lawrence classification) 7 (Type I) 22 (Type II) 12 (Type III)	26 Cannulated screws 12 ORIF Three fragment Excision	Seven non-unions	N/A	Nine patients there was a residual gap following reduction and autologous bone graft
Granata *et al.* (102)	149	4 (4:0)	RCS	Jones fracture (not further classified)	4.5 mm cannulated stainless steel screw	Refracture, bent screw	6 months	Three were revised to a bigger size screw, while orthobiologics and external bone stimulators were also used to augment healing. Fourth patient was revised to the same screw, but also required a second revision surgery for non-union.
					5.0 mm cannulated stainless steel screw	Refracture, bent screw	7 months	
					5.0 mm cannulated stainless steel screw	Refracture, bent screw	2.5 months	
					3.5 mm solid stainless steel screw	Refracture, bent screw	15 months	
Grant *et al.* (54)	30	30 (10:20)	PCS	The fracture pattern was categorized using the Dameron classification	Zone 1 injuries- Weight bear in walking boot. Zones 2 and Three non-weight-bearing cast for 6 weeks.	30 nonon-union	Average time 5.9 months	Zone 1 injuries 1 mm guidewire 90° to fracture. 3 mm compression screw Zone 2/3 Injuries 1.6 mm guidewire Predrilled 4-mm headed screw is then placed intramedullary

CS, case series; DBM, demineralised bone matrix; RCS, retrospective case series; RCT, randomized controlled trial; PCS, prospective case series; ICBG, Iliac crest bone graft.

Conservative vs surgical treatment is decided based on the fracture type, associated injuries, and individual patient characteristics. Controversies remain regarding surgical treatment options for fifth metatarsal fractures intramedullary screw fixation with or without bone grafting, tension band constructs (60), and low-profile plates (61, 62, 63, 64, 65, 66, 67) being the most popular, especially in the general population. Nevertheless, depending on the zone of fracture, several of these may be treated non-operatively; however operative fixation (6, 13, 36) with intramedullary screw and possible biologic augmentation especially for the elite athletes with Zone 2 and 3 injuries remains the standard of care. In contrast, patients who are deemed 'high risk' for surgery with a predisposition to complications, for example vasculopaths or patients with diabetic neuropathy, should be treated non-operatively. Plantar plating may also provide an alternative option for treatment with some promising results to date (63, 64, 67). However, further high-quality studies are required to assess its efficacy and long-term complications (111).

The future for managing fifth metatarsal fractures leaves open several areas of research. First, cadaveric studies should be conducted assessing differences in medullary cavity geometry. Discrepancies affecting surgical management have been identified in other fields such as hip arthroplasty (118). Novel surgical techniques have also been proposed through fixation with an intramedullary screw combined with a high-resistance suture (Fibrewire suture no. 2 cerclage). This proof-of-concept cadaveric study provides an interesting option; however, it is awaiting biomechanical evaluation and comparison in trials to other accepted surgical options (119).

In this review, we have provided a framework of thought; however, the optimal strategy should be individualized to accommodate for both fracture and patient factors. Input from the multidisciplinary team should be sought, and the patient should be thoroughly educated and be actively involved in the decision process.

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References

1. Petrisor BA, Ekrol I & Court-Brown C. The epidemiology of metatarsal fractures. *Foot and Ankle International* 2006 **27** 172–174. (https://doi.org/10.1177/107110070602700303)

2. Hasselman CT, Vogt MT, Stone KL, Cauley JA & Conti SF. Foot and ankle fractures in elderly white women. Incidence and risk factors. *Journal of Bone and Joint Surgery: American Volume* 2003 **85** 820–824. (https://doi.org/10.2106/00004623-200305000-00008)

3. Schwagten K, Gill J & Thorisdottir V. Epidemiology of dancers fracture. *Foot and Ankle Surgery* 2021 **27** 677–680. (https://doi.org/10.1016/j.fas.2020.09.001)

4. Shuen WM, Boulton C, Batt ME & Moran C. Metatarsal fractures and sports. *Surgeon* 2009 **7** 86–88. (https://doi.org/10.1016/s1479-666x(09)80022-x)

5. Carreira DS & Sandilands SM. Radiographic factors and effect of fifth metatarsal Jones and diaphyseal stress fractures on participation in the NFL. *Foot and Ankle International* 2013 **34** 518–522. (https://doi.org/10.1177/1071100713477616)

6. O'Malley M, DeSandis B, Allen A, Levitsky M, O'Malley Q & Williams R. Operative treatment of fifth metatarsal Jones fractures (Zones II and III) in the NBA. *Foot and Ankle International* 2016 **37** 488–500. (https://doi.org/10.1177/1071100715625290)

7. Jones RI. I. Fracture of the base of the fifth metatarsal bone by indirect violence. *Annals of Surgery* 1902 **35** 697–700.2.

8. DeVries JG, Taefi E, Bussewitz BW, Hyer CF & Lee TH. The fifth metatarsal base: anatomic evaluation regarding fracture mechanism and treatment algorithms. *Journal of Foot and Ankle Surgery* 2015 **54** 94–98. (https://doi.org/10.1053/j.jfas.2014.08.019)

9. Keles-Celik N, Kose O, Sekerci R, Aytac G, Turan A & Güler F. Accessory ossicles of the foot and ankle: disorders and a review of the literature. *Cureus* 2017 **9** e1881. (https://doi.org/10.7759/cureus.1881)

10. Smith JW, Arnoczky SP & Hersh A. The intraosseous blood supply of the fifth metatarsal: implications for proximal fracture healing. *Foot and Ankle* 1992 **13** 143–152. (https://doi.org/10.1177/107110079201300306)

11. Shereff MJ, Yang QM, Kummer FJ, Frey CC & Greenidge N. Vascular anatomy of the fifth metatarsal. *Foot and Ankle* 1991 **11** 350–353. (https://doi.org/10.1177/107110079101100602)

12. Donley BG, McCollum MJ, Murphy GA & Richardson EG. Risk of sural nerve injury with intramedullary screw fixation of fifth metatarsal fractures: a cadaver study. *Foot and Ankle International* 1999 **20** 182–184. (https://doi.org/10.1177/107110079902000308)

13. Kavanaugh JH, Brower TD & Mann RV. The Jones fracture revisited. *Journal of Bone and Joint Surgery: American Volume* 1978 **60** 776–782. (https://doi.org/10.2106/00004623-197860060-00008)

14. Lawrence SJ & Botte MJ. Jones' fractures and related fractures of the proximal fifth metatarsal. *Foot and Ankle* 1993 **14** 358–365. (https://doi.org/10.1177/107110079301400610)

15. Pritsch M, Heim M, Tauber H & Horoszowski H. An unusual fracture of the base of the fifth metatarsal bone. *Journal of Trauma* 1980 **20** 530–531. (https://doi.org/10.1097/00005373-198006000-00018)

16. Richli WR & Rosenthal DI. Avulsion fracture of the fifth metatarsal: experimental study of pathomechanics. *American Journal of Roentgenology* 1984 **143** 889–891. (https://doi.org/10.2214/ajr.143.4.889)

17. Seyidova N, Hirtler L, Windhager R, Schuh R & Willegger M. Peroneus brevis tendon in proximal 5th metatarsal fractures: anatomical considerations for safe hook plate placement. *Injury* 2018 **49** 720–725. (https://doi.org/10.1016/j.injury.2018.01.008)

18. Kaneko F, Edama M, Ikezu M, Matsuzawa K, Hirabayashi R & Kageyama I. Anatomic characteristics of tissues attached to the fifth metatarsal bone. *Orthopaedic Journal of Sports Medicine* 2020 **8** 2325967120947725. (https://doi.org/10.1177/2325967120947725)

19. Gu YD, Ren XJ, Li JS, Lake MJ, Zhang QY & Zeng YJ. Computer simulation of stress distribution in the metatarsals at different inversion landing angles using the finite element method. *International Orthopaedics* 2010 **34** 669–676. (https://doi.org/10.1007/s00264-009-0856-4)

20. Fujitaka K, Taniguchi A, Isomoto S, Kumai T, Otuki S, Okubo M & Tanaka Y. Pathogenesis of fifth metatarsal fractures in college soccer players. *Orthopaedic Journal of Sports Medicine* 2015 **3** 2325967115603654. (https://doi.org/10.1177/2325967115603654)

21. Hunt KJ, Goeb Y & Bartolomei J. Dynamic loading assessment at the fifth metatarsal in elite athletes with a history of Jones fracture. *Clinical Journal of Sport Medicine* 2021 **31** e321–e326. (https://doi.org/10.1097/JSM.0000000000000830)

22. Aronow MS, Diaz-Doran V, Sullivan RJ & Adams DJ. The effect of triceps surae contracture force on plantar foot pressure distribution. *Foot and Ankle International* 2006 **27** 43–52. (https://doi.org/10.1177/107110070602700108)

23. Pugliese M, De Meo D, Sinno E, Pambianco V, Cavallo AU, Persiani P & Villani C. Can body mass index influence the fracture zone in the fifth metatarsal base? A retrospective review. *Journal of Foot and Ankle Research* 2020 **13** 9. (https://doi.org/10.1186/s13047-020-0374-6)

24. Karnovsky SC, Rosenbaum AJ, DeSandis B, Johnson C, Murphy CI, Warren RF, Taylor SA & Drakos MC. Radiographic analysis of National Football League players' fifth metatarsal morphology relationship to proximal fifth metatarsal fracture risk. *Foot and Ankle International* 2019 **40** 318–322. (https://doi.org/10.1177/1071100718809357)

25. Jones CP. Cavovarus: fifth metatarsal fractures and revision open reduction internal fixation. *Clinics in Sports Medicine* 2020 **39** 793–799. (https://doi.org/10.1016/j.csm.2020.07.006)

26. Fleischer AE, Stack R, Klein EE, Baker JR, Weil Jr L & Weil Sr LS. Forefoot adduction is a risk factor for Jones fracture. *Journal of Foot and Ankle Surgery* 2017 **56** 917–921. (https://doi.org/10.1053/j.jfas.2017.04.017)

27. Yoho RM, Carrington S, Dix B & Vardaxis V. The association of metatarsus adductus to the proximal fifth metatarsal Jones fracture. *Journal of Foot and Ankle Surgery* 2012 **51** 739–742. (https://doi.org/10.1053/j.jfas.2012.08.008)

28. Stewart IM. Jones's fracture: fracture of base of fifth metatarsal. *Clinical Orthopaedics* 1960 **16** 190–198.

29. Dameron Jr TB. Fractures and anatomical variations of the proximal portion of the fifth metatarsal. *Journal of Bone and Joint Surgery: American Volume* 1975 **57** 788–792. (https://doi.org/10.2106/00004623-197557060-00010)

30. Quill Jr GE. Fractures of the proximal fifth metatarsal. *Orthopedic Clinics of North America* 1995 **26** 353–361. (https://doi.org/10.1016/S0030-5898(20)31997-0)

31. Kane JM, Sandrowski K, Saffel H, Albanese A, Raikin SM & Pedowitz DI. The epidemiology of fifth metatarsal fracture. *Foot and Ankle Specialist* 2015 **8** 354–359. (https://doi.org/10.1177/1938640015569768)

32. Fetzer GB & Wright RW. Metatarsal shaft fractures and fractures of the proximal fifth metatarsal. *Clinics in Sports Medicine* 2006 **25** 139–150, x. (https://doi.org/10.1016/j.csm.2005.08.014)

33. Lehman RC, Torg JS, Pavlov H & DeLee JC. Fractures of the base of the fifth metatarsal distal to the tuberosity: a review. *Foot and Ankle* 1987 **7** 245–252. (https://doi.org/10.1177/107110078700700406)

34. Torg JS. Fractures of the base of the fifth metatarsal distal to the tuberosity. *Orthopedics* 1990 **13** 731–737. (https://doi.org/10.3928/0147-7447-19900701-09)

35. Torg JS, Balduini FC, Zelko RR, Pavlov H, Peff TC & Das M. Fractures of the base of the fifth metatarsal distal to the tuberosity. Classification and guidelines for non-surgical and surgical management. *Journal of Bone and Joint Surgery: American Volume* 1984 **66** 209–214. (https://doi.org/10.2106/00004623-198466020-00007)

36. DeLee JC, Evans JP & Julian J. Stress fracture of the fifth metatarsal. *American Journal of Sports Medicine* 1983 **11** 349–353. (https://doi.org/10.1177/036354658301100513)

37. Stiell I, Wells G, Laupacis A, Brison R, Verbeek R, Vandemheen K & Naylor CD. Multicentre trial to introduce the Ottawa ankle rules for use of radiography in acute ankle injuries. Multicentre Ankle Rule Study Group. *BMJ* 1995 **311** 594–597. (https://doi.org/10.1136/bmj.311.7005.594)

38. David S, Gray K, Russell JA & Starkey C. Validation of the Ottawa ankle rules for acute foot and ankle injuries. *Journal of Sport Rehabilitation* 2016 **25** 48–51. (https://doi.org/10.1123/jsr.2014-0253)

39. Pao DG, Keats TE & Dussault RG. Avulsion fracture of the base of the fifth metatarsal not seen on conventional radiography of the foot: the need for an additional projection. *American Journal of Roentgenology* 2000 **175** 549–552. (https://doi.org/10.2214/ajr.175.2.1750549)

40. Rammelt S, Heineck J & Zwipp H. Metatarsal fractures. *Injury* 2004 **35** (Supplement 2) SB77-86. (https://doi.org/10.1016/j.injury.2004.07.016)

41. Hatch RL, Alsobrook JA & Clugston JR. Diagnosis and management of metatarsal fractures. *American Family Physician* 2007 **76** 817–826.

42. Usmani S, Al-Ramadhan F, Marafi F, Rasheed R & Al Kandari F. Tc-99m HDP single photon emission computed tomography/computed tomography in stress fracture of base of metatarsal bone. *Indian Journal of Nuclear Medicine* 2019 **34** 251–253. (https://doi.org/10.4103/ijnm.IJNM_68_19)

43. Major NM. Role of MRI in prevention of metatarsal stress fractures in collegiate basketball players. *American Journal of Roentgenology* 2006 **186** 255–258. (https://doi.org/10.2214/AJR.04.1275)

44. Pritchard NS, Smoliga JM, Nguyen AD, Branscomb MC, Sinacore DR, Taylor JB & Ford KR. Reliability of analysis of the bone mineral density of the second and fifth metatarsals using dual-energy x-ray absorptiometry (DXA). *Journal of Foot and Ankle Research* 2017 **10** 52. (https://doi.org/10.1186/s13047-017-0234-1)

45. Shimasaki Y, Nagao M, Miyamori T, Aoba Y, Fukushi N, Saita Y, Ikeda H, Kim SG, Nozawa M, Kaneko K *et al.* Evaluating the risk of a fifth metatarsal stress fracture by measuring the serum 25-hydroxyvitamin D levels. *Foot and Ankle International* 2016 **37** 307–311. (https://doi.org/10.1177/1071100715617042)

46. Villacis D, Yi A, Jahn R, Kephart CJ, Charlton T, Gamradt SC, Romano R, Tibone JE & Hatch GF. Prevalence of abnormal vitamin D levels among division I NCAA athletes. *Sports Health* 2014 **6** 340–347. (https://doi.org/10.1177/1941738114524517)

47. Bowes J & Buckley R. Fifth metatarsal fractures and current treatment. *World Journal of Orthopedics* 2016 **7** 793–800. (https://doi.org/10.5312/wjo.v7.i12.793)

48. Akimau PI, Cawthron KL, Dakin WM, Chadwick C, Blundell CM & Davies MB. Symptomatic treatment or cast immobilisation for avulsion fractures of the base of the fifth metatarsal: a prospective, randomised, single-blinded non-inferiority controlled trial. *Bone and Joint Journal* 2016 **98-B** 806–811. (https://doi.org/10.1302/0301-620X.98B6.36329)

49. Baumbach SF, Prall WC, Kramer M, Braunstein M, Böcker W & Polzer H. Functional treatment for fractures to the base of the 5th metatarsal – influence of fracture location and fracture characteristics. *BMC Musculoskeletal Disorders* 2017 **18** 534. (https://doi.org/10.1186/s12891-017-1893-6)

50. Baumbach SF, Urresti-Gundlach M, Böcker W, Vosseller JT & Polzer H. Results of functional treatment of epi-metaphyseal fractures of the base of the fifth metatarsal. *Foot and Ankle International* 2020 **41** 666–673. (https://doi.org/10.1177/1071100720907391)

51. Choi YR, Kim BS, Kim YM, Park JY, Cho JH, Kim S & Kim HN. Hard-soled shoe versus short leg cast for a fifth metatarsal base avulsion fracture: a multicenter, noninferiority, randomized controlled trial. *Journal of Bone and Joint Surgery: American Volume* 2020 **103** 23–29.

52. Dineen HA, Murphy TD, Mangat S, Lukosius EZ, Lin FC, Pettett BJ, Peoples SJ & Hurwitz SR. Functional outcomes for nonoperatively treated proximal fifth metatarsal fractures. *Orthopedics* 2017 **40** e1030–e1035. (https://doi.org/10.3928/01477447-20171012-02)

53. Massada MM, Pereira MA, de Sousa RJ, Costa PG & Massada JL. Intramedullary screw fixation of proximal fifth metatarsal fractures in athletes. *Acta Ortopédica Brasileira* 2012 **20** 262–265. (https://doi.org/10.1590/S1413-78522012000500003)

54. Grant MJ, Molloy AP & Mason LW. The use of percutaneous screw fixation without fracture site preparation in the treatment of fifth metatarsal base nonunion. *Journal of Foot and Ankle Surgery* 2020 **59** 753–757. (https://doi.org/10.1053/j.jfas.2019.08.034)

55. Tan EW, Cata E & Schon LC. Use of a percutaneous pointed reduction clamp before screw fixation to prevent gapping of a fifth metatarsal base fracture: a technique tip. *Journal of Foot and Ankle Surgery* 2016 **55** 151–156. (https://doi.org/10.1053/j.jfas.2015.04.011)

56. Looney AM, Renehan JR, Dean DM, Murthy A, Sanders TH, Neufeld SK & Cuttica DJ. Rate of delayed union with early weightbearing following intramedullary screw fixation of Jones fractures. *Foot and Ankle International* 2020 **41** 1325–1334. (https://doi.org/10.1177/1071100720938317)

57. Marecek GS, Earhart JS, Croom WP & Merk BR. Treatment of acute Jones fractures without weightbearing restriction. *Journal of Foot and Ankle Surgery* 2016 **55** 961–964. (https://doi.org/10.1053/j.jfas.2016.04.013)

58. Yoho RM, Vardaxis V & Dikis J. A retrospective review of the effect of metatarsus adductus on healing time in the fifth metatarsal jones fracture. *Foot* 2015 **25** 215–219. (https://doi.org/10.1016/j.foot.2015.05.006)

59. Lareau CR, Hsu AR & Anderson RB. Return to play in National Football League players after operative Jones fracture treatment. *Foot and Ankle International* 2016 **37** 8–16. (https://doi.org/10.1177/1071100715603983)

60. Lee KT, Kim KC, Young KW, Jegal H, Park YU, Lee HS & Roh Y. Conservative treatment of refractures after modified tension band wiring of fifth metatarsal base stress fractures in athletes. *Journal of Orthopaedic Surgery* 2020 **28** 2309499020926282. (https://doi.org/10.1177/2309499020926282)

61. Huh J, Glisson RR, Matsumoto T & Easley ME. Biomechanical comparison of intramedullary screw versus low-profile plate fixation of a Jones fracture. *Foot and Ankle International* 2016 **37** 411–418. (https://doi.org/10.1177/1071100715619678)

62. Lee SK, Park JS & Choy WS. Locking compression plate distal ulna hook plate as alternative fixation for fifth metatarsal base fracture. *Journal of Foot and Ankle Surgery* 2014 **53** 522–528. (https://doi.org/10.1053/j.jfas.2014.02.021)

63. Mitchell RJ, Duplantier NL, Delgado DA, Lambert BS, McCulloch PC, Harris JD & Varner KE. Plantar plating for the treatment of proximal fifth metatarsal fractures in elite athletes. *Orthopedics* 2017 **40** e563–e566. (https://doi.org/10.3928/01477447-20170327-04)

64. Seidenstricker CL, Blahous EG, Bouché RT & Saxena A. Plate fixation with autogenous calcaneal dowel grafting proximal fourth and fifth metatarsal fractures: technique and case series. *Journal of Foot and Ankle Surgery* 2017 **56** 975–981. (https://doi.org/10.1053/j.jfas.2017.04.035)

65. Ismat A, Rupp M, Knapp G, Heiss C, Szalay G & Biehl C. Treatment of proximal fifth metatarsal fractures with an ulna hook plate. *Foot* 2020 **42** 101653. (https://doi.org/10.1016/j.foot.2019.101653)

66. Kim JB, Song IS, Park BS, Ahn CH & Kim CU. Comparison of the outcomes Between headless cannulated screw fixation and fixation using a locking compression distal ulna hook plate in fracture of fifth metatarsal base. *Journal of Foot and Ankle Surgery* 2017 **56** 713–717. (https://doi.org/10.1053/j.jfas.2017.01.048)

67. Bernstein DT, Mitchell RJ, McCulloch PC, Harris JD & Varner KE. Treatment of proximal fifth metatarsal fractures and refractures with plantar plating in elite athletes. *Foot and Ankle International* 2018 **39** 1410–1415. (https://doi.org/10.1177/1071100718791835)

68. Bishop JA, Braun HJ & Hunt KJ. Operative Versus nonoperative treatment of Jones fractures: a decision analysis model. *American Journal of Orthopedics* 2016 **45** E69–E76.

69. Yue JJ & Marcus RE. The role of internal fixation in the treatment of Jones fractures in diabetics. *Foot and Ankle International* 1996 **17** 559–562. (https://doi.org/10.1177/107110079601700909)

70. Payo-Ollero J, Álvarez Goenaga F, Elorriaga Sagarduy G, Ruiz Nasarre A, Olmos-García MA & Villas Tomé C. Stress fracture of the fifth metatarsal in foot deformity secondary to neuromuscular disease: experiences of deformity correction treatment – a report of 3 cases and review of the literature. *Foot and Ankle Specialist* 2018 **11** 177–182. (https://doi.org/10.1177/1938640017744642)

71. Dameron Jr TB. Fractures of the proximal fifth metatarsal: selecting the best treatment option. *Journal of the American Academy of Orthopaedic Surgeons* 1995 **3** 110–114. (https://doi.org/10.5435/00124635-199503000-00006)

72. Clapper MF, O'Brien TJ & Lyons PM. Fractures of the fifth metatarsal. Analysis of a fracture registry. *Clinical Orthopaedics and Related Research* 1995 **315** 238–241.

73. Smith TO, Clark A & Hing CB. Interventions for treating proximal fifth metatarsal fractures in adults: a meta-analysis of the current evidence-base. *Foot and Ankle Surgery* 2011 **17** 300–307. (https://doi.org/10.1016/j.fas.2010.12.005)

74. Rosenberg GA & Sferra JJ. Treatment strategies for acute fractures and nonunions of the proximal fifth metatarsal. *Journal of the American Academy of Orthopaedic Surgeons* 2000 **8** 332–338. (https://doi.org/10.5435/00124635-200009000-00007)

75. Nishikawa DRC, Aires Duarte F, Saito GH, Bang KE, Monteiro AC, Prado MP & de Cesar Netto C. Treatment of zone 1 fractures of the proximal fifth metatarsal with boot vs hard-soled shoes. *Foot and Ankle International* 2020 **41** 508–512. (https://doi.org/10.1177/1071100720903259)

76. Zwitser EW & Breederveld RS. Fractures of the fifth metatarsal; diagnosis and treatment. *Injury* 2010 **41** 555–562. (https://doi.org/10.1016/j.injury.2009.05.035)

77. Hong CC, Nag K, Yeow H, Lin AZ & Tan KJ. Suture anchor fixation for fifth metatarsal tuberosity avulsion fractures: a case series and review of literature. *Journal of Foot and Ankle Surgery* 2018 **57** 1030–1033. (https://doi.org/10.1053/j.jfas.2018.02.014)

78. Lee TH, Lee JH, Chay SW, Jang KS & Kim HJ. Comparison of clinical and radiologic outcomes between non-operative and operative treatment in 5th metatarsal base fractures (zone 1). *Injury* 2016 **47** 1789–1793. (https://doi.org/10.1016/j.injury.2016.05.016)

79. Valkier C, Fallat LM & Jarski R. Conservative versus surgical management of fifth metatarsal avulsion fractures. *Journal of Foot and Ankle Surgery* 2020 **59** 988–992. (https://doi.org/10.1053/j.jfas.2020.05.003)

80. Wang Y, Gan X, Li K, Ma T & Zhang Y. Comparison of operative and non-operative management of fifth metatarsal base fracture: a meta-analysis. *PLoS ONE* 2020 **15** e0237151. (https://doi.org/10.1371/journal.pone.0237151)

81. Wu GB, Li B & Yang YF. Comparative study of surgical and conservative treatments for fifth metatarsal base avulsion fractures (type I) in young adults or athletes. *Journal of Orthopaedic Surgery* 2018 **26** 2309499017747128. (https://doi.org/10.1177/2309499017747128)

82. Khan S, Axelrod D, Paul R, Catapano M, Stephen D, Henry P & Wasserstein D. Acute fifth metatarsal tuberosity fractures: a systematic review of nonoperative treatment. *PM and R* 2021 **13** 405–411. (https://doi.org/10.1002/pmrj.12427)

83. Husain ZS & DeFronzo DJ. Relative stability of tension band versus two-cortex screw fixation for treating fifth metatarsal base avulsion fractures. *Journal of Foot and Ankle Surgery* 2000 **39** 89–95. (https://doi.org/10.1016/s1067-2516(00)80032-0)

84. Rettig AC, Shelbourne KD & Wilckens J. The surgical treatment of symptomatic nonunions of the proximal (metaphyseal) fifth metatarsal in athletes. *American Journal of Sports Medicine* 1992 **20** 50–54. (https://doi.org/10.1177/036354659202000113)

85. Zhao J, Yu B, Xie M, Huang R & Xiao K. Surgical treatment of zone 1 fifth metatarsal base fractures using the locking compression plate distal ulna hook plate. *Journal of the American Podiatric Medical Association* 2017 **107** 369–374. (https://doi.org/10.7547/15-208)

86. McGarvey WC & Coetzee JC. Midfoot fractures and dislocations. In *Baxter's the Foot and Ankle in Sport*. Eds **D Porter & LC Schon**. S.l.: Elsevier – Health Science, 2020.

87. Schildhauer TAH & MF. Fractures and dislocations of the midfoot and forefoot. In *Rockwood and Green's Fractures in Adults*, pp. 2968–3060. Ed **P Tornetta.** Philadelphia: Wolters Kluwer, 2020.

88. Josefsson PO, Karlsson M, Redlund-Johnell I & Wendeberg B. Closed treatment of Jones fracture. Good results in 40 cases after 11–26 years. *Acta Orthopaedica Scandinavica* 1994 **65** 545–547. (https://doi.org/10.3109/17453679409000911)

89. Konkel KF, Menger AG & Retzlaff SA. Nonoperative treatment of fifth metatarsal fractures in an orthopaedic suburban private multispeciality practice. *Foot and Ankle International* 2005 **26** 704–707. (https://doi.org/10.1177/107110070502600907)

90. Ekrol I & Court-Brown CM. Fractures of the base of the 5th metatarsal. *Foot* 2004 **14** 96–98. (https://doi.org/10.1016/j.foot.2003.12.007)

91. Hunt KJ & Anderson RB. Treatment of Jones fracture nonunions and refractures in the elite athlete: outcomes of intramedullary screw fixation with bone grafting. *American Journal of Sports Medicine* 2011 **39** 1948–1954. (https://doi.org/10.1177/0363546511408868)

92. Vorlat P, Achtergael W & Haentjens P. Predictors of outcome of non-displaced fractures of the base of the fifth metatarsal. *International Orthopaedics* 2007 **31** 5–10. (https://doi.org/10.1007/s00264-006-0116-9)

93. Holmes Jr GB. Treatment of delayed unions and nonunions of the proximal fifth metatarsal with pulsed electromagnetic fields. *Foot and Ankle International* 1994 **15** 552–556. (https://doi.org/10.1177/107110079401501006)

94. Portland G, Kelikian A & Kodros S. Acute surgical management of Jones' fractures. *Foot and Ankle International* 2003 **24** 829–833. (https://doi.org/10.1177/107110070302401104)

95. Mologne TS, Lundeen JM, Clapper MF & O'Brien TJ. Early screw fixation versus casting in the treatment of acute Jones fractures. *American Journal of Sports Medicine* 2005 **33** 970–975. (https://doi.org/10.1177/0363546504272262)

96. Goodman SB, Jiranek W, Petrow E & Yasko AW. The effects of medications on bone. *Journal of the American Academy of Orthopaedic Surgeons* 2007 **15** 450–460. (https://doi.org/10.5435/00124635-200708000-00002)

97. Porter DA, Duncan M & Meyer SJ. Fifth metatarsal Jones fracture fixation with a 4.5-mm cannulated stainless steel screw in the competitive and recreational athlete: a clinical and radiographic evaluation. *American Journal of Sports Medicine* 2005 **33** 726–733. (https://doi.org/10.1177/0363546504271000)

98. Low K, Noblin JD, Browne JE, Barnthouse CD & Scott AR. Jones fractures in the elite football player. *Journal of Surgical Orthopaedic Advances* 2004 **13** 156–160.

99. Kerkhoffs GM, Versteegh VE, Sierevelt IN, Kloen P & van Dijk CN. Treatment of proximal metatarsal V fractures in athletes and non-athletes. *British Journal of Sports Medicine* 2012 **46** 644–648. (https://doi.org/10.1136/bjsports-2011-090389)

100. Roche AJ & Calder JD. Treatment and return to sport following a Jones fracture of the fifth metatarsal: a systematic review. *Knee Surgery, Sports Traumatology, Arthroscopy* 2013 **21** 1307–1315. (https://doi.org/10.1007/s00167-012-2138-8)

101. Yates J, Feeley I, Sasikumar S, Rattan G, Hannigan A & Sheehan E. Jones fracture of the fifth metatarsal: is operative intervention justified? A systematic review of the literature and meta-analysis of results. *Foot* 2015 **25** 251–257. (https://doi.org/10.1016/j.foot.2015.08.001)

102. Granata JD, Berlet GC, Philbin TM, Jones G, Kaeding CC & Peterson KS. Failed surgical management of acute proximal fifth metatarsal (Jones) fractures: a retrospective case series and literature review. *Foot and Ankle Specialist* 2015 **8** 454–459. (https://doi.org/10.1177/1938640015592836)

103. Reese K, Litsky A, Kaeding C, Pedroza A & Shah N. Cannulated screw fixation of Jones fractures: a clinical and biomechanical study. *American Journal of Sports Medicine* 2004 **32** 1736–1742. (https://doi.org/10.1177/0363546504264929)

104. Ochenjele G, Ho B, Switaj PJ, Fuchs D, Goyal N & Kadakia AR. Radiographic study of the fifth metatarsal for optimal intramedullary screw fixation of Jones fracture. *Foot and Ankle International* 2015 **36** 293–301. (https://doi.org/10.1177/1071100714553467)

105. Scott RT, Hyer CF & DeMill SL. Screw fixation diameter for fifth metatarsal jones fracture: a cadaveric study. *Journal of Foot and Ankle Surgery* 2015 **54** 227–229. (https://doi.org/10.1053/j.jfas.2014.11.010)

106. Porter DA. Fifth metatarsal Jones fractures in the athlete. *Foot and Ankle International* 2018 **39** 250–258. (https://doi.org/10.1177/1071100717741856)

107. Ebraheim NA, Haman SP, Lu J, Padanilam TG & Yeasting RA. Anatomical and radiological considerations of the fifth metatarsal bone. *Foot and Ankle International* 2000 **21** 212–215. (https://doi.org/10.1177/107110070002100305)

108. Wright RW, Fischer DA, Shively RA, Heidt Jr RS & Nuber GW. Refracture of proximal fifth metatarsal (Jones) fracture after intramedullary screw fixation in athletes. *American Journal of Sports Medicine* 2000 **28** 732–736. (https://doi.org/10.1177/03635465000280051901)

109. Bigsby E, Halliday R, Middleton RG, Case R & Harries W. Functional outcome of fifth metatarsal fractures. *Injury* 2014 **45** 2009–2012. (https://doi.org/10.1016/j.injury.2014.06.010)

110. Duplantier NL, Mitchell RJ, Zambrano S, Stone AC, Delgado DA, Lambert BS, Moreno MR, Harris JD, McCulloch PC, Lintner DM *et al.* A biomechanical comparison of fifth metatarsal Jones fracture fixation methods. *American Journal of Sports Medicine* 2018 **46** 1220–1227. (https://doi.org/10.1177/0363546517753376)

111. Young KW, Kim JS, Lee HS, Jegal H, Park YU & Lee KT. Operative results of plantar plating for fifth metatarsal stress fracture. *Foot and Ankle International* 2020 **41** 419–427. (https://doi.org/10.1177/1071100719895273)

112. Kadar A, Ankory R, Karpf R, Luger E & Elias S. Plate fixation of proximal fifth metatarsal fracture. *Journal of the American Podiatric Medical Association* 2015 **105** 389–394. (https://doi.org/10.7547/14-035)

113. Cheung CN & Lui TH. Proximal fifth metatarsal fractures: anatomy, classification, treatment and complications. *Archives of Trauma Research* 2016 **5** e33298. (https://doi.org/10.5812/atr.33298)

114. Chuckpaiwong B, Queen RM, Easley ME & Nunley JA. Distinguishing Jones and proximal diaphyseal fractures of the fifth metatarsal. *Clinical Orthopaedics and Related Research* 2008 **466** 1966–1970. (https://doi.org/10.1007/s11999-008-0222-7)

115. O'Malley MJ, Hamilton WG & Munyak J. Fractures of the distal shaft of the fifth metatarsal. 'Dancer's fracture'. *American Journal of Sports Medicine* 1996 **24** 240–243. (https://doi.org/10.1177/036354659602400223)

116. Morgan C & Abbasian A. Management of spiral diaphyseal fractures of the fifth metatarsal: a case series and a review of literature. *Foot* 2020 **43** 101654. (https://doi.org/10.1016/j.foot.2019.101654)

117. Ruta DJ & Parker D. Jones fracture management in athletes. *Orthopedic Clinics of North America* 2020 **51** 541–553. (https://doi.org/10.1016/j.ocl.2020.06.010)

118. Yang Z, Jian W, Li ZH, Jun X, Liang Z, Ge Y & Shi ZJ. The geometry of the bone structure associated with total hip arthroplasty. *PLoS ONE* 2014 **9** e91058. (https://doi.org/10.1371/journal.pone.0091058)

119. D'Hooghe P, Caravelli S, Massimi S, Calder J, Dzendrowskyj P & Zaffagnini S. A novel method for internal fixation of basal fifth metatarsal fracture in athletes: a cadaveric study of the F.E.R.I. technique (fifth metatarsal, extra-portal, rigid, innovative). *Journal of Experimental Orthopaedics* 2019 **6** 45. (https://doi.org/10.1186/s40634-019-0213-5)

120. Nolte P, Anderson R, Strauss E, Wang Z, Hu L, Xu Z & Steen RG. Heal rate of metatarsal fractures: a propensity-matching study of patients treated with low-intensity pulsed ultrasound (LIPUS) vs. surgical and other treatments. *Injury* 2016 **47** 2584–2590. (https://doi.org/10.1016/j.injury.2016.09.023)

121. Blum A, Zarqh O, Peleg A, Sirchan R, Blum N, Salameh Y & Ganaem M. Vascular inflammation and endothelial dysfunction in fracture healing. *American Journal of Orthopedics* 2012 **41** 87–91.

122. Jiao H, Xiao E & Graves DT. Diabetes and its effect on bone and fracture healing. *Current Osteoporosis Reports* 2015 **13** 327–335. (https://doi.org/10.1007/s11914-015-0286-8)

123. Karlamangla AS, Burnett-Bowie SM & Crandall CJ. Bone health during the menopause transition and beyond. *Obstetrics and Gynecology Clinics of North America* 2018 **45** 695–708. (https://doi.org/10.1016/j.ogc.2018.07.012)

124. Brinker MR, O'Connor DP, Monla YT & Earthman TP. Metabolic and endocrine abnormalities in patients with nonunions. *Journal of Orthopaedic Trauma* 2007 **21** 557–570. (https://doi.org/10.1097/BOT.0b013e31814d4dc6)

125. Glasgow MT, Naranja Jr RJ, Glasgow SG & Torg JS. Analysis of failed surgical management of fractures of the base of the fifth metatarsal distal to the tuberosity: the Jones fracture. *Foot and Ankle International* 1996 **17** 449–457. (https://doi.org/10.1177/107110079601700803)

126. Larson CM, Almekinders LC, Taft TN & Garrett WE. Intramedullary screw fixation of Jones fractures. Analysis of failure. *American Journal of Sports Medicine* 2002 **30** 55–60. (https://doi.org/10.1177/03635465020300012301)

127. Ritchie JD, Shaver JC, Anderson RB, Lawrence SJ & Mair SD. Excision of symptomatic nonunions of proximal fifth metatarsal avulsion fractures in elite athletes. *American Journal of Sports Medicine* 2011 **39** 2466–2469. (https://doi.org/10.1177/0363546511417566)

128. Panteli M, Pountos I & Giannoudis P. Nonunions of fifth metatarsal fractures: our institutional experience. In *Orthopaedic Trauma Association 2014 Annual Meeting*; October 15–18, 2014; Tampa, FL, 2014.