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Rare Proximal Diaphyseal Stress Fractures of the Fifth Metatarsal Associated With Metatarsus Adductus

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ABSTRACT

Before the report of English surgeon Robert Jones, who sustained a fracture to his fifth metatarsal while dancing around a tent pole, metatarsal fractures were thought to be the result of direct trauma to the foot. The mechanism of metatarsal fractures, in particular, those involving the fifth metatarsal, is now well understood. Patients with an adducted alignment of their forefoot can overload the fifth metatarsal base, putting them at an increased risk of fractures of this bone. Studies have reported that 2 distinct types of proximal diaphyseal or junctional fractures of the fifth metatarsal occur: the acute proximal diaphyseal or transverse proximal diaphyseal fracture and the proximal diaphyseal stress fracture. The radiographic characteristics associated with proximal diaphyseal stress fractures of the fifth metatarsal can vary by the chronicity; however, the findings typically entail a radiolucent fracture line with surrounding reactive sclerosis. In addition, a reduced medullary canal width can be appreciated. In the present retrospective analysis of patients with stress-related trauma to the fifth metatarsal base with an adducted forefoot, 2012 foot trauma cases were reviewed at 3 separate institutions. Of the 2012 cases, 22 (1.11%) met the outlined criteria of stress fractures of the fifth metatarsal base and underlying metatarsus adductus.

Stress fractures to the metatarsal bones are common, constituting 9% to 35% of all stress fractures (1). In a study of 320 athletes, the tibia (49.1%), tarsals (25.3%), and metatarsals (8.8%) were the most frequently involved bones affected by a stress fracture (2). Arangio (3), in a series of 49 subjects, found the following percentages for fifth metatarsal fractures; tuberosity, 76%; proximal diaphysis (Jones), 4%; proximal diaphysis (stress), 0%; middle diaphysis, 4%; distal diaphysis, 14%; neck, 2%; and head, 0%. Battaglia et al (4) using different classification zones than those used by Arangio (3) found: avulsions in 68%, true Jones in 25%, and shaft/neck in 7%. Vogler et al (5) identified the fifth metatarsal proximal metaphyseal–diaphyseal junction fractures frequency rate as 0.7% to 1.9% in a combined total of 10,988 foot fractures.

In 1976, Dameron (6) noted 3 different proximal zones of injury to the fifth metatarsal. The first has been classified as an avulsion fracture or zone 1 injury at the base of the fifth metatarsal and occurring by indirect loading. This fracture type occurs by a direct blow or sudden inversion of the rearfoot with weight on the lateral metatarsal, placing tension along the soft tissue insertions of the fifth metatarsal base, leading to avulsion of the tuberosity. Zone 2 injuries are considered true Jones fractures occurring at the metaphyseal–diaphyseal junction. They represent an acute injury caused by adduction of the forefoot that results in a fracture that propagates laterally toward the fourth metatarsal base. The third type, zone 3, has been referred to as a proximal diaphyseal stress fracture. The fracture is produced by tensile forces that result in microfractures at the lateral cortex of the fifth metatarsal base.

The Torg classification system was described in 1984; it evaluated the radiographic parameters to describe the age of the fracture on presentation. The Torg classification divides the fractures into 3 types according to the radiographic characteristics (7): type I (acute), which can be appreciated by the narrow fracture line and no intramedullary sclerosis; type II (delayed union) will result in a widened fracture gap and intramedullary sclerosis; and type III (nonunion), which will demonstrate obliteration of the medullary canal.

A valid process of classifying proximal diaphyseal fractures of the fifth metatarsal involves identifying the fracture according to the mechanism of injury. It must be recognized that fractures of the proximal diaphyseal junction can occur by multiple mechanisms but will not contain the same radiographic features to the careful eye. Jones (8) reported that fifth metatarsal base fractures can occur by indirect mechanisms. The acute type occurs when the heel is off the

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ground and the body weight expends itself on the fifth metatarsal, rotating it slightly inward (8). Because the base of the fifth metatarsal is held tightly by ligamentous support, the distal aspect will adduct relative to the proximal diaphysis, which acts as a fulcrum. If the grounded foot is unable to compensate by inverting, a fracture will occur at the proximal diaphysis (9). Kavanaugh et al (10) postulated that this lack of inversion will concentrate the forces at the proximal diaphysis of the fifth metatarsal.

Alternatively, proximal diaphyseal stress fractures of the fifth metatarsal are caused by submaximal repeated stress. The maximal stress found in the fifth metatarsal results in an oblique load (load directed 30° to 60°) in the proximal diaphysis of the fifth metatarsal 3.38 to 4.05 cm distal from the tuberosity (11).

Certain radiographic characteristics are associated with proximal diaphyseal fifth metatarsal stress fractures. These include a radiolucent fracture line, reactive sclerosis surrounding the fracture, a reduced medullary canal width due to sclerotic formation, "heaped up" erratic bone callus on the outer margin of the fracture, and a fracture line that is often wider plantarly and laterally, with sparing of the dorsomedial cortices (9).

Recent studies have investigated the biomechanics of different foot types that are conducive to overloading areas of the foot and ultimately result in stress-related trauma. Two previous studies examined a link between metatarsus adductus and stress fractures of the fifth metatarsal and lateral aspect of the foot. Theodorou et al (1) published the first study to our knowledge of metatarsus adductus associated with metatarsal fractures. The limitations of their work included a failure to obtain weightbearing radiographs for measurement of the metatarsus adductus angle (MAA) and that their study identified fractures of metatarsals 1 through 5. Yoho et al (12) published a case-control study of 60 total patients and the association of metatarsus adductus and Jones fractures. Their results showed an increased association in patients with Jones fractures and metatarsus adductus (12). Their study did not evaluate metatarsus adductus and rearfoot alignment. In addition, their study did not report any exclusion criteria for the mechanism of injury.

Raikin et al (13) investigated the predisposing effect of varus rearfoot alignment in patients who had sustained Jones fractures. The results of their study indicated that most patients sustaining Jones fractures will have evidence of varus rearfoot alignment.

In the present study, we were interested in determining the association of patients with an adducted forefoot and the incidence of stress-related trauma in the fifth metatarsal. We hypothesized that a relationship would exist between stress fractures of the proximal fifth metatarsal and the presence of metatarsus adductus. Our primary aim was to determine the incidence of proximal fifth metatarsal stress fractures in patients with clinically relevant metatarsus adductus. We undertook a retrospective cohort study at 3 separate institutions during an approximately 7-year period to evaluate this correlation.

Materials and Methods

A retrospective multicenter study reviewed closed proximal diaphyseal fifth metatarsal fractures from December 2007 through March 2013 from 3 hospitals in Massachusetts: Steward St. Elizabeth's Medical Center (Brighton, MA), New England Baptist Hospital (Boston, MA), and Saint Vincent Hospital (Worcester, MA).

Data were abstracted from the medical records at each of the participating institutions, applying the "International Classification of Diseases, 9th revision" (World Health Organization, Geneva, Switzerland) code 825.25 to extract isolated closed metatarsal fractures. Fractures of the fifth metatarsal were identified by 2 of us (K.E.W., S.M.W.). The additional radiographic features, defined below, of the proximal fifth metatarsal fractures diagnosed as stress fractures and the remaining proximal fifth metatarsal fractures of interest in the present study were determined by 1 of us (K.E.W.). The radiographic measurements were performed by 1 of us (K.E.W.) using the picture archiving and communication system imaging software (McKesson Radiology, San Francisco, CA) and IMPAX® (AGFA Healthcare, Mortsel, Belgium). Statistical analysis of the compiled data was completed by the same investigator (K.E.W.), with attention given to data type and distribution. The results were described in terms of the mean and standard deviation and ranges. Statistical comparisons were made between the variables of interest in patients with proximal fifth metatarsal stress and nonstress (acute direct or indirect trauma) fractures using the Wilcoxon rank test. Statistical significance was defined at the 5% ($p \leq .05$) level.

The fractures were identified radiographically that met the following criteria: proximal diaphyseal incomplete fractures of the lateral plantar cortex, a spared medial cortex, reactive sclerosis, and a decreased medullary canal width. These radiographic parameters are equivalent to a Torg type II fracture, representing a delayed union (stress fracture) (7). The fractures were included if they were within the range of 15 to 40 mm from the base of the styloid process, placing them in the region of the proximal diaphyseal bone of the fifth metatarsal (Fig. 1). This distance was determined by the region that Dameron (6) describes as zone 3 proximal diaphyseal stress fractures. Fractures with involvement of the epiphysis or styloid process and those that were intra-articular were excluded from our study. We also focused on proximal fifth metatarsal fractures that were not considered stress fractures according to our interpretation of the information in the medical records and radiographs (Fig. 2) to compare the features of these fractures with those of the stress fractures.

Patients with a history of direct and significant (major) trauma or crush injuries to the foot were excluded from the present study. Any patients with underlying metabolic conditions or predisposing factors such as osteoporosis, rheumatoid arthritis, osteomalacia, fibrous dysplasia, hyperparathyroidism, Paget's disease, previous foot surgery, or diabetic neuropathic osteoarthropathy were excluded from the present study.

Radiographic measurements were obtained using fully weightbearing radiographs. The MAA was identified on anteroposterior (dorsoplanar) radiographs using Engel's angle (Fig. 3). For the purposes of the present study, any measurement ≥18° was considered significant for metatarsus adductus (14,15). The angle was measured by defining the 4 corners of the second cuneiform with a longitudinal bisection and an intersection of this with a bisection of the second metatarsal bone.

To determine the degree of rearfoot varus weightbearing, lateral radiographs were retrospectively assessed. Two measurements were used to classify the rearfoot alignment. The first was the calcaneal inclination angle (CIA or calcaneal pitch; Fig. 4). On a lateral radiograph, this angle is created with a line drawn from the plantar-most surface of the calcaneus to the inferior border of the distal articular surface and the transverse plane (13). According to Solis et al (16), a calcaneus in varus will be associated with a calcaneal inclination angle of ≥30°. The second radiographic measurement obtained was the talar-first metatarsal angle (Meary's angle; Fig. 5). This angle is formed between the long axis of the talus and the first metatarsal on a weightbearing lateral view (13). Paulos et al (17) reported a mean average Meary's angle of ≥20° in patients with pes cavus. These 2 radiographic parameters (i.e., CIA of ≥30° and Meary's angle of ≥20°) were used as our cutoff values for patients with a varus alignment. Statistical descriptions of the data were made, and comparisons of the demographic and outcome variables made using tests of the null hypothesis. Continuous data were compared using Student's *t* test, and categorical data were compared using the Wilcoxon rank sum (Mann Whitney U) test. Statistical significance was defined at the 5% ($p \leq .05$) level (Table 1).

Results

A total of 2012 foot fractures were reviewed at 3 separate institutions. Of the 2012 cases, 51 (2.53%) were proximal metaphyseal–diaphyseal junction fractures of the fifth metatarsal (30 males [58.8%] and 21 females [41.2%]). Of the 51 cases, 22 (1.11%) met our inclusion criteria (17 males [77.3%] and 5 females [22.7%]), and their mean age was 32 ± 14 (range 17 to 62) years. The weightbearing radiographic data of the metatarsal stress fractures in these 22 patients are summarized in Table 2. The mean average distance of the stress fracture from the styloid process, as measured on the dorsoplanar radiographs, was 27.5 ± 5 (range 18 to 36.6) mm. All 22 patients (100%) displayed an Engel's angle >18°, indicative of metatarsus adductus. The mean MAA was 26.4° ± 6.1° (range 18.2° to 39.3°). The mean average CIA was 23.6° ± 4.8° (range 17.3° to 33.4°), and 17 limbs (77.3%) were deemed in varus alignment by a CIA of >20°. The mean average Meary's angle was 3.3° ± 2.6° (range 0.2° to 12.1°), and only 1 patient's radiographs (0.05%) displayed an abnormal Meary's angle (12.1°).

Of the 51 patients with fifth metatarsal fractures identified, 29 did not meet the inclusion criteria. The data for these 29 patients are summarized in Table 3. The radiographs for these 29 patients were analyzed for the MAA, CIA, and Meary's angle. In addition, these patients all had a related history of direct or indirect trauma. The mean average MAA in the latter group was 24.7° ± 4.8° (range 13.0° to 37.3°). Of the 29 patients, 15 had an MAA >18° (51.7%). Of these 29