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Second metatarsal stress fracture in sport: comparative risk factors between proximal and non-proximal locations

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Background: Stress fractures of the second metatarsal are common injuries in athletes and military recruits. There are two distinct areas in the second metatarsal where stress fractures develop: one proximal (at the base) and the other non-proximal (distal). Diagnosis can be difficult, and there is a difference in prognosis and treatment of the two types of stress fracture. Therefore differentiation of fracture location is warranted. Differences in risk factors and clinical outcomes between proximal and non-proximal stress fractures have not been studied.
Objective: To determine whether different risk factors and/or clinical outcomes associated with proximal and non-proximal stress fractures of the second metatarsal exist.
Methods: Patients diagnosed with proximal stress fractures of the second metatarsal were included in the study. Retrospectively, an age-matched control group with a non-proximal stress fracture was selected for comparison. Statistical analysis involved bivariate comparisons of demographic variables and clinical measurement between the two groups.
Results: Patients with proximal stress fractures were more likely to be chronically affected, usually exhibited an Achilles contracture, showed differences in length of first compared with second metatarsal, were more likely to experience multiple stress fractures, and exhibited low bone mass. In addition, a high degree of training slightly increased the risk of a non-proximal fracture, whereas low training volume was associated with a proximal stress fracture.
Conclusion: The signs, symptoms and clinical findings associated with proximal metatarsal stress fractures are different from those of non-proximal stress fractures.

A stress fracture of the metatarsal bones is one of the most common overuse injuries in athletes, second only to a tibial stress fracture in incidence.[1] Stress fractures of the metatarsal bones comprise 3.7% of all sport-related injuries, with the second and third metatarsal accounting for 80–90% of the fractures.[1–3] Stress fractures of the metatarsals are also common in military recruits and in long-distance runners. It has been reported that 10%[4] to 20%[5] of stress fractures in athletes and 23%[6] of stress fractures in military recruits are located in the metatarsals. Anatomically, the second to fourth metatarsals have ligamentous anchoring between the heads of the metatarsal, which protect against fracture displacement, but which can increase plantar-oriented forces during weight bearing.[7] The second to fourth metatarsals are the weakest cross-sectionally, despite the fact that the second and third metatarsals encounter high peak pressures during weight-bearing activities.[8] Kinematic contributors to stress such as muscle fatigue[9] and the normally higher bending strains at the second digit during running[10] further increase the forces placed on the second metatarsal. The association of valgus deformity of the hind foot[11 12] with second metatarsal fractures and the presence of osteoporosis[13 14] have also been reported. However, none of these factors explains why more than 95% of stress fractures of the second metatarsal occur at the non-proximal aspect of the metatarsal bone. The exact reason why non-proximal fractures are more prevalent than proximal fractures is unclear, despite comprehensive biomechanical analysis.[15–17]

Proximal stress fractures of the second metatarsal are much less common than non-proximal second metatarsal stress fractures. In addition, the recovery time of a proximal fracture is usually prolonged, and delayed and non-union is often seen.[18 19] Boden *et al*[18 20] considered proximal fractures to be high-risk fractures compared with non-proximal fractures specifically in association with recuperation period, treatment needed, and the potential for complications. Non-proximal fractures usually heal well with symptomatic treatment within 6–8 weeks, whereas proximal fractures develop delayed or non-union, which may require surgical intervention.[19] Increasing load and rate to the second metatarsal is believed to be a cause of stress injury for both locations,[15 21] as this descriptive mechanism and the clinical findings of a proximal fracture have been reported in several studies.[22–24] However, to date the exact risk factors and causes predicting a proximal stress fracture of the second metatarsal are still unclear.

The purpose of this study was to outline the clinical signs, symptoms and physical factors associated with proximal and non-proximal stress fractures of the second metatarsal in a retrospective sample. The findings may help to identify risk factors associated with the potential for such fractures. We hypothesise that the identifying factors associated with each fracture are indeed different and lead to mechanical explanations for each encountered stress fracture.

MATERIALS AND METHODS

Subjects

Patients retrospectively diagnosed with a proximal stress fracture of the second metatarsal were included in this study. They underwent a complete radiographic examination, including foot plain anterior to posterior (AP), oblique and lateral radiography for initial diagnosis. Because of the difficulty in diagnosing a metatarsal stress fracture, a confirmatory diagnosis was sometimes made using MRI or bone scan. All patients received bone densitometry after the diagnosis had been made to determine the contribution of bone mass to the stress fracture. Those with measurable low bone mass were treated appropriately with osteoporosis medication if not contraindi-

Table 1 Baseline characteristics of patients divided into groups with proximal and non-proximal stress fractures of the second metatarsal

	Proximal fractures (n = 13)	Non-proximal fractures (n = 45)	p Value
Age (years)	44.13 (19.67)	45.58 (20.4)	0.8192
Male	44.0%	31.1%	0.4465
BMI	25.2 (3.01)	25.55 (3.3)	0.7180
Caucasian	76.90%	82.20%	0.4465
Sport participation	100%	91.1%	0.6222
Basketball	3 (23.1%)	2 (4.4%)	0.1218
Football	1 (7.7%)	1 (2.2%)	0.9289
Soccer	0	1 (2.2%)	0.9289
Running	7 (53.8%)	38 (84.4%)	0.0508
Golf	2 (15.4%)	0	0.0695
Others	0	3 (6.7%)	0.3390

BMI, body mass index.
Values are mean (SD), percentages or number (%).

cated. All were patients at Duke University Medical during the period 1996–2005.

Retrospectively, a comparison control group was enrolled if they exhibited a stress fracture of the second metatarsal in any region other than the proximal base of the bone. The control group was age matched (based on 5 years difference). Like the group with proximal stress fractures, all subjects underwent a complete radiographic examination, including foot plain AP, oblique and lateral radiography for initial diagnosis followed by a method of confirmatory diagnosis.

General demographic data (including age, sex, marital status, weight, height, body mass index, race, work and recreational activities) were recorded as well as specific sport participation and level of sport participation (operationally defined as <0.5 h a week, 0.5–15 h a week or >15 h a week). Patient history was collected including specific topics such as the duration of symptoms and history of other stress fractures. Possible causes of a metatarsal stress fracture such as associated foot pathology (eg, first ray hypermobility, abnormal arch of foot, short first metatarsal) and general medical condition were carefully analysed. First ray hypermobility was defined as relative motion of the first ray with respect to the second ray by more than 8 mm.[25 26] Flat and cavus foot were defined by careful qualitative examination by experienced orthopaedists, on the basis of hindfoot angle, arch height and forefoot abduction.[27] Achilles contracture (heel cord tightness) was defined by physical examination on the basis of criteria outlined by Silfverskiöld.[28] Leg length was assessed with the subject in the supine position using qualitative bilateral measurement. Leg length was measured from anterior superior iliac spine to lateral malleolus. Leg length inequality was defined as more than 1.5 cm difference.[29] Every patient who had a shorter first metatarsal compared with the second metatarsal on AP plain radiography of the foot was included in short first metatarsal group (Morton's toe). Differences between distal articular surface on AP plain radiography of the first and second metatarsal was recorded in millimetres. All data collection procedures were conducted through the Orthopedic Surgery Division of Duke University Medical Center under institutional review board approval.

Statistical analysis

Univariate statistics are reported including the baseline statistics of age, race, gender, sport participation and sport type, and include examination values such as duration of symptoms and foot posture and assessment. Comparative bivariate analyses of duration of symptoms, foot and ankle postural examination, sport type, and additional medical findings were performed. $p<0.05$ was considered significant. All analyses were performed using SPSS software (SPSS Inc, Chicago, Illinois, USA).

RESULTS

This study included 58 fractures in 54 patients. Nine patients exhibited proximal stress fractures of the second metatarsal, four of which were bilateral, making a total of 13 proximal fractures. There were 45 non-proximal fractures included as well. Baseline demographic data (age, gender, body mass index, race and sport participation) between the two groups were not significantly different (table 1).

All of the patients indicated that the injury was caused or exacerbated by sport. Fifty five (94.8%) patients had participated regularly in sport in the preceding 3 months. Nine (15.5%) had trained less than 0.5 h a week, whereas 12 (20.7%) reported training for more than 15 h a week. Forty five (77.6%) participated in running, five (8.6%) played basketball, two (3.4%) played football and soccer, and three (7.0%) were engaged in other sports.

The mean (SD) duration of symptoms across the two samples was 2.8 (12.5) weeks. Patients with a proximal fracture were significantly more likely to report symptom durations of >3 months ($p<0.05$). Table 2 compares duration of symptoms.

There was a trend toward significance for stress injury at a non-proximal location for patients who reported high levels of training (>15 h a week) ($p = 0.06$). Unexpectedly, low training volume (<0.5 h a week) was associated with significantly increased risk of stress fracture at the proximal location ($p<0.05$).

Postural examination identified seven subjects (12.1%) with pes planus, one (1.7%) with pes cavus, and 25 (43.1%) with a short first metatarsal (Morton's toe). Six subjects (10.3%) exhibited hallux valgus, eight (13.8%) had hallux rigidus, three (5.2%) displayed a tight heel cord, four (6.9%) presented with first ray hypermobility, but none had leg length inequality. Of the postural findings, Achilles contracture and the ratio of first to second metatarsal length were significantly ($p<0.05$) different between the two groups. Table 3 provides comparative findings of the postural foot examinations.

Fracture location was identified by plain radiograph in 45 (77.6%) cases, by bone scan in three (5.52%), and by MRI in 10 (17.2%). Of the group with proximal fractures (n = 13), five (38.5%) required bone scan and MRI for diagnosis. There were five (38.5%) delayed diagnoses in the proximal group (range 26–125 days) and 10 (22.2%) in the non-proximal group (range 14–64 days). Sixteen (27.6%) had abnormal bone densitometry (osteopenia or osteoporosis according to the WHO classification) potentially secondary to underlying diseases such as metabolic bone disease, chronic renal failure, or the female athlete triad (amenorrhoea, anorexia and low bone mass). Values were reported as normal, osteopenia or osteoporosis. Thirty two (55.2%) had underlying diseases that did not involve bone density (such as diabetes and hypertension). Patients with proximal fractures were significantly more likely to have bilateral fatigue fractures, a history of other stress fractures (ie, tibia), and abnormalities in bone densitometry measurements. Table 4 compares additional medical findings.

DISCUSSION

Our findings suggest that selective identifiers are prevalent in patients with proximal versus non-proximal stress fractures of the second metatarsal. Patients with proximal stress fractures are more likely to be chronically affected, to exhibit an Achilles contracture, to have size differences in length of first compared with second metatarsal, to experience multiple stress fractures,

Table 2 Comparison of duration of symptoms between proximal and non-proximal location of second metatarsal stress fractures

Duration of symptoms	No with proximal fracture (n = 13)	No with non-proximal fracture (n = 45)
1–3 days	0	2 (4.4)
3–7 days	2 (15.4)	23 (51.1)
1–3 weeks	2 (15.4)	14 (31.1)
3 weeks–3 months	1 (7.7)	4 (8.9)
>3 months	8 (61.5)*	2 (4.4)

Values in parentheses are percentages.
*Significantly different from group with non-proximal fractures ($p<0.05$).

and to exhibit low bone mass. In addition, they participated in sport but reported low levels of training. To our knowledge, this is the first study that has examined demographic, sport and examination criteria that differentiate proximal and non-proximal stress fractures of the second metatarsal.

Stress fractures of the second metatarsal are common in athletes and other groups that perform repetitive loading activities of the lower extremities.[6] The location of a stress fracture is generally along the metatarsal shaft and/or neck and only rarely at the proximal base. Classifying the location of the fracture may improve outcome and reduce risk of complications.[20] Metatarsal shaft fractures are correctly and effectively treated with activity restriction, whereas proximal stress fractures risk the potential of non-union when treated conservatively. Because proximal stress fractures are often overlooked during examination,[23 30] the recognition of clinical covariates such as those identified in our study may be useful to the examining clinician.

Many theories exist on the aetiology of stress fractures of the lower extremities, including anatomical foot abnormality, longitudinal arch dysfunction, excessive forefoot varus, leg length inequality,[31] pes planus,[32] cavus foot[33–35] and first ray hypermobility.[25] Achilles contracture has been hypothesised to increase plantar pressure, thus increasing risk of a metatarsal stress fracture.[36] Ringham *et al*[37] have suggested that excessive external rotation of the hip from femoral antetorsion produces foot hyperpronation, which may lead to stress fractures in the lower extremities. Others[38–40] have identified risk factors such as abnormal menstruation, eating disorders and low bone mass (the female athlete triad) as associated factors of lower extremity stress fractures. Our study supports the suggestion that low bone mass, Achilles contracture and a short first metatarsal (Morton's toe) may lead to stress fracture of the second metatarsal at a proximal location but failed to find a significant difference between proximal and non-proximal fractures with various foot postures such as excessive pronation or supination.

A short first metatarsal compared with the second metatarsal (Morton's toe) has been hypothesised to increase the risk of a second metatarsal stress fracture.[33 41] In our study, the average length of the first metatarsal compared with the second metatarsal in patients with proximal stress fractures of the second metatarsal was 80%. This finding corresponds to the value of O'Malley *et al*,[24] who reported 82%, and exceeds that of Drez *et al*[41] (less than 73% of second metatarsal length). In our study, this finding was associated only with proximal fractures; the other studies did not specify the location of the fracture. We further hypothesised that a short first metatarsal produced abnormal overloading stress along the full second metatarsal length. In association with poor bone quality, a second metatarsal stress fracture may therefore occur at the weakest (proximal) location.

Selected studies have investigated risk factors for a fracture at the base of the second metatarsal that were outside the criteria of our investigation. Hamilton[33] reported the risk factors of anterior ankle impingement, amenorrhoea and anorexia nervosa. In a study of ballet dancers, O'Malley *et al*[24] suggested that the en pointe position (ballet position of toe standing), selected nutritional deficits, hypo-oestrogenism, selected training protocols, and the hardness of the floor might also be causative. All proximal stress fractures at the second metatarsal in our study were caused by sport-related injuries other than dance. This implies that the mechanism of injury is not limited to extreme plantar flexion of the foot and ankle (used commonly by dancers), but other mechanisms are also involved.

Low training volume (<0.5 h a week) was significantly ($p<0.05$) associated with the risk of stress fracture at the base of the second metatarsal. A trend toward significance was observed in people who trained for more than 15 h a week. Whether the findings of significance from low training levels can be extrapolated as causative is not known. It is possible that training was reduced because subjects in our study had chronic symptoms and thus may have modified their activity accordingly or the low training level may be associated with disuse osteopenia. The literature on training generally supports the notion that an abrupt increase in training intensity, duration and frequency[42 43] without adequate rest can disturb the osteoclast–osteoblast coupling cycle and increase the risk of a stress fracture. An alternative explanation is disuse atrophy, which can lead to osteopenia[44] and/or weakness of muscles around the foot and ankle, which can increase plantar pressure leading to stress fracture.[9 15–17]

Table 3 Comparison of foot examination postures for proximal and non-proximal stress fracture of the second metatarsal

	No with proximal fracture (n = 13)	No with non-proximal fracture (n = 45)	p Value
Pas planus	4 (30.8)	3 (6.7)	0.0619
Pes cavus	1 (7.7)	0	0.5046
Hallux rigidus	3 (22.1)	5 (11.1)	0.5186
Hallux valgus	2 (15.4)	4 (8.9)	0.8725
Achilles contracture	3 (22.1)	0	0.0093*
First ray hypermobility	2 (15.4)	2 (4.4)	0.4533
Leg length discrepancy	0	0	–
First/second metatarsal length	0.80 (0.2)	0.95 (0.25)	0.0341*

Values in parentheses are percentages.
*Significance at $p<0.05$.

Table 4 Comparison of additional medical findings between proximal and non-proximal stress fractures of the second metatarsal

	No with proximal fractures (n = 13)	No with non-proximal fractures (n = 45)	p Value
Bilateral stress fractures	8 (61.5)	0	<0.0001*
Underlying diseases	8 (61.5)	24 (53.3)	0.8357
Other stress fracture(s)	7 (53.8)	55 (11.1)	0.0030*
Abnormal bone densitometry	10 (76.9)	6 (13.3)	<0.0001*

Values in parentheses are percentages.
*Significance at p<0.01.

Bone quality is an important factor that may influence a stress fracture at the base of the second metatarsal. Our study shows that abnormal bone densitometry (osteopenia or osteoporosis according to the WHO classification) was significantly associated with a proximal stress fracture versus a non-proximal stress fracture. Furthermore, subjects in our study were more likely to report a history of other stress fractures or bilateral stress fractures of the second metatarsal base. Like any other long bone, the metatarsal base (metaphysis) is more susceptible to injury than the shaft (diaphysis) because the metaphyseal area has more trabecular bone, which is easily weakened when osteoporotic.[44] Our study also supports the findings of Muehleman *et al*[45] and Courtney *et al*[46] who concluded that bone mineral density, not bone geometry, provided the overall strength of metatarsal bone.

The duration of symptoms in proximal stress fractures of the second metatarsal was significantly longer than in the non-proximal fracture group (especially >3 months). There are possible explanations for this finding. Firstly, a proximal metatarsal stress fracture is often ill-defined and less debilitating than a fracture in the non-proximal location. Consequently, the prolonged duration of symptoms may be correlated with delayed diagnosis and recovery time, a finding supported by Boden *et al*.[20] Secondly, because of mismanagement, proximal stress fractures may fail during selected conservative treatment that is successful for non-proximal stress fractures.

Limitations of the study

There are limitations of this study. Our limited sample consists of retrospectively analysed subjects with both proximal and non-proximal fractures. The rarity of proximal stress fractures of the second metatarsal prevented a stronger comparison, and, because the sample size was small, some comparative analyses would probably not meet power requirements. However, this study includes the largest sample we are aware of involving proximal second metatarsal stress fractures and compares these fractures with a control (non-proximal fracture) group. A multicentre study may improve the ability to develop a complete list of risk factors for proximal second metatarsal fractures.

CONCLUSIONS

A proximal stress fracture of the second metatarsal is an uncommon stress injury but can lead to serious complications. The differences in risk factors compared with a stress injury to the same bone at a non-proximal location are longer duration of symptoms, reports of training <0.5 h a week, shorter first metatarsal length, Achilles contracture, and especially abnormal bone density (including history of previous stress fracture and bilateral stress fracture). Early recognition and proper non-operative treatment of this high-risk fracture can minimise potential complications. The findings of this study may serve to improve differential recognition of patients with a proximal second metatarsal fracture.

What is already known on this topic

- Proximal stress fractures of the second metatarsal are uncommon overuse injuries, exclusively reported in ballet dancers and directly associated with dance-related postures of the foot. Outcomes of conservative treatment are typically unfavourable and often lead to poor union.
- Non-proximal metatarsal stress fractures are a more common overuse injury and generally heal with appropriate conservative care.

What this study adds

- Proximal stress fractures of the second metatarsal are possible in non-dancers.
- Longer duration of symptoms, training <0.5 h a week, shorter first metatarsal length, Achilles contracture, and abnormal bone density (including history of stress fracture and bilateral stress fracture) are potential associated risk factors of proximal second metatarsal injuries in non-dancers.

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