Central Metatarsal Fractures: A Radiographic Review

Alayna Puccinelli, DPM
Clay Ballinger, DPM
Donald Green, DPM
Donna Agan, EdD

INTRODUCTION

Metatarsal fractures are relatively common foot injuries, accounting for 35% of all foot fractures and 5% of total skeletal fractures (1). Fifth metatarsal fractures occur most frequently, followed by central metatarsal fractures (metatarsals 2-4), and then first metatarsal fractures. Central metatarsal fractures are more likely to affect multiple metatarsals. Reports have demonstrated that 63% of third metatarsal fractures occurred concurrently with second or fourth metatarsal fractures and 28% with both (2). Both direct and indirect traumas have been implicated in metatarsal fractures. Petrisor et al found that most metatarsal fractures are caused by low-energy trauma such as a simple twist or fall from standing height (2). Direct trauma is another cause of metatarsal fractures, particularly at the diaphysis.

Central metatarsal bases articulate with the tarsal bones and have strong ligamentous attachments dorsally, plantarly, and transversely (3). The metatarsal shafts serve as the origin for the plantar and dorsal interossei. These multiple soft tissue attachments affect the type of displacement or angulation that occurs when there is a fracture. Dorsal angulation of the metatarsal shaft with plantar displacement of the head occurs secondary to the pull of the long flexors and intrinsic musculature (4, 5). Oblique fractures of the shaft tend to shorten, also due to the pull of the intrinsic muscles (6). Displacement or angulation medially or laterally is also relatively common.

Because of the multiple soft tissue attachments and relatively stable proximal articulations, fractures involving the central metatarsals tend to be rather stable. For this reason, nonunion is an uncommon complication. Malunion, however, has been reported as the most common complication, especially after closed treatment (3). Specifically, fractures involving the metatarsal neck and shaft have a higher incidence of malunion (7). Malunion involving disruption of the metatarsal parabola or sagittal plane can lead to early loading and increased pressure during gait (8).

Much has been written about treatment techniques and clinical outcomes of fifth metatarsal fractures; however, there are few studies reporting on surgical and nonsurgical management and outcomes of central metatarsal fractures. As with most other fractures, nondisplaced or minimally displaced fractures of central metatarsals can be treated nonoperatively. But, the decision to treat operatively versus nonoperatively based on the level of displacement or angulation is different for every physician. Commonly acceptable levels that guide surgical treatment include greater than 10 degrees of angulation or 3-4 mm of displacement (4, 9). However, there are no studies that support these specific numbers.

The purpose of this study was to assess the radiographic outcomes of patients with central metatarsal fractures treated operatively and nonoperatively and to compare the amount of displacement and/or angulation pre-treatment and post-treatment between the 2 groups. We hypothesized that patients treated operatively would have significantly better radiographic outcomes compared to those treated nonoperatively.

MATERIALS AND METHODS

We reviewed the radiographs of all patients treated for metatarsal fractures, based on the ICD-9 code 285.25 and CPT code 28485, by 1 of 2 podiatrists at Scripps Clinic in San Diego, CA occurring between January 3, 2006 and March 30, 2015. Scripps Institutional Review Board approved the record review. There were a total of 2,940 patients and of them, 329 had central metatarsal fractures. Inclusion criteria consisted of patients with metatarsal neck, shaft, or base fracture(s) of the second, third, and/or fourth metatarsals with or without concomitant first or fifth metatarsal fractures who had pre-treatment and 2 sets of post-treatment anterior posterior, lateral, and medial oblique radiographs. Exclusion criteria consisted of any nondisplaced, stress, pathologic, or pediatric fracture and those without sufficient radiographs to review.

Statistical Analysis

Statistical analysis was performed using SPSS software. The paired sample *t*-test, Pearson R correlation coefficient for determining association between variables, 1-way ANOVA, and 2-way ANOVA were all used to analyze the data. *P* values less than or equal to 0.05 (5%) were considered statistically significant. All data included had an adequate sample population and followed a normal bell curve.

We created 4 different groups defined by the plane of displacement or angulation, and this included transverse plane displacement, multi-plane displacement, sagittal plane displacement, and transverse plane angulation. For the purposes of this study, the multi-plane displacement group signified some level of shortening along with some displacement in the transverse plane with no clear identification of displacement in 1 plane. There were not enough cases of sagittal plane angulation to have enough power to include in this study. For each group, we measured the amount of displacement and/or angulation pre-treatment, post-treatment short-term follow-up (1-3 weeks), and post-treatment long-term follow-up (2 months to 3 years). Using these measurements, the amount of improvement or progress (changes in displacement/angulation) was calculated from pre-treatment to post-treatment short- and long-term as well as changes within the interval between the short- and long-term follow-up with comparisons being made between the operatively and nonoperatively treated groups.

RESULTS

A total of 46 patients (34 females, 12 males) with 93 fractures were included in the study after applying the inclusion and exclusion criteria. The mean ± SD age of the subjects was 46 ± 44 years (range 18-90 years). Twenty-three patients with 42 fractures were treated operatively, including percutaneous pinning, and/or a combination of plates and screws. Twenty-three patients with 51 fractures were treated nonoperatively, including a 4-6 week period of immobilization with weight-bearing limitations.

The mean pre-treatment amount of displacement/angulation, standard deviations, and *P* values for the operative and nonoperative groups are shown in Table 1. Prior to treatment, the mean transverse displacement for the operative group was 3.66 ± 2.72 mm compared to the nonoperative group, which was 1.44 ± 1.19 mm. The differences between the 2 groups were statistically significant ($P = 0.003$). The mean pre-treatment multi-plane displacement for the operative group was 4.17 ± 1.18 and 1.94 mm ± 1.18, respectively, and this was also statistically significant ($P = 0.000$). Therefore, the operative group's pre-treatment displacement was statistically significantly higher than that of the nonoperative group.

The mean pre-treatment sagittal plane displacement was 3.07 ± 2.87 mm for the operative group and 2.03 mm ± 1.62 for the nonoperative group and for the transverse plane angulation was 20.22° ± 12.53° for the operative group and 16.91° ± 9.62° for the nonoperative group. For both of these, the differences in mean displacement/angulation between the operative and nonoperative groups was not statistically significant ($P = 0.266$ and $P = 0.307$, respectively). Therefore, the operative group's pre-treatment displacement/angulation was statistically similar to that of the nonoperative group (Table 1).

Tables 2-5 depict the progress, or changes, seen in the amount of displacement/angulation after calculating the differences between the pre-treatment values and the post-treatment values both in the short- and long-term follow-up periods. A positive number depicts improvement, or a decrease, in displacement, while a negative number depicts loss of correction, or an increase, in the amount of displacement.

For the transverse plane displacement group, in which both pre-treatment groups were dissimilar, the mean post-treatment changes in displacement in the short- and long-term follow-up periods are shown in Table 2. For the short-term follow-up, the operative group had a mean improvement by 3.22 mm ± 2.84, while the nonoperative group had worsened amount of displacement by 0.018 mm ± 0.859. For the long-term follow-up, the operative group had a mean improvement by 3.16 mm ± 3.01 and the nonoperative group had a mean improvement by 0.221 mm ± 0.967. The differences between the operative and nonoperative groups was statistically significant for both follow-up periods ($P = 0.000$ and 0.001, respectively). Within the interval between the 2 follow-up periods, the

Table 1. Pretreatment displacement/angulation

	Group	N	Mean (mm)	SD	*t*-test ($P \leq 0.05$)
Pre-treatment transverse displacement	Op	19	3.66	2.72	0.003
	Nonop	34	1.44	1.19	
Pre-treatment multi-plane displacement	Op	9	4.17	1.17	0.000
	Nonop	12	1.94	1.18	
Pre-treatment sagittal displacement	Op	19	3.07	2.87	0.266
	Nonop	12	2.03	1.62	
Pre-treatment transverse angulation	Op	27	20.2°	12.5	0.307
	Nonop	23	16.9°	9.63	

operative group lost some correction by 0.067 mm ± 0.924 and the nonoperative gained some correction by 0.238 mm ± 0.698. These differences were not statistically significant (*P* = 0.187).

For the multi-plane displacement group, in which both pre-treatment groups were dissimilar, the mean post-treatment changes in displacement are shown in Table 3. For the short-term follow-up, the operative group had a mean improvement by 3.62 mm ± 1.21, which was greater than the nonoperative group with a mean improvement by only 0.067 mm ± 1.37. Additionally, in the long-term, the operative group had a mean improvement by 3.40 mm ± 1.47, which was greater than the nonoperative group with a mean improvement by 1.22 mm ± 2.16. These differences were statistically significant for both follow-up periods (*P* = 0.000 and 0.03, respectively). Within the interval between the 2 follow-up periods, the operative group lost some correction by 0.425 ± 1.07 mm and the nonoperative gained some correction by 1.20 mm ± 1.68. These differences were statistically significant (*P* = 0.034) (Table 3).

For the sagittal plane displacement group, in which both pre-treatment groups were similar, the mean post-treatment changes in displacement are shown in Table 4. At the short-term follow-up, the operative group had a mean improvement by 2.96 mm ± 2.91, while the nonoperative group had a mean increase in displacement by 0.10 mm ± 1.11. Long-term, the operative group had a greater mean improvement in displacement by 2.34 mm ± 1.71 compared to the nonoperative group, which had a mean improvement by 0.475 mm ± 1.51. Both of these differences were statistically significant (*P* = 0.002 and 0.005, respectively). The interval period shows that, between the short- and long-term follow-up periods, the operative group lost some correction by 0.556 mm ± 0.388 while the nonoperative gained some correction by 0.575 mm ± 1.06, and these differences were not statistically significant (*P* = 0.07) (Table 4).

For the transverse plane angulation group, in which both pre-treatment groups were similar, the mean post-treatment changes in displacement are shown in Table 5. At

Table 2. Transverse displacement

Progress	Group	N	Mean improvement (mm)	SD	*t*-test (*P* ≤ 0.05)
Short-term	Op	18	3.22	2.85	0.000
	Nonop	34	-0.018	0.859	
Long-term	Op	18	3.16	3.01	0.001
	Nonop	34	0.221	0.967	
Interval	Op	18	-0.067	0.924	0.187
	Nonop	34	0.238	0.698	

Table 3. Multi-plane displacement

Progress	Group	N	Mean improvement (mm)	SD	*t*-test (*P* ≤ 0.05)
Short-term	Op	9	3.62	1.21	0.000
	Nonop	12	0.067	1.37	
Long-term	Op	8	3.40	1.47	0.030
	Nonop	9	1.22	2.16	
Interval	Op	8	-.425	1.07	0.034
	Nonop	9	1.20	1.68	

Table 4. Sagittal plane displacement

Progress	Group	N	Mean improvement (mm)	SD	*t*-test (*P* ≤ 0.05)
Short-term	Op	19	2.96	2.91	0.002
	Nonop	12	-0.100	1.12	
Long-term	Op	18	2.34	1.71	0.005
	Nonop	12	0.475	1.52	
Interval	Op	18	-0.556	0.388	0.070
	Nonop	12	0.575	1.06	

the short-term follow-up, the operative group had a mean improvement by 17.89° ± 13.4°, while the non-operative group had mean worsening of angulation by 2.52° ± 9.43°. Long-term, the operative group had a mean improvement by 17.2° ± 14.5° compared to the nonoperative group, which had a mean worsening of angulation by 0.700° ± 7.64°. Both of these differences were statistically significant ($P = 0.000$ for both). Within the interval between the 2 follow-up periods, the operative group lost some correction by 0.478° ± 5.55° while the nonoperative gained some correction by 2.60° ± 5.11°, and these differences were not statistically significant ($P = 0.202$).

DISCUSSION

The goal of treatment for central metatarsal fractures is to maintain a functional, plantigrade forefoot by restoring the metatarsal parabola as well as the sagittal plane length and axis in order to avoid prolonged disability and dysfunction (3, 7). Metatarsalgia secondary to malunion has been described as the most common complication after closed treatment of these fractures (3, 7, 10). Sagittal plane displacement of the fracture can lead to excessive pressure at the metatarsal heads or transfer irritation adjacent metatarsals, respectively. Although transverse plane malalignment is typically better tolerated, significant displacement can lead to irritation at the metatarsal heads with ambulation or symptoms of a neuroma. Additionally, increased shortening can lead to a malaligned metatarsal parabola causing transfer lesions and increased pain (2, 3, 6). Therefore, the decision to treat surgically versus nonsurgically is dictated by the risk of malunion if adequate anatomic reduction cannot be achieved and maintained.

There are few research studies that present the treatment and outcomes of central metatarsal fractures and none that specifically evaluate the anatomic reduction achieved based on radiographic measures. Spector et al examined 12 patients with central metatarsal fractures and correlated the clinical outcomes with treatment (4). They found that fractures treated with nonanatomic open reduction and internal fixation resulted in only "fair" clinical outcomes, suggesting that achieving proper anatomic reduction is associated with better clinical outcomes. Alaepuz et al evaluated the mid- and long-term results of central metatarsal fractures and the factors contributing to poor results (10). Overall, they found that 41% had poor functional results independent of treatment, and correlated this with residual displacement, especially in the sagittal plane. These results also suggest that failure to achieve accurate anatomic reduction is correlated with poor functional outcomes. Commonly reported values indicating the need for surgical fixation for better anatomic reduction of metatarsal fractures is 3-4 mm of displacement or greater than 10 degrees of angulation (4, 9). However, there is no study that validates these specific values, nor is there one that provides any treatment guidelines based on the initial amount of displacement/angulation.

Our study assessed the radiographic outcomes of central metatarsal fractures treated operatively compared to nonoperatively, including the amount of anatomic reduction achieved and maintained over time, based on the pre-treatment amount and plane of displacement/angulation. Although it is out of the scope of this study to provide exact guidelines as to when to surgically treat central metatarsal fractures based on the amount of initial displacement/angulation, we were able to draw some conclusions about which type of treatment achieves better reduction depending on the initial plane of displacement/angulation. Perhaps, those that had less residual displacement/angulation after treatment resulted in better functional outcomes based on previous literature.

Overall, those fractures treated nonoperatively did not achieve accurate anatomic reduction but had a small amount of improvement in the reduction over time as signified by the "interval" changes between the short- and long-term follow-up periods. Operatively treated fractures resulted in better anatomic reduction but lost a small percentage of the correction over time.

We could not make conclusions about treatment effectiveness with regard to the fractures with transverse and multi-plane displacement because the operatively treated group had started with a mean pre-treatment displacement that was higher than the nonoperatively treated group, and the difference was statistically significant (Table 1). Therefore, as expected, the operative group had a greater

Table 5. Transverse plane angulation

Progress	Group	N	Mean improvement (Degrees)	SD	*t*-test ($P \leq 0.05$)
Short-term	Op	27	17.9	13.4	0.000
	Nonop	23	-2.52	9.43	
Long-term	Op	23	17.2	14.5	0.000
	Nonop	20	-0.700	7.64	
Interval	Op	23	-0.478	5.55	0.202
	Nonop	20	2.60	5.11	

amount of correction compared to the nonoperative group when there was transverse or multi-plane displacement (Tables 2, 3).

However, when there was sagittal displacement or transverse angulation, conclusions could be made about the effectiveness of surgical treatment versus nonsurgical treatment since both groups started with a similar amount of pretreatment displacement/angulation that had no statistical significance (Table 1). After treatment in the short- and long-term follow-up periods, the operative group had a greater mean improvement compared to the nonoperative group, and the difference was statistically significant (Tables 4, 5). Thus, based on our study, sagittal plane displacement (mean of 2-3 mm) or transverse plane angulation (mean of 17-20°) requires operative treatment to achieve better anatomic reduction.

Overall, the operatively treated group lost a small amount of correction between the short- and long-term follow-up but still maintained a greater amount of correction compared to the nonoperatively treated group. Conversely, the nonoperative group had a small improvement in anatomic reduction between the short- and long-term follow-up periods, but it still did not achieve better anatomic reduction when compared to the operative group.

The results of this study support the idea that central metatarsal fractures treated operatively result in better anatomic correction compared to those treated nonoperatively. When treated nonoperatively, there is a slight improvement over time, but adequate anatomic reduction is not consistently achieved. Operative treatment achieves better anatomic reduction, but it may lose a fraction of the reduction over time. A mild amount of multi-plane (~2 mm) or transverse plane (~1.5 mm) displacement can be treated nonoperatively with good anatomic correction. Displacement in the sagittal plane (2-3 mm) or angulation in the transverse plane (17-20°) requires operative treatment for better anatomic reduction.

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