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Original Research

Foot Loading and Gait Analysis Evaluation of Nonarticular Tibial Pilon Fracture: A Comparison of Three Surgical Techniques

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ABSTRACT

The aim of our study was to investigate which technique among hybrid external fixation, plate and screws, and intramedullary nailing produces better outcomes in foot loading when treating type 43.A1, 43.A2, and 43.A3 fractures, according to the AO classification. From November 2011 to December 2014, 34 patients, including 25 (73.5%) males and 9 (26.5%) females with an average age of 32.3 (range 16 to 67) years, with a type A tibia fracture were treated with intramedullary nailing, plate and screws, or hybrid external fixation. The patients were divided into 3 groups: 16 (47%) received hybrid external fixation, 10 (29.4%) received plate and screw fixation, and 8 (23.5%) received intramedullary nailing fixation. The follow-up protocol included clinical and radiologic evaluations performed at 15 days, 1 month, 3 months, 6 months, and 12 months after surgery. The selected outcome parameters for the 3 groups were as follows: visual analog scale for pain of the traumatized tibia, interval from surgery to weightbearing, average time required for fracture recovery, subjective and objective Ovadia–Beals scores, baropodometric examination at 12 months, walking recovery at 12 months, outcomes, and surgical complications. The endpoint assessment was set at 12 months. The results showed that incorrect reduction of a type A tibia fracture can lead to changes in the sagittal balance line for foot loading and pace training. In conclusion, these findings have shown that the experience of the surgeon in the reduction of the fracture and knowledge of the method of synthesis is essential.

In 1911, the French surgeon Destot described the tibial pilon as an anatomic unit (1), defining the anatomic limit within 5 cm of the joint line, and the mechanism determining the fracture type. They represent ~1% of all fractures of the lower extremities and ≤10% of all tibial fractures (1). The average patient age is 35 to 40 years, the fractures are more common in males than in females, and their incidence is increasing, probably as a result of the increase in survival from road accidents (1). From an anatomic aspect, the tibial pilon has a thin skin, precarious vascularization, and no muscle insertions. These factors concur to make the healing phenomena of the soft tissue more complex, which also favors the exposure of fractures due to high-energy trauma (2). Pilon fractures in the distal tibia result from rotational or axial forces that can range from low to high energy as the usual consequences of road accidents or falls from a considerable height and thereby producing a spectrum of metaphyseal or metaphyseal and articular injuries. These fractures can be difficult to manage, especially when associated with significant soft tissue injury. Several surgical options and devices are available to treat these fractures. In addition, the timing of definitive surgery is crucial with respect to the condition of the soft tissues (3). The goal of the orthopedic surgery in nonarticular fractures of the tibial pilon is to preserve the anatomic and biomechanical tibial axis and the correct orientation of the ankle (4). Despite the progress made in managing these fractures, new developments in the field have continued to lead to better outcomes. The aim of our study was to investigate which technique among hybrid external fixation (HEF), plate and screws (PS), and intramedullary nailing (IN) produces better outcomes in foot loading when treating type A 4.3 fractures, according to the AO classification.

Patients and Methods

From November 1, 2011 to December 31, 2014 at the U.O.C. Orthopedics and Traumatology Unit, AORN Gaetano Rummo (Benevento, Italy), 34 consecutive patients with

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Table 1
Description of population*

Variable	HEF Group	PS Group	IN Group
Patients (n)	16	10	8
Age (y)			
Mean average	31.6	30.8	34.5
Range	16-67	18-60	21-55
Gender			
Male	13	7	5
Female	3	3	3
Ratio	4.33:1	2.33	1.67
Fracture type, AO classification			
Type A	8 (50)	4 (40)	4 (50)
Type B	4 (25)	4 (40)	2 (25)
Type C	4 (25)	2 (20)	2 (25)
Employment			
Agricultural activity	3 (18.7)	4 (40)	1 (12.5)
Industrial sector	10 (62.5)	5 (50)	4 (50)
Tertiary industry	3 (18.7)	1 (10)	3 (37.5)
Type of accident			
Fall from height	10 (62.5)	3 (30)	3 (37.5)
Traffic accident	6 (37.5)	7 (70)	5 (62.5)
ARRCO			
Mean average	6.3	6.4	6.2
Range	4 to 10	4 to 10	4 to 9
Nonunion scoring system			
Mean average	22.6	21.5	22.9
Range	14 to 31	16 to 35	12 to 33

Data presented as n (%), unless otherwise noted.
Abbreviations: ARRCO, Algoritmo Rischio Ritardo Consolidazione Ossea (Bone Consolidation Delay Risk Algorithm); HEF, hybrid external fixation; IN, intramedullary nailing; PS, plate and screws.
* No statistically significant differences were found among the 3 groups ($p > .05$ for all).

type 43.A1, 43.A2, and 43.A3 fractures were treated using 3 different surgical techniques: HEF, locked IN, and PS using minimally invasive plate osteosynthesis. In all patients treated, the line of distal tibial fracture was a minimum of 30 mm distant to the tibiotalar joint line. All the patients had the same associated injury: an upper fibular syndesmotic fracture to the proximal one third of the tibia. All fibular fractures were synthesized using Kirschner wire. All patients underwent surgery within 48 hours of their injury. The exclusion criteria were a medical history of previous fractures or musculoskeletal disorders of the lower limbs, limb heterometry, or spinal disease and heavy smoking, alcoholism, or drug abuse. All patients were informed in a clear and comprehensive manner about the 3 types of treatment and the corresponding surgical and conservative alternatives. The patients were treated according to the ethical standards of the Declaration of Helsinki and were invited to read, understand, and sign the informed consent form for surgery and the present study. The 34 patients were divided into 3 groups. The first group was treated with HEF and included 16 (47%) patients. The second group was treated with PS and included 10 (29.4%) patients. Finally, the third group was treated with IN and included 8 (23.5%) patients (Table 1).

In addition to surgery, all patients received pre- and postoperative heparin prophylaxis (deep vein thrombosis prophylaxis) and antibiotic prophylaxis. The first day after surgery, all the patients were placed in an open foot brace to maintain the foot at 90° relative to the leg after they had performed active and passive kinesis of the ankle and muscle strengthening exercises of the lower extremities to avoid any equinus contracture or other complications.

The follow-up protocol included clinical and radiologic evaluations performed at 15 days, 1 month, 3 months, 6 months, and 12 months after surgery. The chosen outcome parameters were as follows: the visual analog scale for pain in the traumatized tibia, the interval surgery to weightbearing, the mean average time required for fracture recovery, the subjective and objective Ovadia–Beals scores (5), baropodometric examination findings at 12 months, walking recovery at 12 months, and possible complications. At the 12-month follow-up examination, all the patients underwent dynamic pedography with analyses of the load, pressure, and force-time integral to investigate possible changes in the gait pattern. The endpoint assessment was set at 12 months postoperatively.

Dynamic Pedography

Dynamic pedography was performed using a multifunctional platform on a treadmill with individually calibrated, capacitive, and captive digital sensors (Zebris FDM-THM, GmbH, Munich, Germany). The patients were allowed an unlimited number of test walks without shoes. At least 5 accurate measurements per injured side were performed, and the average of the values was included in the subsequent analysis. The data were imported into an electronic spreadsheet (Excel®, Microsoft Office™; Microsoft, Seattle, WA) for further processing. We divided the foot into 10 areas (heel, midfoot, metatarsals 1 to 5, hallux, second toe, and toes 3 to 5) for pressure, loading, contact time during the roll-over process, and the force-time integral. The maximum loading, contact time during the roll-over process, and force-time integrals were analyzed and averaged, and the gait axis was depicted. The podography was conducted by 3 of us (G.R., R.C., M.P.).

Statistical Analysis

Descriptive statistics were used to summarize the characteristics of the study group and subgroups, including the mean ± standard deviation of all continuous variables. The *t* test was used to compare continuous outcomes. The χ^2 test or Fisher's exact test (for subgroups <10 patients) was used to compare the categorical variables. Statistical significance was defined at the 5% ($p \le .05$) level.

The reliability and validity of the correlation between the podographic results and Ovadia–Beals scores were determined using Cohen's kappa coefficient. The statistical analyses were performed by 2 of us (L.M., M.B.).

Results

None of the patients in the present series required a blood transfusion, and no cases of rotation of the distal fibula occurred. The average score of the nonunion scoring system was 15.6 (range 8 to 24) points in the HEF, 15.8 (range 8 to 24) points in the PS, and 16.1 (range 8 to 24) points in the IN groups ($p > .05$). At 12 months, the mean visual analog scale score for pain in the traumatized tibia was, on average, <2 in the 3 groups (Fig. 1; $p > .05$). In the IN group, partial weightbearing was achieved by a mean average of 2.3 (range 1 to 4) days after surgery, and total weightbearing in the IN group was achieved 20.7 (range 15 to 30) days after surgery ($p = .0197$). In the PS group, partial weightbearing was achieved by an average of 30.5 (range 20 to 38) days after surgery, and total weightbearing was achieved by 60.4 (range 31 to 95) days after surgery ($p = .0197$). In the HEF group, total weightbearing was achieved an average of 30.7 (range 20 to 38) days after surgery and total weightbearing by 50.5 (range 31 to 75) days after surgery ($p = .0197$). A statistically significant shorter duration was required for early partial weightbearing and total weightbearing in the IN group ($p < .05$).

In the IN group, bone healing was achieved a mean average of 50.3 (range 35 to 72) days after total weightbearing. In the PS group, bone healing was achieved a mean average of 59.2 (range 36 to72) days after total weightbearing. In the HEF group, bone healing was achieved an average of 46.7 (range 42 to 63) days after total weightbearing. No statistically significant difference ($p > .05$) was observed in the time to bone healing after total weightbearing in the 3 groups.

At the 12-month follow-up point, the subjective results, measured using the Ovadia–Beals parameters (5), were 95% excellent in the IN group, 90% excellent in the HEF group, and 85% excellent in the PS group. The remaining results were considered good. Also, at 12 months after surgery, the objective results according to Ovadia and Beals (5) were 85% excellent in the IN group, 85% excellent in the HEF group, and 75% excellent in the PS group ($p > .05$ among the 3 groups). The remaining results were included in the good category (Table 2; $p > .05$ among the 3 groups).

Dynamic pedography revealed a subtly compromised walking pattern on the injured side. We considered only the injured side in the 3 groups in our study. In the heel region, loading was lower (IN group, 510 ± 98 N; PS group, 500 ± 102 N; HEF group, 502 ± 102 N; $p > .05$), and the force-time integral was lower (IN group, 173 ± 73 N*s; PS group, 177 ± 78 N*s; HEF group, 171 ± 74 N*s; $p \ge .05$). Under the first metatarsal region, the loading was also less (IN group, 142 ± 72 N; PS group, 141 ± 70 N; HEF group, 146 ± 67; $p > .05$), and the force-time integral was lower (IN group, 68 ± 38 N*s; PS group, 70 ± 36 N*s; HEF group, 72 ± 38 N*s; $p > .05$). Under the fourth metatarsal, the loading was higher (IN group, 128 ± 45 N; PS group, 126 ± 43 N; HEF