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THE MAIN CAUSES OF UNSATISFACTORY OUTCOMES OF TREATMENT FOR FOOT INJURIES

V.O. Kalensky*, P.A. Ivanov

Multisystem and Multiple Injury Department
N.V. Sklifosovsky Research Institute for Emergency Medicine of the Moscow Healthcare Department,
Bolshaya Sukharevskaya Square, 3, Moscow 129090, Moscow, Russian Federation

*** Contacts:** Vsevolod O. Kalensky, Junior Researcher of the Multisystem and Multiple Injury Department, N.V. Sklifosovsky Research Institute for Emergency Medicine. Email: vsevolod.kalenskiy@gmail.com

BACKGROUND The foot is a special anatomical structure in its complexity. A large number of articular and ligamentous structures provide effective amortization and adaptation to surface features when walking. At the same time, if it is damaged, restoration of its anatomic structure is significantly difficult for a surgeon and may cause a number of complications and consequences. These issues are significant in patients with multisystem and multiple trauma.

AIM OF STUDY To identify the most common causes of unsatisfactory outcomes of treatment for foot injuries in patients with isolated, multiple and multisystem trauma.

MATERIAL AND METHODS Treatment of 216 patients was analyzed. We revealed 129 fractures of the calcaneus, 25 fractures of metatarsal bones and/or toes of the foot, 21 fractures of the talus, 18 Lisfranc lesions, 13 fractures of midfoot bones, and 10 multiple trauma of the foot. The multisystem trauma occurred in 38.4% of cases, isolated trauma of the foot was revealed in 36.7% and multiple injuries were observed in 24.9%. When evaluating the results, early and late complications were taken into account, and the functional outcome was determined by the Foot Function Index (FFI) after 6, 12 and 24 months.

RESULTS Among patients with closed fractures of the calcaneus, the problems of healing of the postoperative wound appeared in 3.5% of cases in operative treatment. The frequency of secondary displacements was 5.8%. By 24 months in patients after surgical and conservative treatment, similar functional outcomes were observed. Among patients with open fractures, skin necrosis occurred in 7 out of 25 cases and wound infection was observed in 15 cases. When fixing with wires, secondary displacement was observed in 4 cases out of 18. The average FFI score by 24 months was 59.5. In patients with forefoot fractures, wound healing complications occurred in 2 cases. The average score on the FFI scale was 93.7±8.1. In patients with fractures of the talus, wound complications were not noted, avascular necrosis (AVN) developed in 9 patients, osteoarthrosis (OA) developed in 15 cases. The average FFI after 2 years was 93.2±5.5 in patients without AVN and OA, and 63.6±23.1 in patients with AVN and/or OA. Among patients with midfoot trauma, infectious complications and secondary displacement were not observed. Osteoarthrosis occurred in 13 patients, including 8 patients with lesions of the Lisfranc joint. The difference in functional outcomes between patients with developed osteoarthrosis and without it differed in mean values, but was not statistically significant.

CONCLUSION The causes of unsatisfactory outcomes of treatment for foot trauma are wound complications against the background of open fractures of the calcaneus, avascular necrosis of the talus and posttraumatic arthrosis of the foot joints. It is advisable to continue research to find the best algorithm for treatment in these cases.

Keywords: foot injuries, calcaneus, talus, lisfranc injury, patient outcomes

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ORCID of authors
V.O. Kalensky: 0000-0001-7088-3206
P.A. Ivanov: 0000-0002-2954-6985

AVN – avascular necrosis
CT – computed tomography
FFI – foot function index
OA – osteoarthrosis

BACKGROUND

Foot truma may be considered as a special category of skeletal injuries due to the special features of anatomy, trauma itself and treatment. The foot consists of a lot of joints, which carry the same intensity loads, despite being relatively small in size compared to other joints of the skeleton. In particular, the ankle joint, as well as a complex of talonavicular and subtalar joints, called *"acetabulum pedis"*, carry loads similar to the knee and hip joints, which are bigger. A lot of moving joints and a unique ligamentous tendon apparatus provide excellent damping properties of the foot, the ability to adapt to uneven surfaces during walking, and as a consequence, the long functioning of the foot and all overlying parts of the musculoskeletal system without the development of overload pathologies.

The complex anatomy of the foot results in multivariance and the multicomponent damage, as well as technical difficulties in the operative restoration of its anatomy. The high energy of damaging factors, exposing bone and ligament structures of small size, leads to multifragmentary fractures with defects of bone tissue resulting from the impression, and concomitant multiple ligament ruptures (Fig. 1, 2). Left without proper treatment, these injuries lead to disruption in adaptation and amortization of the foot, as well as persistent pain syndrome [1].

Fig. 1. The X-ray image of a patient who has fallen from a height of 1 m. The X-ray image of a patient with low-energy trauma. Fracture of calcaneu s with minimal displacement

Fig. 2. The X-ray image of a patient affected by a fall from a height of 15 m.
The X-ray image of a patient with high-energy trauma. Fracture of calcaneus with significant displacement, rupture of Chopart joint with dislocation of talar head

It is difficult to visualize this complex three-dimensional structure. Therefore, most modern guidelines recommend not to be limited to examination and radiography, but perform computed tomography (CT) to almost all injuries of the foot and ankle [2-4].

Traumatologists have to set the correct tactics of treatment. Accurate repositioning of bone structures with restoration of anatomical shape is always preferable, but requires both knowledge and skills. Careful treatment of soft tissues is particularly important here, since necrosis, especially in the region of the posterior foot, is a big problem because of the anatomical shortage of soft tissue structures and the absence of a muscle compartment. However, complications often develop even with the right treatment tactics and may appear in a patient at different stages of recovery.

The complexity of providing surgical care in trauma to the foot causes a lot of controversy and, as a result, scientific research and development, but nevertheless, the "blind spots" in this area of knowledge are still significant.

The aim of the study was to identify the most frequent causes of unsatisfactory outcomes of treatment for trauma of the foot in patients with isolated, multiple and multisystem trauma.

MATERIAL AND METHODS

In Dec, 2013 – Dec, 2016, 289 patients with fractures of the foot bones were treated at the Department of Multiple and Multisystem trauma of the N.V. Sklifosovsky Research Institute for Emergency Medicine. The criterion for inclusion into the study was the fracture of one or more bones of the foot. The criterion for exclusion was the lack of information on the exact diagnosis, type of treatment and/or the presence of complications, as well as all cases of fractures without displacement, fractures of talus processes, avulsive fractures of navicular and fifth metatarsal bone. The study included 216 patients, and 73 patients were excluded. In 129 patients, the fracture of one or both calcaneus bones was diagnosed, 25 patients had fractures of metatarsal bones and/or toes, 21 patients had fractures of talus, 18 patients had the Lisfranc joint lesion, 13 patients had fractures of midfoot bones, 10 patients had bone fractures of different parts of the foot (multiple trauma of the foot). The mean age of the patients was 41±11.7 years. There were 167 patients of working age (77.4%). The multisystem trauma of several anatomical regions occurred in 38.4% of cases (83 patients), isolated trauma of the foot occurred in 36.7% (79 patients), and multiple injury of the skeleton was diagnosed in 24.9% (54 patients).

In 129 patients, 160 fractures of the calcaneus were diagnosed (in 31 cases bilateral damage occurred). *Sanders* classification was used, according to which type II fractures took place in 63.5%, type III — in 29.7%, and type IV — in 6.8%. In 25 cases (15.6%), fractures were open. Closed fractures were managed using conservative methods (in 49

cases, 36.3%), and surgical treatment with the use of various methods of repositioning and fixation. In 20 cases (14.8%), open reposition and osteosynthesis were used, in 66 (48.9%) — mini-invasive reposition and fixation with screws or a rod. Treatment of open fractures always included primary surgical debridementt of the wound, and reposition and fixation with wires were performed in 18 cases (72.0%). Fixation with wires was preferred because of simple and quick performing. In the remaining 7 cases, repositioning and fixation were not performed.

In the diagnosis and treatment of fractures of metatarsal bones and toes, special classifications were not used. In 2 cases, a fracture of the first metatarsal bone was diagnosed, in 19 cases there were fractures of other metatarsal bones, and there were 5 cases of toes fractures. Multiple fractures of forefoot bones were observed in 18 patients. Open fractures are diagnosed in 7 cases. The tactics of treatment of forefoot fractures were determined on the basis of location and the degree of fragmental displacement. Closed fractures of the 2^{nd}-5^{th} metatarsal bones with moderate displacement, fractures of the 5^{th} metatarsal bone in the 1^{st} and 3^{rd} zones (according to *Lawrence* and *Botte*), fractures of smaller toes and extra-articular fractures of the grea toe were treated condervatively. Fractures of the 1^{st} metatarsal bone, fractures of the 5^{th} metatarsal bone in the 2^{nd} zone, intra-articular fractures of the great toe and fractures with significant displacement were operated. Primary surgical debridement was performed for metatarsal bones together with intramedullar fixation with wires.

The fractures of the talus were classified by *Hawkins*. There were two cases of type I fracture, 8 cases of type II fracture, 9 cases of type III fracture, and 2 cases of type IV fracture. In 4 patients, fractores were open. In all observations, open reposition and osteosynthesis with screws and/or plates were performed.

The lesions of the Lisfranc joint were classified according to the classification of injuries of the tarsus-metatarsal joint by *E. Quenu* and *G. Kuss*. At the same time, there were 8 cases of type *A* injury, 1 caseof type *B*, and 9 cases of type *C*. There were no open injuries. In all cases, operative treatment was performed, consisting in open reposition and fixation with screws and wires. Three patients underwent primary arthrodesis.

In patients with midfoot trauma, multiple fractures prevailed (in 11 cases out of 13). There were 8 cases of scaphoid bone fracture, 7 cases of cuboid bone fracture, and 5 cases of cuneiform bones fractures. There were no open injuries. Special classification in the diagnosis did not use. Conservative treatment was used for multifrafmental fractures without coarse shortening, and surgical treatment was performed for fractures with significant displacement and fractures with incomplete dislocation of adjacent joints. The operation consisted of open repositioning, osteosynthesis and fixation of adjacent joints with screws.

In case of injuries of several parts of the foot, the most frequent combinations were fractures of calcaneus and talus (4 cases, 1 open injury), fracture of cuneiform bones with Lisfranc's joint damage (4 cases), calcaneus and scaphoid fractures with dislocation in the joint of Chopar in one case, open fractures of talus and calcaneus with dislocation in the Lisfranc joint and multiple fractures of metatarsal bones in one case (Fig.3).

Fig. 3. The X-ray of the foot. There is a gross displacement of the fragments of talus and calcaneus, incongruent articular surfaces of the Lisbon fractions

The information on the frequency of various injuries and options of treatment is shown in Table 1.

The catamnesis was tracked in 112 patients (51.8%), the observation period varied from 6 months to 3 years. When evaluating the results of treatment among early complications, tissue necrosis, postoperative infection and secondary displacement were taken into account. If necrosis of soft tissues developed, wound revision, necrectomy and vacuum drainage of the wound were performed before its secondary healing. If there were signs of wound infection, the wound was also explored and sanitized, the discharge was taken for inoculation, extensive lavage and necrectomy were performed. Antibiotic therapy was prescribed empirically in the first few days, and then by the results of inoculation. Secondary displacements, as a rule, were revealed in terms of at least 2 weeks after surgery and repeated attempts to improve the position of fragments were not taken.

Table 1

The distribution of patients by the type of lesions and options of treatment

Type of damage	Type of damage	Patients, *n* (%)		
		Conservative treatment	Surgical treatment	Total

			Open	Mini-invasive	
Fracture of calcaneus	closed	49 (36.3%)	20 (14.8%)	66 (48.9%)	135 (84.4%)
	open	7 (28.0%)	0 (0.0%)	18 (72.0%)	25 (15.6%)
Fracture of the talus	closed	0 (0.0%)	17 (100.0 %)	0 (0.0%)	17 (81.0%)
	open	0 (0.0%)	4 (100.0%)	0 (0.0%)	4 (19.0%)
Bone fractures in the middle part of the foot	closed	4 (30.8%)	9 (69.2%)	0 (0.0%)	13 (100.0%)
	open	-	-	-	0 (0.0%)
Damage to the joint of Lisfranc	closed	0 (0.0%)	17 (94.4%)	1 (5.6 %)	18 (100.0%)
	open	-	-	-	0 (0.0%)
Fractures of metatarsals and toes	closed	11 (57.9%)	2 (10.5%)	6 (31.6%)	19 (76.0%)
	open	0 (0.0%)	0 (0.0%)	6 (100.0%)	6 (24.0%)
Multiple fractures of the foot bones	closed	0 (0.0%)	8 (100.0%)	0 (0.0%)	8
	open	0 (0.0%)	2 (100.0%)	0 (0.0%)	2

Among late complications, contractures, deformations of the foot and avascular necrosis of bone structures were taken into account. Functional outcomes were assessed according to the *Foot Function Index (FFI)* scale, patinets were surveyed either in person or via email 6, 12, 24 and 36 months later.

When comparing the qualitative indicators during the processing of the results, the Pearson's agreement criterion was used, when comparing the quantitative indices, the type of distribution was determined by the Shapiro-Wilk method and using the Kolmogorov-Smirnov test. Under normal distribution, Kruskel-Wallis variance analysis methods were used, and for abnormal analysis nonparametric comparison methods were used (*U*-Mann-Whitney test). For counting, the *Statistica* program was used 10.0. The critical level of significance of the null statistical hypothesis was assumed to be 0.05.

RESULTS

The results of treatment, as well as the type and frequency of complications, differed depending on the location and type of the foot damage.

Among patients with closed calcaneus fractures, skin necrosis and infectious complications were reported in 3.5% of surgical procedures (3 patients) and did not occur with conservative treatment. The frequency of secondary displacements among operated patients with the use of plates, screws and rods was 5.8% (5 patients).

Regardless of whether the fractures were conservatively or operatively treated, 24 months later, similar functional outcomes were observed that corresponded to good results on the *FFI* scale (Table 2). The difference between the mean values persisted, but was not statistically significant ($p>0.05$).

Table 2

Functional outcomes according to the FFI scale in patients with calcaneus fractures 2 years after trauma

Type of damages	Type of fracture	Patients		
		Conservative treatment	Operative treatment	
			Open	Mini-invasive
Fracture of calcaneus	Closed	79.4 ± 17.2	89.5 ± 9.0	81.3 ± 9.4
	Open	-	-	59.5 ± 20.5

There was another situation among patients with open fractures. Necrosis of the skin in the wound area appeared in 7 cases out of 25, superficial wound infection was observed in 9 cases, and deep wound infection developed in 6 cases. The timing of wound healing in the region of the posterior foot was long (up to 3 months) (Fig. 4). In 4 cases of 18 with wire fixation, a secondary displacement occurred with a change in the Beller angle by more than 10 degrees. In many situations, the achieved good repositioning could not be retained with the help of wires fixation, so the quality of intraoperative reposition was worse than among those operated by other methods, the total proportion of patients with complications reached 72.0 %. In the long-term period, outcomes were statistically significantly worse than in patients with closed lesions (an average of 59.5 *FFI* 24 months later, $p<0.05$).

Fig. 4. Photos of a patient with an open fracture of the calcaneus: A - the wound after i njury; B - developing necrosis of the skin in the early postoperative period; C - wound condition 2 weeks after necrectomy and local treatment

In the treatment of patients with fractures of the forefoot bones there were no such complications as skin necrosis, postoperative infection and secondary displacement of fragment. In the group of open injuries of the forefoot, against the background of degloving wounds, in 2 cases, there was marginal necrosis of the skin, which did not require soft tissue plasty. Infectious complications and secondary displacement of fragments were not revealed. The *FFI scores* for the surveys 2 years after treatment averaged 93.7±8.1.

Among patients with fractures of the talus, cases of skin necrosis and infectious complications and secondary displacement were not observed. The problems in the delayed period prevailed. Avascular necrosis (AVN) of the talus block developed in 9 patients, 42.8% (in 4 patiens with a fracture of the block and in 5 patients with a fracture of the neck). The most frequent location of AVN was the posterolateral block (Fig. 5). Osteoarthritis (OA) of the ankle joint of various degrees was diagnosed in 15 cases (71.4%). Long-term outcomes mostly depended on the presence of AVN or OA. In the group of patients who did not have similar problems, the *FFI* score 2 years after injury was an average of 93.2±5.5. In the group of patients with AVN and OA, the average *FFI* score was 63.6±23.1, but the difference was statistically insignificant ($p>0.05$) due to the small number of observations. Within 3 years, the need for arthrodesis of adjacent joints arose in 2 patients after fracture of the block and its subsequent necrosis with collapse and pain syndrome (9.5%).


Fig. 5. The X-ray image of a patient with partial avascular necrosis of the talus block, 2 months after the surgery

In groups with injuries of the midfoot and the Lisfranc joint, there were no infectious and necrotic complications or cases of secondary displacement after fixation. Osteoarthritis was the main cause of unsatisfactory outcomes in patients with fractures of the talus. This complication was observed in 5 patients with midfoot bones injuries (38.5%) and in 8 patients with lesions of the Lisfranc joint (44.4%). The difference in functional outcomes between patients with developed osteoarthrosis and without it differed in mean values, but was not statistically significant (Table 3).

Table 3

Functional results of treatment in patients according to the FFI scale 2 years after trauma

Type of damage	Osteoarthritis		*R*
	Yes	No	
Fracture of midfoot bones	71.5±17.2	89.1±9.1	0.84
Trauma of the joint of Lisfranc	61.9±22.8	85.3± 1.3	0.44

Multiple foot injuries represented a group of severe lesions. The worst results were revealed in a patient with a combination of open fractures of the calcaneus and talus and dislocation in the joint of Lisfranc. Among early complications, necrosis of the skin of a postoperative wound was observed. There followed a long treatment of the wound and secondary displacement of the fragments against the background of wires fixation. After wound healing,

pain and deformity of the foot were required to perform subtalar arthrodesis, calcaneus osteotomy and sphenoid resection of themidfoot in later terms. As a result, the functional result 2 years after the injury was 40.3 points out of 100. A similar structure of complications arose in the patient with a combination of open fractures of the talus and calcaneus. The combination of lesions of the midfoot and Lisfranc joint did not lead to such severe consequences, however, post-traumatic OA occurred in 3 patients out of 4. The average *FFI* score in these patients was 66.5±19.8.

DISCUSSION

In this article, we did not focus on a few of the worst functional results among patients after conservative treatment of calcaneus fractures. According to our study, in most cases patients managed to achieve good function rational outcomes in the course of conservative therapy, but this required a longer rehabilitation period (up to 2 years). This trend is described in a number of large-scale comparative studies [5, 6].

At the same time, in our series of patients with open fractures of the calcaneus, a high incidence of wound complications, long periods of treatment and insufficient mechanical stability of fixation was revealed. According to reports in the press, many authors face similar problems. *S.J. Thornton et al.* ascertained the occurrence of necrotic and infectious complications in 29%, in 2 cases they led to limb amputation [7]. In a study of *J.R. Worsham et al.*, despite the fact that 44 out of 62 patients did not undergo internal osteosynthesis, in 5 cases (8%) infectious complications resulted in limb amputation [8]. Similar statistics of complications were demonstrated by *B. Wiersema et al*. [9]. At the same time, other authors report better outcomes when using a different treatment strategy. *E.A. Koski et al.* reported 35 patients with necrotic and infectious complications after open fractures and open calcaneus osteosynthesis. The authors used free soft tissue plasty to cover the soft tissue defect in the area of the posterior foot. In all the observations, infectious complications were cured [10]. *A.E. Ulusal et al.* presented a similar statistics when using a free soft-tissue flap in the treatment of fractures of the calcaneus 3B type according to the *Gustilo-Anderson* classification. The healing of soft tissues without signs of infection was achieved in 88% of cases [11].

In our study, the osteosynthesis of the calcaneus with wires had some shortcomings: high frequency of secondary displacements, infection, immobilization of the foot due to transarticular fixation and inconvenience to the patient. These problems can be solved with the use of mini-invasive technique and stable fixing structures instead of wires. When searching for the possibilities of stable fixation in conditions of open fractures and involved soft tissues, we considered the experience of authors who applied percutaneous reposition and osteosynthesis with screws. In particular, *A.W. Hammond* and *B.D. Crist* presented good results for this method in patients with high risk of postoperative complications not even having a single case of necrosis or infection in 17 patients [12].

In the treatment of fractures of the talus, the soft-tissue coverage and stable low-traumatic fixation did not cause difficulties. Instead, remote complications occurred in the form of AVN of the talus block and post-traumatic OA. A number of measures for the treatment of osteonecrosis have been described in the literature [13, 14], but attempts to perform revascularization of the talus during primary osteosynthesis are much less common in the literature. *H. Tang et al.* presented in 2010 9 cases of AVN with type 2 fractures by *Hawkins* with plasty of the neck of the talus with a rotated bone graft from the cuboid bone on the vascular pedicle. The authors didn't reveal a single case of avascular necrosis after surgery [15]. The fact that AVN occurs more often in the posterolateral part of the block, rather than in its anterior part or neck, where the authors suggest to fix an autograft, also remains questionnable. At the same time, we did not find any publications related to targeted revascularization of the block. Thus, measures for primary revascularization of the talus bone during the implementation of osteosynesis are an attractive but poorly studied method to manage avascular necrosis and post-traumatic arthrosis.

With regard to post-traumatic osteoarthritis of the Lisfranc joint, which led to disfunction and pain in 38.5% of patients with its damage, it should be noted that among the few patients with primary arthrodesis, the results were better, and repeated operations were performed only to remove the screws. If in the literature the question of the benefits of surgical treatment over the conservative can be considered solved [16], the choice of operative techniques and, in particular, the use of primary arthrodesis, is currently being discussed. *T.V. Ly et al.* in the presented randomized controlled study revealed significantly better outcomes in primary arthrodesis, especially in patients with exclusively ligamentary ruptures [17]. *Shahin Sheibani-Rad et al.* noted a similar trend in their systematic review [18].

CONCLUSION

Currently, in the literature there are data on possible ways to improve outcomes in the above categories of patients. It is advisable to continue research to verify their effectiveness and rationality. The most frequent causes of unsatisfactory outcomes of treatment for foot injuries in patients with isolated, multiple and multisystem trauma are wound complications against the background of open fractures of the calcaneus (up to 72.0%), avascular necrosis of the talus block (42.8%) and post-traumatic arthrosis of the ankle joint (71.4%), joints of the midfoot and the joint of Lisfranc (from 38.5 to 44.4%).

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