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Early Soft Tissue Coverage after Complex Foot Trauma

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Abstract. Complex foot injuries require early and durable soft tissue coverage to reduce infection rates and fibrosis, thereby improving the functional outcome. Definitive wound closure with tissue transfer was achieved as an emergency procedure within 24 hours in 2 of 28 cases, as urgent revision within 72 hours in 9 of 28 cases, and as early revision within 120 hours in 15 of 28 patients. To evaluate the global foot function the Maryland Foot Score was applied to 17 of 28 patients at the 1-year follow-up. The mean score was 74.2 (of 100) points, indicating "good" to "sufficient" foot function. The outcome was superior compared with a series of 18 consecutive open calcaneus fractures with delayed soft tissue coverage (64.4 points). These results were confirmed with a modified Merle d'Aubigné Score. The overall infection rate could be lowered to 7.1% after complex foot injuries with early soft tissue coverage compared to 26 open calcaneus fractures (19.2%). Functional scores allow a reasonable overall assessment of the results, but they are centered on subjective criteria. Thus they must be viewed in conjunction with radiologic and biometric factors as well as criteria valuable for plastic reconstruction, such as two-point discrimination and durability. Unfortunately, emergency flap procedures are still rare in foot surgery, although they permit primary stable osteosynthesis even with complex foot trauma. The foot should gain the same functional rank as the hand with respect to acute or emergency flap procedures to avoid further complications.

The implicit reconstructive goal following complex foot trauma is a plantigrade foot with reliable soft tissue coverage, a preserved sensate sole, and reasonable range of motion. In contrast, the available literature indicates that open injuries to the foot are associated with high infection rates, prolonged hospitalization, and poor functional results [1–4]. Even if the infection is eradicated, predominantly locomotive restriction persists because of extensive fibrosis and prolonged immobilization. Poor functional results are seen consistently with delayed or inadequate débridement in the polytraumatized patient, in which case secondary reconstructive and corrective surgery is often conducted as a salvage procedure [4, 5].

Among the reasons for poor functional results are delayed wound débridement in polytraumatized patients, inadequate attempts to "preserve foot function," delayed soft tissue coverage, and improper flap selection with respect to the mechanical qualities or arterial supply [4–7]. The concept of emergency or urgent soft tissue coverage (*urgence differée*) [8] after fractures with disruption or severe contusion of the skin aims at reducing the risk of infection and the number of repeat operations, thereby minimizing the duration of hospitalization and invalid status of the patients. Other important issues in regard to flap coverage of multilayer defects in the foot are shoe fitting, durability, and donor site morbidity [9–13].

The dilemma of comparing the results of various studies of foot surgery lies in the great variety of the scoring systems used. We employed two frequently used scoring systems, the Maryland Foot Score [14] and a modified Merle d'Aubigné Score [15], to evaluate the functional results after complex reconstruction of the foot with primary stabilization and early soft tissue coverage. These results are compared to a more homogeneous cohort of patients with isolated open calcaneus fractures. The value of the scoring systems was assessed, and limitations are discussed.

Materials and Methods

Complex Foot Trauma

Since May 1996, in close collaboration between plastic and trauma surgeons, early reconstruction of the bone and soft tissues was performed in 28 patients with complex foot trauma. All patients were assessed with respect to the severity of trauma according to the Hanover Polytrauma Score (PTS) [16] and the complex foot trauma score (CFTS) [4]. Each level affected by a fracture or dislocation between the ankle/pilon (level I) and the tarsometatarsal (Lisfranc's) joint and below (level V) is credited with 1 point; a maximum of 3 points is given depending on the degree of soft tissue damage (according to the Tscherne classification) [17], and supplemental points are given for degloving injuries and subtotal amputations (Fig. 1). Complex foot trauma is present with a score exceeding 5 points, which may be expected in approximately 10% of all cases [5]. All injuries were treated as emergencies with aggressive initial débridement. Primary stable osteosynthesis was performed for first- and second-degree open fractures. For third-degree open fractures, minimally invasive

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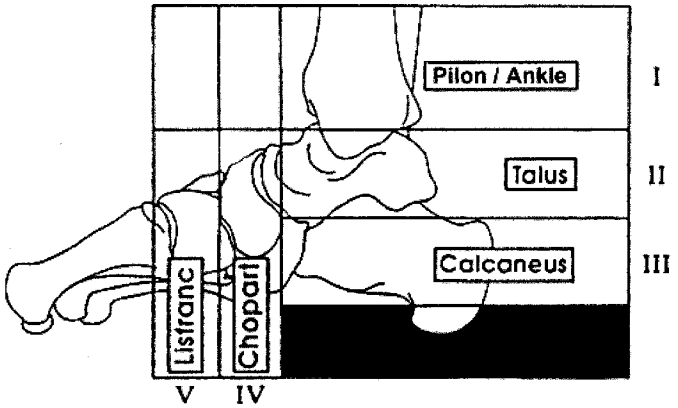

Fig. 1. Complex foot trauma score. Each affected principal region (I–V) is credited with 1 point; 1 to 4 points are given for the extent of soft tissue damage. Complex foot trauma is defined as an injury resulting in 5 points or more. (a) Dislocation fracture level I to IV, 1 to 5 points; (b) open/closed dislocation (1–3 degrees) or degloving injury/subtotal amputation (4 degrees), 1 to 4 points; (c) combination (a + b) (minimum), 5 points. (Adapted from Zwipp [4], with permission.)

Acute		**Early**	**Delayed**
Emergency Procedure	Urgent Revision		
0-24 h	24-72 h	72-120 h	more than 120 h

Fig. 2. Proposed definition of timing for tissue transfer for complex foot trauma.

stabilization and additional tibiometatarsal transfixation was preferred. The timing of soft tissue reconstruction was referred to as the acute phase when reconstruction was done within 72 hours, which was achieved in 11 of 28 cases; an emergency procedure (within 24 hours) was done in 2 cases, and urgent operation (24–72 hours), was done in 9. All in all, 26 of the 28 patients underwent definitive early flap coverage within 120 hours of the complex foot trauma (Fig. 2).

The flap design was chosen based on the like-is-like principle, considering Hidalgo's plantar zones [12, 18, 19]. Of the 28 patients, 18 had isolated trauma to the foot with a mean CFTS of 5.05; 3 patients had multiple injuries (PTS 8.33) with a mean CFTS of 5.33; and 7 were polytraumatized (PTS 22.7) with a mean CFTS of 5.42. Fractures and severe soft tissue damage at the following levels (and combinations of them) were seen: pilon and ankle in 11 cases, talus in 4 cases, calcaneus in 14 cases, mid-tarsal (Chopart's) joint in 6 cases, tarsometatarsal (Lisfranc's) joint in 5 cases, multiple fractures or traumatic amputations of the metatarsals and toes in 4 cases. All were open foot injuries ($n = 26$) or closed injuries with an impeding compartment syndrome that warranted fasciotomy ($n = 2$). One example of each group is illustrated in Figures 3 and 4. Of the open foot injuries, 3 were classified as first-degree, 11 as second-degree, and 10 as third-degree open fractures according to the Tscherne et al. classification [17].

Defect coverage was achieved with local flaps in 16 cases (6 distally based sural artery neurocutaneous flaps; 2 extensor digitorum brevis muscle flaps; 2 flexor digitorum brevis muscle flaps; 2 medial plantar (instep) flaps; 1 dorsalis pedis island pedicle flap; 1 fasciocutaneous island flap; 1 lateral calcaneal flap; 1 abductor digiti minimi muscle flap; and 12 free tissue transfers (5 fasciocutaneous radial forearm flaps; 1 lateral forearm flap; 4 latissimus dorsi flaps; 1 rectus abdominis muscle flap; 1 serratus anterior muscle flap). To obtain primary closure all muscle flaps were covered with split-thickness skin grafts immediately.

Calcaneus Fractures

To allow an evaluation of the early flap procedures for open foot injuries, the results were compared with those from a group of open calcaneus fractures treated with delayed soft tissue closure. Between October 1993 and December 1998 at the Trauma Department of the Dresden University Hospital, 235 fractures of the calcaneus were treated, among them 178 displaced fractures with open reduction and internal fixation (ORIF). In 26 cases (11%) open fractures of the calcaneus were seen, and all were treated surgically.

Intraarticular fractures with displacement of the subtalar joint of more than 1 mm or extraarticular fractures with varus deformity of the hindfoot of more than 5 degrees or hindfoot valgus of more than 10 degrees were treated with ORIF. Open fractures were operated on immediately with aggressive débridement of the wound, indirect fracture reduction and temporary fixation with percutaneous K-wires, or through a limited approach and tibiometatarsal transfixation. Temporary wound closure was obtained with synthetic skin substitutes. A second look was conducted after 48 hours. If soft tissue conditions allowed a stable internal osteosynthesis, it was performed approximately 10 days after the injury via an extended lateral approach [14, 20, 21]. After reduction of the tuberosity and sustentacular fragments, the posterior facet and, if involved, the anterior facet and calcaneocuboid joint internal fixation were reconstructed with a standard "Tampa" calcaneal plate modeled to the lateral wall of the calcaneus [21]. With substantial bone loss after elevation of the posterior facet fragment, autologous cancellous bone grafting from the ipsilateral iliac crest was used to fill up the defect. If critical soft tissue conditions, especially on the lateral side, prevented open reduction and internal fixation, no plate osteosynthesis was performed beyond 14 days after the injury because of the increased risk of superficial or deep infection. In these cases the tibiometatarsal external fixator and K-wires were left in place until the fracture had healed.

Definitive wound closure, with autologous skin grafting or tissue transfer, was achieved after single or multiple second-look surgeries between 1 and 2 weeks. If the defect was medial, wound closure was carried out at the same session as ORIF via the extended lateral approach. Postoperative active and passive range of motion (ROM) exercises were postponed until the skin grafts had healed. Partial weight-bearing was allowed the fifth day after surgery and full weight-bearing 6 to 12 weeks after surgery depending on the degree of comminution, the amount of cancellous bone grafting, and radiographic evidence of bone healing [21].

Fig. 3. This 26-year-old man had multiple fracture-dislocations at Chopart's and Lisfranc's joints as well as serial fractures of the metatarsals combined with extensile dorsal soft tissue avulsion after being run over by a mini-excavator. **a.** Initial stabilization with K-wires and supplemental tibiotarsal transfixation. **b.** Radical débridement of all avital tissue left a multilayer soft tissue defect at the whole dorsum pedis. **c, d.** Soft tissue coverage with a fasciocutaneous radial forearm flap within 12 hours as an emergency procedure resulted in a vital, mobile, stable dorsum pedis and near-normal foot function, as evidenced by his heel and toe gait 10 months after the injury.

Follow-up

Patients were reevaluated after a minimum of 10 months postoperatively. The patients with complex foot trauma who underwent early reconstruction and flap coverage (also referred to as group A) were compared with patients with open calcaneus fractures who were treated operatively with delayed osteosynthesis and soft tissue closure (group B).

The follow-up protocol included a patient interview, clinical examination, and radiologic examination (weight-bearing radiographs of both feet, ankles, and calcanei: "Harris view") in all patients. Axial and coronal computed tomography (CT) was con-

Fig. 4. a. A 17-year-old boy with multilayer soft tissue necrosis after a third-degree closed calcaneus fracture with compartment syndrome after a motorcycle accident treated primarily with dorsal fasciotomy. **b.** After radical débridement the calcaneus fracture was openly reduced and stabilized with Kirschner wires; a latissimus dorsi flap with a plantar (instep) monitor island was applied to the almost circular resulting defect. **c, d.** Stable soft tissue coverage 4 months after tissue transfer at the plantar (c) and lateral (d) aspects with sufficient overall foot function at the 1-year follow-up.

ducted after hardware removal. The overall functional results were assessed with the Maryland Foot Score [14] and a modified Merle d'Aubigné score [15]. All follow-up investigations including scoring were done by the two senior authors (P.B. and S.R.).

Results

Complications

The following complications and secondary procedures were observed with early flap procedures after complex foot trauma (group A): one case (3.6%) of thrombosis and partial flap necrosis (coincidental with angiography), one case (3.6%) of persisting infection below a radial forearm flap after an aviator's astragalus with subtotal foot amputation and wound contamination by soil and grass, resulting in an overall infection rate of 7.1%. All necrotic tissue was excised in the patient with partial flap necrosis. The resulting defect after débridement was temporarily covered with synthetic skin substitutes and definitively closed with skin grafting, resulting in a retracted scar with restricted ROM. In the second case persisting infection was treated with surgical débridement (astragalectomy), implantation of antibiotic beads, immobilization, and intravenous antibiotics. The infection resolved with this regimen and tibocalcaneal arthrodesis with bone graft interposition was performed, preserving the flap. Minor complications were skin graft loss in one case (3.6%) and two cases of venous congestion following distally based sural artery neurocutaneous flaps (7.1%) that resolved with decongestion of the flaps. Debulking or defatting of muscle flaps was conducted as a supplementary secondary procedure in two cases. Altogether, three of the six observed complications were direct consequences of the flap coverage method and resolved in two cases with secondary procedures (decongestion of the venous stalk of the flap).

After open calcaneal fractures were treated surgically with delayed osteosynthesis (group B), the observed infection rate was 19.2% (5 of 26 cases), which was considerably higher than in group A. Looking at the calcaneus fractures as a whole, the overall infection rate in 178 patients treated surgically was 4.5%. However, five of eight infections occurred after open injuries. In four cases deep soft tissue infection resolved with serial débridements, intravenous antibiotics, and prolonged immobilization. In one case osteomyelitis developed, resulting in a protracted course that finally ended in subtalar arthrodesis. No amputations were necessary. No wound hematoma was observed because of delayed soft tissue closure. Superficial wound edge necrosis developed in one case (3.8%) and resolved with local antiseptic treatment.

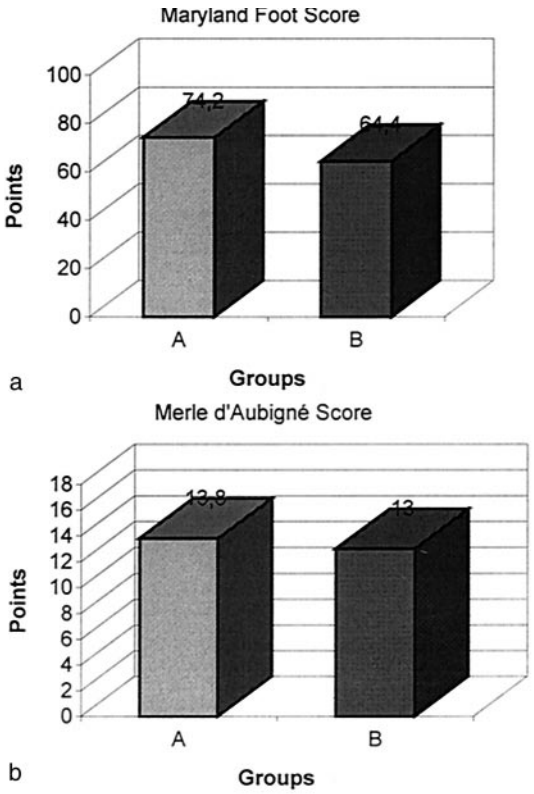

Fig. 5. Functional 1-year results according to the Maryland Foot Score (**a**) and the modified Merle d'Aubigné Score (**b**) for the two groups. A: complex foot trauma with severe soft tissue disruption treated with early reconstruction and flap coverage; B: open calcaneus fractures treated operatively with delayed soft tissue coverage. Statistical analysis was not performed because of the relatively small sample size.

Follow-up

At the time of this writing, follow-up was a minimum of 10 months (mean 14 months) for 17 of the 28 patients (61%) in the group who had early soft tissue transfer and osteosynthesis after complex foot trauma (group A) and for 18 of 26 patients (69%) in the group with open calcaneus fractures treated with delayed soft tissue closure and osteosynthesis (group B). The mean age was 40.1 years (range 15–71 years) in group A with a male/female ratio of 6:1. The mean age in group B was 39.6 years (range 14–80 years) with a male/female ratio of 4:1, resulting in two inhomogeneous groups but of comparable patient profile concerning size, age, and gender. The average Maryland Foot Score (maximum 100 points) was 74.2 (range 35–93) for group A and 64.4 (range 31–97) for group B. The average Merle d'Aubigné Score (maximum 18 points) was 13.8 (range 5–18) for group A and 12.9 (range 8–18) for group B. The results are summarized in Figure 5. With the relatively low numbers, statistical analysis did not seem to be of value; therefore no significance tests were conducted. The average plantar two-point discrimination after tissue transfer was 27 mm (range 20–35 mm) in the patients with flap coverage for plantar defects, compared to less than 15 mm in those with normal feet.

Discussion

The difficulty of assessing outcome after foot trauma is evidenced by the great variety of existing scores, which hampers comparison among studies. Almost all authors use different scoring systems when reporting treatment results after calcaneus fractures, and so far no score clearly demonstrates its superiority [22]. The Maryland Foot Score (with a total of 100 points) is easily applicable to the whole foot [14]. It consists predominantly of subjective factors, with pain (45 points) being the major contributor. Alignment of the foot and ROM are of considerably less importance and are based on clinical judgment rather than numeric values.

The American Orthopaedic Foot and Ankle Society (AOFAS), in an effort to provide a standard method for reporting the clinical status of the foot and ankle, introduced four rating systems for the ankle-hindfoot, mid-foot, hallux, and lesser toes [23], which have been widely used by American authors. However, for complex foot trauma with multiple injuries to various regions of the foot, subdivision with the four scales did not seem practical in the present study.

Another widely used score for foot surgery is a modification of Merle d'Aubigné's functional score [15] that was originally designed to evaluate hip function [24]. With a maximum of 18 points it is quick and easily applicable, but it is also less accurate. In contrast to the above-mentioned scales, this score assigns numeric values to excellent, good, fair, and poor results. It was included in this study for comparison because many European authors still refer to it.

The results of the present study showed homogeneity within the scoring systems and good reproducibility between the two scores when comparing the results after complex foot trauma (group A), which means that ranges and mean values were similar with the two scores. However, when assessing the results of calcaneus fractures (group B), the modified Merle d'Aubigné score seemed to tend toward falsely good results (even in patients with greater limitations) and to level out differences among the patients. The range is smaller, and the mean score (as a percentage of the total points) is considerably higher than with the Maryland Foot Score.

Despite all the difficulty achieving a reliable assessment of outcome, the present study showed a clear tendency toward better results after early soft tissue coverage compared with delayed coverage after open injuries to the foot. In this preliminary series the seemingly inevitable high infection rate after open fractures of the calcaneus could be lowered to less than half that after early flap procedures. Muscle flaps have vividly demonstrated their ability to control osteomyelitis [9]. In a retrospective study with 532 free tissue transfers, Godina [25] reported significantly better results with respect to the infection rate, which was 1.5% after early soft tissue coverage (< 72 hours) compared with 17.5% after delayed soft tissue resurfacing. The same applies to stable fixation of the fractures. Bray et al. [26] reported better ROM and shorter hospitalization after primary stable osteosynthesis of open ankle fractures compared with a delayed osteosynthesis. In addition, early rigid stabilization of fractures enhances soft tissue healing [10] and helps minimize the need for external fixation, which itself carries a risk for pin-track infection. In the present study overall foot function, as judged by both the Maryland Foot Score and the Merle d'Aubigné Score, after early osteosynthesis and soft tissue coverage after complex foot trauma was superior to delayed os-

teosynthesis and soft tissue resurfacing of isolated open calcaneal fractures.

It must be noted that these results are preliminary, with only about two-thirds of the patients being eligible for follow-up in both groups and a mean follow-up of only 14 months. Another limitation of the study is the comparison of such different patient cohorts, such as those with complex foot trauma and those with isolated calcaneus fractures. The reason for doing so was simply that the annual total numbers of multiply injured feet with soft tissue disruption are limited, whereas calcaneus fractures are among the most frequent injuries to the foot. Because in almost 80% of cases they are accompanied by at least second-degree of soft tissue compromise, [21] these injuries can, despite some limitations, serve as a comparison.

The opinions in the literature as to when soft tissue coverage is considered "acute" or "early" vary considerably. Godina [25] performed early coverage within 72 hours; Cierny et al. [27] considered coverage within 7 days early; and Yaremchuck et al. [28] recommended flap closure within 2 weeks. In our series the ideal of achieving soft tissue closure within 72 hours, as described originally with the concept of *urgence differée* by Iselin [8] and already practiced with severe hand injuries [29], could not be accomplished in all cases, but 26 of 28 tissue transfers were done within 120 hours after the accident. The authors' proposal for a description of the timing of tissue transfer is given in Figure 2. Among reasons for delaying soft tissue coverage are a critical overall condition of the patient because of accompanying life-threatening injuries and instantaneous availability of a plastic surgery team.

In the multiply injured patient, foot injuries are often awarded a relatively low priority. Unfortunately, emergency or early flap procedures are still rare in foot surgery, though they permit primary stable osteosynthesis and functional aftertreatment even with complex foot trauma. Early tissue transfer is possible only in close collaboration between plastic and trauma surgeons with the technical equipment and operative capacities of a major clinic. In Germany, at present, an estimated 25 hospitals (mostly university medical centers) would be able to perform emergency flap procedures on a routine basis. However, if a patient with complex foot trauma is seen at small hospitals, transfer to a medical center within 72 hours is possible in most instances. Of course, a critical overall condition of the polytraumatized patient does not permit these procedures. When faced with the decision of preserving the foot or amputation after severe foot trauma, Tscherne suggested primary amputation at the level of injury in patients with a high polytrauma score [30].

Conclusions

The foot should gain the same functional rank as the hand with respect to acute or emergency flap procedures to avoid further complications. In our preliminary series a lowered infection rate and satisfactory 1-year results were seen after early soft tissue coverage for complex foot trauma.

Résumé

Les lésions complexes du pied nécessitent une couverture précoce et durable pour réduire le taux d'infection et de fibrose, améliorant ainsei l'évolution. Une couverture définitive de la plaie par transfert de tissu a été réalisé soit en urgence (moins de 24 heures) dans 2/28 cas, soit comme un procédé de révision (moins de 72 heures) dans 9/28 cas ou comme un procédé de reprise (moins de 120 heures) chez 15/28 patients. Afin d'évaluer la fonction globale, on a appliqué le Maryland Foot Score chez 17 des 28 patients à l an de l'intervention. Le score moyen a été de 74.2 de 100 points possibles indiquant une fonction du pied «satisfaisante» ou «suffisante». En comparaison avec une série de 18 patients ayant eu une couverture retardée de tissu mous pour fracture de calcanéum ouverte, l'évolution a été considérée comme supérieure (64.4 points). Ces résultats ont été confirmés par le score de Merle d'Aubigné modifié. Le taux global d'infection a pu être abaissé à 7.1% après des lésions complexes du pied par couverture précoce de tissus mous comparé aux résultats des 26 fractures de calcanéum ouvertes (19.2%). Les scores fonctionnels permettent une évaluation globale du résultat, cependant, ils sont basés sur des critères subjectifs. Ainsi ils doivent être pris en conjonction avec des facteurs radiologiques et biométriques ainsi qu'avec des critères pour reconstruction plastique tels que la discrimination tactile en deux points et la durabilité. Malheureusement, les procédés de couverture par lambeaux sont rarement pratiqués en chirurgie du pied en urgence bien qu'ils permettent une ostéosynthèse primitive stable même en cas du traumatisme du pied complexe. Dans ce contexte, le pied doit pouvoir bénéficier et gagner le même rang fonctionnel que la main en ce qui concerne la couverture précoce pour éviter des complications ultérieures.

Resumen

Los traumatismo complejos del pie requieren un precoz y duradero recubrimiento con tejidos blandos para reducir el porcentaje de infecciones y de fibrosis, lo que mejorará el resultado funcional final. La oclusión definitiva con tejidos trasplantados se realizó de urgencia (dentro de las primeras 24 horas) en 2/28 casos, como urgencia diferida (dentro de las 72 horas) en 9/28 casos y de forma precoz (120 horas) en 15/28 pacientes, Para valorar la función global del pie, tras 1 año de seguimiento se utilizó la Escala del pie de Maryland en 17/28 pacientes. La puntuación media fue de 74.2 sobre 100 puntos lo que implicaba desde una "buena" hasta una "suficiente" función del pie. Los resultados fueron mucho mejores que los obtenidos con una serie de 18 fracturas abiertas de calcáneo que fueron ocluidas con tejidos blandos tardíamente (64.4 puntos). Estos resultados se confirmaron utilizando la escala evaluativa modificada de Merle d'Aubigné. La incidencia global de infección descendió a un 7.1% en traumatismo complejos del pie recubiertos precozmente con tejidos blandos. Este hecho contrasta con el 19.2% de infecciones registradas tras fracturas abiertas del calcáneo. Las evaluaciones funcionales permiten juzgar adecuadamente los resultados globales, a pesar de que los criterios de valoración sean mas bien subjetivos. Por ello, estos resultados deben revisarse en conjunción con los hallazgos radiológicos y parámetros biomecánicos, así como con los criterios de valoración utilizados en cirugía plástica reconstructura. Desgraciadamente la utilización urgente de colgajos es poco frecuente en la cirugía del pie, a pesar de que permiten realizar una osteosíntesis primaria estable incluso en traumatimos complejos del mismo. El pie ha de alcanzar desde el punto de vista funcional la misma importancia que la mano, por lo

que respecta a la utilización precoz y urgente de colgajos de tejidos blandos, con objeto de evitar complicaciones tardías.

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