



## Review Article

# Foot and ankle fractures during childhood: review of the literature and scientific evidence for appropriate treatment<sup>☆</sup>



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## ARTICLE INFO

## Article history:

Received 27 October 2015

Accepted 30 October 2015

Available online 13 September 2016

## Keywords:

Ankle joint

Calcaneus

Talus

Child

## ABSTRACT

Foot and ankle fractures represent 12% of all pediatric fractures. Malleolar fractures are the most frequent injuries of the lower limbs. Hindfoot and midfoot fractures are rare, but inadequate treatment for these fractures may result in compartment syndrome, three-dimensional deformities, avascular necrosis and early post-traumatic arthritis, which have a significant impact on overall foot and ankle function. Therefore, the challenges in treating these injuries in children are to achieve adequate diagnosis and precise treatment, while avoiding complications. The objective of the treatment is to restore normal anatomy and the correct articular relationship between the bones in this region. Moreover, the treatment needs to be planned according to articular involvement, lower-limb alignment, ligament stability and age. This article provides a review on this topic and presents the scientific evidence for appropriate treatment of these lesions.

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## Fraturas do tornozelo e do pé na infância: revisão da literatura e evidências científicas para o tratamento adequado

## RESUMO

As fraturas do tornozelo e do pé representam 12% de todas as fraturas pediátricas. Fraturas maleolares são as lesões mais frequentes dos membros inferiores; fraturas do retropé e mediopé são raras, mas o seu tratamento inadequado pode resultar em síndrome de compartimento, deformidades tridimensionais, necrose avascular e osteoartrose pós-traumática precoce, as quais apresentam impacto significativo na função global do tornozelo e pé.

## Palavras-chave:

Articulação do tornozelo

Calcâneo

Tálus

Criança

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<http://dx.doi.org/10.1016/j.rboe.2016.09.001>

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Portanto, os desafios no tratamento dessas lesões na criança são o diagnóstico adequado e tratamento preciso para se evitarem as complicações. O objetivo do tratamento é restaurar a anatomia normal e a relação articular correta entre os ossos da região. Além disso, o tratamento deve ser planejado de acordo com acometimento articular, o alinhamento dos membros inferiores, a estabilidade ligamentar e a idade. O algoritmo de tratamento dos traumas complexos do tornozelo e pé na infância é descrito. Este artigo apresenta uma revisão sobre o tema e as evidências científicas para o tratamento adequado dessas lesões.

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## Introduction

Ankle and foot fractures account for 12% of all pediatric fractures. They usually require investigation through careful imaging exams for proper diagnosis.<sup>1</sup> In recent decades, a significant increase has been observed in incidence rates, including those related to complex trauma of this anatomical topography.<sup>2</sup> Inappropriate therapeutic decisions can result in serious complications, such as compartment syndrome, three-dimensional deformity, avascular necrosis, and early post-traumatic osteoarthritis, with negative impact on the overall function of the ankle and foot.<sup>3</sup> This article aims to present the scientific evidence for the treatment of these traumatic injuries.

## Malleolar fractures

Injuries of the epiphyseal plates around the ankle represent 10–25% of all growth plate injuries. Therefore, they are the most prevalent physeal injuries in the lower limbs.<sup>1</sup> Such tibia and distal fibula injuries can lead to post-traumatic bone growth disorders. Fractures of the medial malleolus are particularly critical and are underdiagnosed in incomplete radiographic investigation.<sup>2</sup>

The typical fracture patterns at ankle level per age are:

1. Impaction fracture with distal flexion of the tibia (under 10 years of age)
2. Fracture of the medial malleolus (around 10 year-old)
3. Epiphyseal and metaphyseal fractures (prepubertal period)
4. Transition fractures in the physeal region (12–14 years of age).

Malleolar fractures result from indirect trauma mechanism by adduction, abduction, and external rotation of the foot against the lower leg. The fracture line is also determined by the position of the foot at the time of the accident. In about three-quarters of cases, the foot is in supine position (inversion), while in one-quarter, the foot is in prone position (eversion).<sup>3</sup>

The classification system developed by Lauge-Hansen<sup>4</sup> consists of these components and can be used for children and adolescents, accordingly.<sup>1</sup> Dias and Tachdjian<sup>5</sup> modified this classification for children and introduced the plantar supination-flexion type.

The classification systems proposed by Aitken<sup>6</sup> or Salter and Harris<sup>7</sup> are related to growth plate injuries. They are divided as follows:

1. Pure injury of the growth plate
2. Epiphyseal injury with wedge fracture of the metaphysis (Aitken II)
3. Epiphyseal injury with wedge fracture of the epiphysis (Aitken II)
4. Meta-epiphyseal fracture that crosses the physeal line (Aitken III)
5. Compression fracture of the growth plate
6. Physeal lesion with growth plate defect (added posteriorly by Peterson<sup>8</sup>)

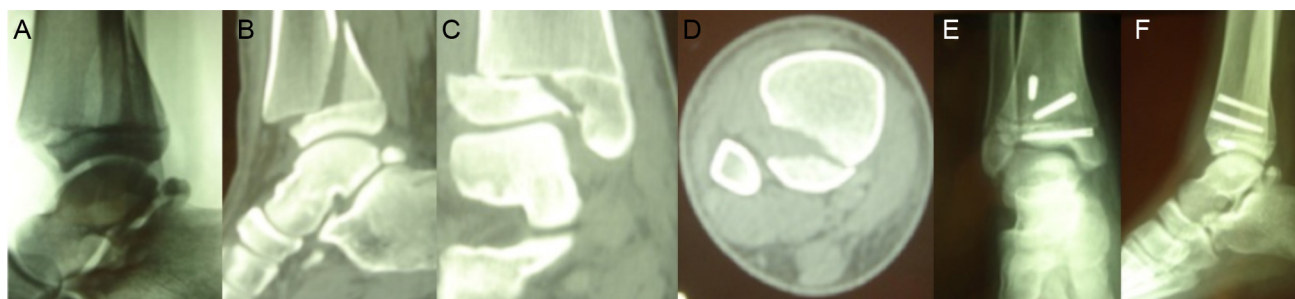
The physeal plate of the distal tibia is responsible for 45% of the growth in length of the leg; ossification of this region occurs between 12 and 14 years of age, over a period of 1 year and 6 months. This process begins in the medial portion, moving toward the central third of the epiphysis, and posteriorly advancing to the lateral region; thus, the last portion to be calcified is the anterolateral (Chaput's tubercle). Fractures of the distal tibia at this stage (transitional) represent a separate entity. The energy of trauma can lead to horizontal or perpendicular (sagittal) lines, and sometimes in a third plane (frontal), with the formation of a dorsal wedge, which results in biplanar or triplanar injuries.<sup>9</sup> Suspected "transitional" fractures in adolescents require an investigation through accurate imaging, preferably with the aid of computed tomography (Fig. 1).

## Therapeutic evidence

Fracture-dislocations are ideally treated after intravenous analgesia, with anesthesiologist monitoring for patient safety; the joint is reduced and the fracture is aligned with the lower limb to prevent further damage to soft tissues and chondral tissue.

The *emergency indication* for immediate surgery occurs in cases of open fracture or cases of closed fracture with severe soft tissue damage, such as extensive subcutaneous detachment, massive internal pressure from the bone fragments, or compartmental syndrome.<sup>3</sup>

*Minimally displaced or non-displaced fractures* may be treated conservatively with immobilization without weight bearing for three to four weeks.



**Fig. 1 – (A) Profile radiography of a triaxial fracture of the right ankle. (B–D) Sagittal, coronal, and axial sections of computed tomography of the right ankle. (E and F) Anteroposterior and profile postoperative radiographs showing the fixation with compression screws.**

Initially *diverted* fractures, particularly Salter–Harris type I physal detachment, may be successfully treated after closed reduction and immobilization without weight bearing for three to four weeks.

The anatomical reduction of displaced *Salter–Harris type II–IV* fractures in children and adolescents is usually difficult due to the tough, thick periosteum. Often, the interposition of that tissue or even of the neurovascular bundle at the fracture site prevents closed reduction.<sup>10</sup>

There is insufficient evidence in the literature indicating the exact tolerable point for opting for conservative treatment. However, there are many indications that open reduction and internal fixation of deviated fractures greatly reduce the risk of premature closures when compared with conservative therapy.<sup>11–13</sup> Many studies have shown better long-term outcomes in patients treated with anatomical reduction.<sup>14–16</sup>

At first, open reduction should be made in extra-articular fractures (Salter–Harris type II) with fragment deviations greater than 3 mm, or in cases where repositioning is impossible due to interposition. In intra-articular fractures, open reduction is recommended for those with a displacement measuring 2 mm or more<sup>14</sup>; however, some authors argue that this procedure should be performed in fractures greater than 1 mm.<sup>17,18</sup>

Osteosynthesis should be made with screws parallel to the epiphysis and, where possible, perpendicular to the fracture line, for interfragmentary compression. When instability is present, which requires implants to be passed through the growth plates, this should be made with Kirschner wires only temporarily.<sup>14,17,18</sup>

Usually, after stabilization of the tibia, the *fibula* presents aligned and stable; otherwise, stabilization of the fibula can be sufficiently achieved with intramedullary Kirschner wires.<sup>19</sup>

The typical *biplane fracture* is a bone avulsion of the anterior and lateral edge of the tibia in the frontal plane (Tillaux–Chaput fragment), representing a ligament injury of the *anterior syndesmosis*; fragments should be anatomically reduced, and the stabilization should be made with a small screw.<sup>3</sup>

The *triplane fracture* is also articulate and presents an additional fracture perpendicular to the medial malleolus, resulting in a metaphyseal wedge. After anatomical reduction, stabilization of these additional pieces is made with compression screws parallel to the epiphysis.<sup>20</sup>

The operated limb is immobilized with a sural-podal splint during the period of healing of surgical incisions wounds, for 7–10 days. After this period, weight bearing is authorized, with the use of a protective immobilization boot until the end of the fourth postoperative week. Full unprotected weight bearing is authorized based on patient complaints and radiographic control.<sup>3</sup>

### Talus fractures

These are extremely rare, due to the high elastic resilience of this bone, which is mostly consisted of cartilage in childhood.<sup>21</sup> Published studies indicate an annual prevalence from 0.01% to 0.08% in children.<sup>22,23</sup> Talus neck fractures are the most common, being similar to those of adults, as classified by Hawkins<sup>24</sup>; followed by talar body fractures, with high trauma mechanism. Finally, fractures of the talar head are usually secondary to dislocation of the midtarsal joint (Chopart).<sup>25</sup>

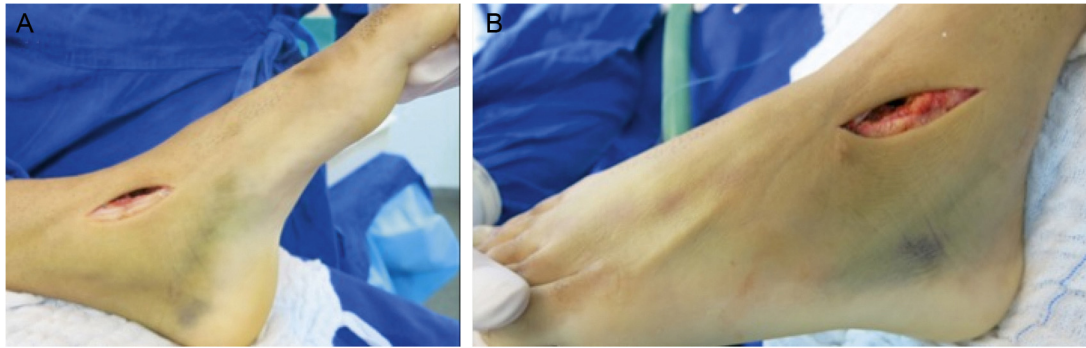
In turn, peripheral talar fractures (lateral and posterior processes) are very rare and difficult to diagnose in this age group, requiring investigation through precise imaging exams with the aid of computed tomography; when untreated, they result in foot pain and limitation of the subtalar joint in adulthood.<sup>23</sup>

Central and peripheral fractures of the talus were classified by the Marti<sup>26</sup> uniform classification system, which was later adopted for adults:

1. peripheral fractures (lateral process, posterior process, head)
2. central fractures without displacement (neck and body)
3. central fractures with displacement or dislocation of a central joint (mainly subtalar)
4. multifragmentary central fractures or fracture-dislocations with displacement of at least two joints

With increasing patient age (about 12 years), the number of high-energy injuries and therefore the severity of the fracture clearly increase.<sup>27,28</sup>

Due to the central position of the talus between the leg and foot as well as its position in three key joints, small residual misalignments, articular congruence, small remaining joint fragments, or even inadequate osteosynthesis of these fractures can result in considerable limitations of global ankle and



**Fig. 2 – (A) Medial access route for surgical treatment of talus fracture. (B) Lateral access route for surgical treatment of talus fracture.**

foot function, in between 27% and 38% of cases, an observation that has been well described in the literature.<sup>29-35</sup>

The greatest problems arise mainly due to joint misalignments or axial displacements, typically with varus deformity of the talar neck and consequent shortening of the medial column of the foot.<sup>35</sup>

#### **Therapeutic evidence**

Nonsurgical treatment is recommended only in minimally displaced or undisplaced fractures.<sup>21</sup> The treatment of choice for all displaced talar fractures is anatomic reduction and stable internal fixation; for a sufficient view of the repositioning of the anatomical axes, two access routes are usually required (medial and lateral; Fig. 2).<sup>36</sup>

The fixation should be made with screws, which balance the mechanical efficiency and minimize damage to the cartilage surfaces; in younger children, crossing Kirschner wires allow for adequate stability.<sup>3</sup>

Osteochondral fragments are fixed with fibrin glue or absorbable pins.

The additional presence of a situation of instability is due to a capsuloligamentous injury or bone comminution; in a critical tissue situation, it may be due to the external fixator.<sup>21</sup>

The risk of avascular necrosis associated with central fractures involves high-energy trauma and the degree of displacement, with an incidence of 16% of observed cases.<sup>27,37</sup> Children under 6 years of age are the most affected, especially when late-diagnosed.<sup>37</sup>

The spontaneous course of talar body necrosis in childhood is generally good, with a gradual remodeling of the talus in the course of two years; therefore, it is not necessary to prevent weight bearing in the affected leg for a long period of time.<sup>3</sup>

When timely, corrective joint preservation surgery can improve prognosis. Osteoarthritis signs are reported on average two years after the fracture in up to 17% of patients.<sup>38</sup> Meier et al.<sup>39</sup> observed long-term need for ankle arthrodesis in 25% of cases, at a mean of 11 years after the injury.

#### **Calcaneal fractures**

They represent merely 0.05% to 0.15% of all fractures in childhood. Only 5% of all calcaneal fractures occur in

childhood. The peak age is between 8 and 12 years, and the most prevalent trauma mechanisms are falls from height or traffic accidents.<sup>40,41</sup>

When compared with adults, there is a higher proportion of extra-articular fractures.<sup>42-44</sup> Extra-articular fractures affect the calcaneal tuberosity and sometimes show an articular line without deviation of the posterior facet.<sup>45</sup> Computed tomography is the best imaging method to confirm diagnosis and rule out intra-articular involvement.

Wiley and Proffitt<sup>46</sup> reported late diagnosis in 43% of the extra-articular calcaneal fractures.

Stress fractures in infants are described at the beginning of gait (toddler's fracture). In this scenario, the children refuse to walk; two weeks thereafter, radiography shows bone sclerosis in the calcaneal tuberosity with spontaneous recovery.<sup>47</sup>

The apophysis of the calcaneal tuberosity is visible in profile radiography in girls between 5 and 13 years and in boys between 7 and 15 years. Occasionally, acute fracture of the apophysis is described and should be treated with suture.<sup>48</sup> This is different from osteochondrosis of the calcaneal apophysis (Sever's disease), which is secondary to an inflammatory or overload process.<sup>45</sup>

In adolescents who practice sports, a special form of injury is the avulsion fracture of the calcaneus tendon in the posterolateral edge of the calcaneal tuberosity, presenting the duck-beak sign in radiography. Due to the considerable pressure of the skin over the Achilles tendon, this is an orthopedic emergency that requires reduction and fixation in the first hours after the injury.<sup>42</sup>

As a sign of plasticity, Clint et al.<sup>49</sup> analyzed 227 calcanei and observed a significant change in the Böhler angle, depending on the age. Up to 5 years of age, the mean value was 15°; between 5 and 10 years, a significant increase to 55° was observed, reaching up to 37° at 13, which is very similar to the adult value. Two retrospective series indicated good long-term results from conservative treatment of deviated intra-articular fractures.<sup>50,51</sup> However, degenerative changes in the subtalar joint and significant shortening of the calcaneus were observed after 12 years.<sup>47</sup>

Ceccarelli et al.,<sup>51</sup> when assessing adolescents aged 15-17 years with deviated intra-articular fractures, observed significantly worse results in the conservative treatment when compared with surgical treatment.



**Fig. 3 – (A and B) Lateral radiograph of the foot and axial radiograph of the calcaneus. (C and D) Coronal and oblique axial cut of the foot. (E and F) Anteroposterior and profile postoperative radiographs showing the fixation with plate and compression screws. (G and H) Lateral radiograph of the foot and axial radiograph of the calcaneus in the late postoperative period.**

### Therapeutic evidence

Since the exact extent of spontaneous correction and the clinical relevance of residual misalignments in calcaneal fractures at the pediatric age are not known, open reduction and internal fixation are usually recommended.<sup>2,30,33,52</sup>

In adolescents over 15 years, the adult criteria are applied: joint deviation >1 mm, and enlargement or loss of height of more than 20% when compared with the opposite side.<sup>53</sup>

In single line fractures, closed reduction and percutaneous fixation with Kirschner wires or screws are options.

When the implants interfere with physis growth, the use of low-profile plates on the lateral wall (Fig. 3) has shown both good and excellent results in recent studies.<sup>2,30,52,54</sup>

Load on the affected limb must be forbidden for six weeks.

### Chopart and Lisfranc fracture-dislocations

The most prevalent mechanism is direct trauma, such as crush injuries, falling objects, and traffic accidents.<sup>44</sup>

A careful clinical evaluation (plantar ecchymosis) is an indispensable prerequisite for the identification of these rare lesions. Compartment syndrome must be ruled out through direct pressure measurements, particularly in unconscious patients.

Radiographic investigation includes the following views: profile, dorsoplantar at 30° cephalic (midtarsal) tilt or 20° cephalic (Lisfranc) tilt, and oblique with plantar inclination at 45°.<sup>3</sup>

As these lesions are still often underestimated, additional computed tomography exams are useful for correct diagnosis and appropriate surgical planning.<sup>20,29,48</sup>

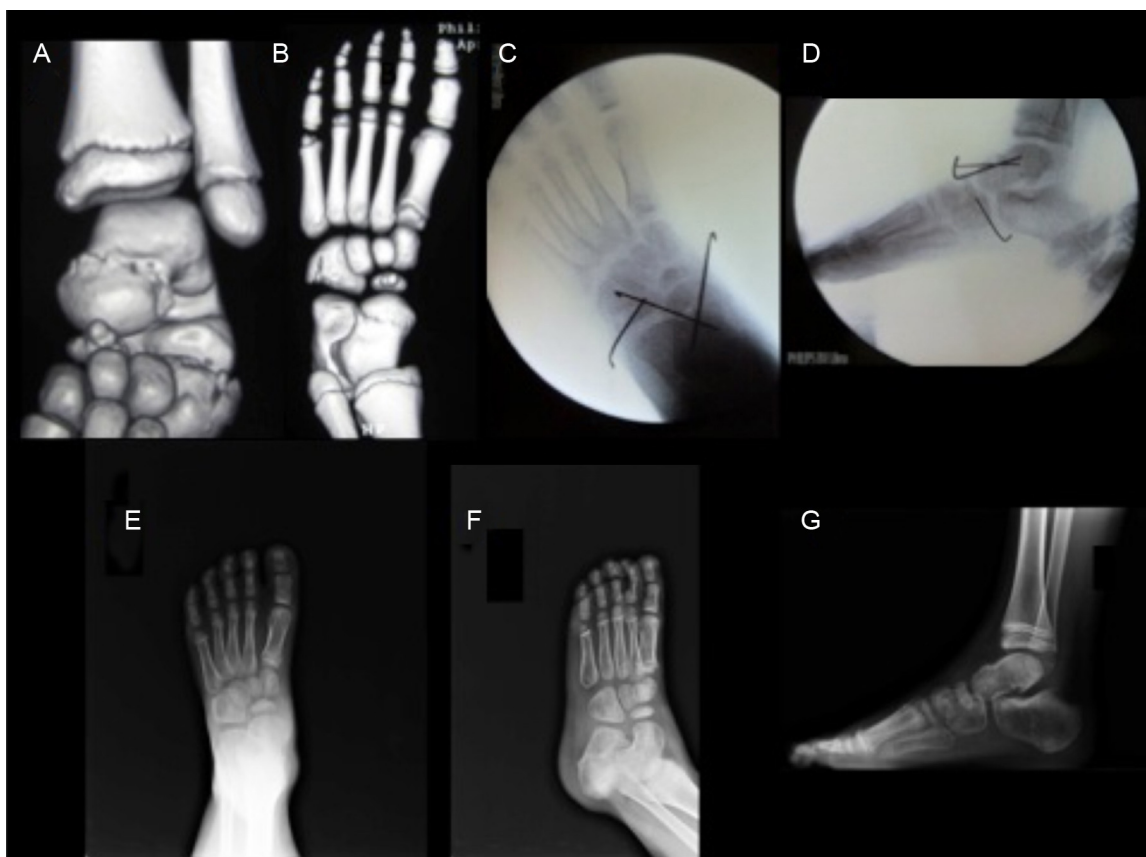
Cuboid fractures are rare in adults and very unusual in children. Published studies indicate that these fractures represent up to 5% of all tarsal fractures.<sup>21</sup>

The experience with deviated cuboid fractures in the pediatric population is limited to case reports.<sup>10,14,15,21,24,27,29,42</sup> These injuries often result in subluxation or Chopart joint dislocation, as they are usually associated with other foot fractures.<sup>4,12,14,20,27</sup>

The cuboid plays an important role in maintaining the length and flexibility of the lateral column of the foot. Therefore, surgical treatment of diverted fractures of the cuboid is usually performed to prevent the shortening of the lateral column, joint incongruity, abduction deformities, and post-traumatic arthritis.<sup>27,42,51</sup>

Zwipp et al.<sup>33</sup> reported a combined Chopart dislocation (transtalar/transcuboidal) in a child aged 8 years, treated in the early 1990s. In another report, only the talar neck fracture was identified and stabilized with Kirschner wires. This patient developed post-traumatic osteoarthritis, both in talonavicular and in the cuboid-calcaneal joint, and underwent triple arthrodesis three years after the injury.<sup>17</sup>

Midtarsal injuries are usually associated with ligament injuries,<sup>55</sup> due to the trauma mechanism in abduction or forced adduction of the forefoot against the hindfoot. Studies show that, together with compression fractures of a column (calcaneal-cuboid or talonavicular), there is instability or avulsion fracture in the contralateral column.<sup>25</sup>



**Fig. 4 – (A and B) Three-dimensional reconstruction of a computed tomography showing fracture with shift of transition of the neck/head of the talus and shortening of the lateral column due to cuboid fracture. (C and D) Anteroposterior and profile postoperative radiographs showing the fixation with Kirschner wire of the cuboid and talus fractures. (E, F, and G) Anteroposterior, profile, and oblique radiographs of foot in the late postoperative period.**

### Therapeutic evidence

The long-term findings in the conservative treatment of these do not indicate compensation and proper remodeling throughout the child's growth.<sup>44,56,57</sup> In particular, one case of attempted closed reduction and fixation with percutaneous Kirschner wires showed subtle residual misalignment or incomplete reduction, negatively impacting the final results due to painful deformities.<sup>3,21</sup>

The treatment of choice is the open reduction, aiming to rebuild articular surfaces and restore the shaft and stabilization ratios (Fig. 4).

The fixation of the bone component is individualized, and depends on the fracture pattern and the concomitant ligamentous instability.

Temporary joint transfixion for four to six weeks is often required.<sup>19</sup>

Fixation with Kirschner wires appears to be sufficient to stabilize cuboid fractures in children. In cases of great shortening of the cuboid, a bone graft is used to maintain the length of the side column.<sup>10,21,24,42</sup>

Lisfranc dislocations should also be anatomically reduced and stabilized with temporary transarticular Kirschner wires.

The starting point for correct reduction is the second radius, the base of the second metatarsal and intermediate cuneiform.

### Fractures of the metatarsals and toes

Between 70% and 90% of all foot fractures in children involve the metatarsals and toes, which generally have low rates of complications.<sup>1,58,59</sup>

In isolated metatarsal fractures, displacement is usually small and due to the action of the displaced interosseous muscle and ligament insertions; thus, the choice for conservative treatment is safe.

The same applies to fractures of two metatarsals with little displacement in the same direction, with stable tarsometatarsal joints; shortening and minimum deviation in the sagittal plane do not negatively impact late results.<sup>3</sup>

Apophysis of the base of the fifth metatarsal is visible in girls between 10 and 12 and in boys between 12 and 15 years. Iselin apophysitis is self-limiting and should be treated with immobilization of short duration (three weeks).

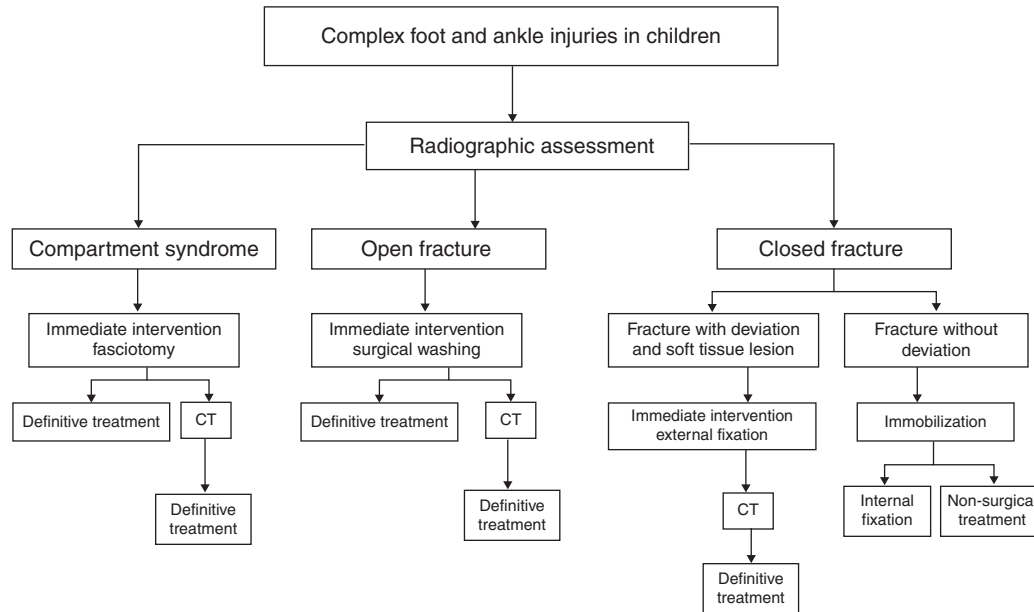


Fig. 5 – Algorithm for treatment of complex foot and ankle injuries in children.

### Therapeutic evidence

Displacements with cortical contact are, in principle, eligible for nonsurgical treatment; however, an axis deviation of more than 20° or associated instability are better treated with open reduction and intramedullary antegrade Kirschner wires, especially in children over 12 years.

In turn, avulsion fractures that are displaced from the base of the fifth metatarsal, unlike Iselin apophysitis, should be reduced with a tension band.<sup>20</sup>

Intra-articular or condylar phalangeal fractures are the result of a direct trauma mechanism. Anatomical reductions are particularly important in the first and fifth toes, in order to avoid stunting or early metatarsophalangeal osteoarthritis.

Fractures of the central toes are re-aligned and protected with splints and shoes to avoid dorsiflexion during gait.

Fractures of the distal phalanx, combined with skin lacerations or subungual hematoma, are considered to be exposed fractures; they should be treated with due care in order to avoid osteomyelitis.<sup>60</sup>

As a rule, fractures of the metatarsals are protected from load for four weeks and phalanges fractures, for three weeks.

### Complex lesions

The term complex ankle and foot injury is reserved for fractures involving serious soft tissue damage, including vascular and nerve damage, usually with joint involvement of bone tissue and is associated with a high risk of complications.<sup>27,55</sup>

The main causes of injuries in children are traffic accidents, fall from height, and bicycle accidents.<sup>60,61</sup>

In adults, there is standard protocol for the management of complex trauma to achieve optimal functional results. In children, the scenario is different, mainly due to lower frequency

of this type of injury, the large percentage of radiolucent skeletons, and the more resistant soft tissue coverage; therefore, the use of a precise treatment algorithm is also of fundamental importance in the pediatric age group (Fig. 5).<sup>62</sup>

The treatment decision is based on the full extent of the lesions, which are evaluated by the system developed by Zwipp et al.<sup>57</sup>

The system considers the number of regions of the affected foot (ankle, talus, calcaneus, Chopart joint, Lisfranc joint, and forefoot), as well as the degree of soft tissue injury (open or closed), according to the description by Tscherne and Oestern; each affected topographic region receives 1–3 points for soft tissue injury, and degloving or partial traumatic amputation are assigned 4 points. A score of 5 or higher is a diagnostic criterion for complex ankle and foot trauma.<sup>57</sup>

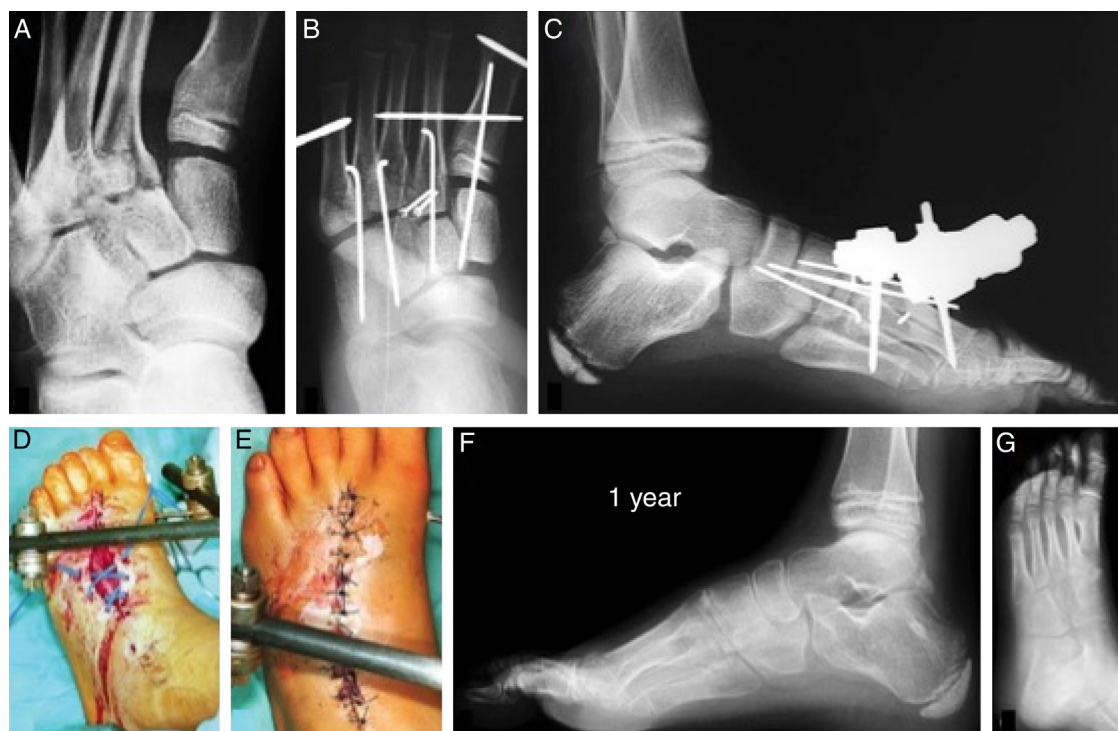
The reported complication rate is 27.5%, which include superficial infections, compartment syndrome, soft tissue necrosis, bone growth disorder, non-union, and post-traumatic osteoarthritis. In contrast with adults, it is important to report that exposed fractures in childhood do not exclude compartment syndrome; around 50% of patients with compartment syndrome have exposed fracture.<sup>62</sup>

The final functional results show a mean of 82.3 (59–100) points in the AOFAS score.<sup>62</sup>

### Therapeutic evidence

In polytrauma cases, treatment is staged: life support measures in the emergency room, complete debridement, and extensive washing, combined with stable external fixation. After the stabilization of the vital functions, the definitive treatment of fractures depends on the individual pattern.<sup>3</sup>

Preventing infection, maintaining or restoring soft tissue condition, and restoring bone alignment and joint reduction are important principles for the treatment of complex foot and ankle trauma.<sup>62</sup>



**Fig. 6 – (A) Anteroposterior radiograph of the foot showing tarsometatarsal fracture-dislocation. (B and C) Anteroposterior and profile postoperative radiographs showing the fixation with Kirschner wire and aid of an external fixator. (D and E) Postoperative clinical aspect showing damage of skin coverage. (F and G) Lateral and anteroposterior radiographs of the foot in the late postoperative period.**

At 12 years of age, 96% of girls and 88% of boys are skeletally mature. In younger patients with a large proportion of cartilage area on the articular surfaces, the essential part of treatment is the restoration of the length, width, height, and rotation; under 12 years of age, stabilization with Kirschner wires is sufficient. In cases of great instability, the aid provided by the external fixator is key (Fig. 6).<sup>62</sup> In patients over this age, restoring the anatomic joint reduction is also required.<sup>57</sup>

During emergency surgery, one should not consume surgical time with reconstruction challenges; the definitive treatment is planned after soft tissue recovery and complete diagnosis with the aid of computed tomography. Joints are reconstructed with support plates and special screws.<sup>62</sup>

A decisive factor for the prognosis is a safe and permanent skin coverage, involving all the resources of reconstructive microsurgery, including free flaps.<sup>62</sup>

Even in total or subtotal foot amputations, replantation is justified selected cases, as the functional success observed in the small number of cases reported is more favorable than in adults. However, in this scenario, decision between limb salvage or re-implantation is based on the sum of lesions and on the principle “life before limb”.<sup>54</sup>

### Conclusions for clinical practice

In the last decade, malleolar and foot bone fractures in pediatric patients have presented an increase in prevalence

and severity. Diagnosis through sophisticated imaging exams allows for a more appropriate therapeutic decision. Current treatment principles indicate a tendency toward surgical treatment in order to minimize the most frequent complications, such as compartment syndrome, bone growth disorders, three-dimensional deformity, avascular necrosis, and early post-traumatic osteoarthritis.

### Conflicts of interest

The authors declare no conflicts of interest.

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