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# Pediatric and Adolescent Ankle Fractures: Current Concepts and Advances in Management

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## Abstract

Pediatric and adolescent ankle fractures are frequently encountered injuries, often involving the distal tibial growth plate and requiring special management due to the potential for growth disturbances. Recent developments in imaging, surgical techniques, and rehabilitation have significantly improved outcomes. This review highlights contemporary practices in the diagnosis and treatment of ankle fractures in younger patients, with a focus on advances in diagnostic tools, operative management, and individualized care. It also explores the integration of new technologies, such as 3D printing and artificial intelligence, in fracture planning and management, reflecting the current standard of care.

**Keywords:** Pediatric, ankle fractures, distal tibial physeal injuries, Salter-Harris injuries, internal fixation, decision making.

## Introduction

Pediatric and adolescent ankle fractures are among the most common injuries encountered in orthopedics, with physeal fractures accounting for 25–40% of pediatric injuries [1, 2]. Given their potential to disrupt growth, timely and appropriate management is crucial. This review outlines current concepts, advances in diagnostic imaging, and emerging technologies influencing the management of these fractures in 2024.

## Epidemiology and Mechanisms of Injury

Ankle fractures in children typically occur between 8 and 15 years of age, often as a result of sports-related trauma or falls. Males are more frequently affected, with a male-to-female ratio of 2:1 [3, 4]. Physeal injuries are of particular concern due to the ongoing growth of the distal tibial physis, which accounts for approximately 35–40% of tibial growth [5]. The most common types of fractures include Salter-Harris types I-IV, with triplane and Tillaux fractures being unique to this age group due to the pattern of growth plate closure [6].

## Diagnostic Imaging and Classification

Plain radiography remains the first-line imaging modality, but there is increasing reliance on advanced imaging techniques such as computed tomography (CT) and magnetic resonance imaging to improve fracture characterization [7, 8]. CT scans are particularly useful in diagnosing triplane and Tillaux fractures, providing a detailed three-dimensional view that aids in treatment planning [9]. The classification of these fractures, as per Salter and Harris (1963), remains the gold standard, though advancements in imaging have led to refinements in classification systems, especially for more complex fractures [10].

## Standard Treatment Approaches

The treatment of pediatric ankle fractures depends on the degree of displacement, the involvement of the physis, and the age of the patient. Non-displaced or minimally displaced fractures can typically be managed non-operatively with cast immobilization [1]. However, displaced fractures, especially those involving the physis, may require closed or open reduction and internal fixation to ensure appropriate alignment and prevent growth disturbances [4, 5].

For physeal fractures, early intervention is critical to avoid long-term sequelae such as growth arrest or angular deformity. Closed reduction under fluoroscopy is often sufficient, but in cases of significant displacement or failed reduction, open reduction and internal fixation (ORIF) are indicated [6]. Physeal bar resection or guided growth techniques may be considered in cases of pre-mature growth arrest [2].

## Advances in Surgical Techniques and Fixation

Recent advances in surgical techniques have improved the

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**Figure 1:** A complex ankle fracture with a Salter-Harris type 2 injury of the distal tibia and a green stick fracture of the fibula.

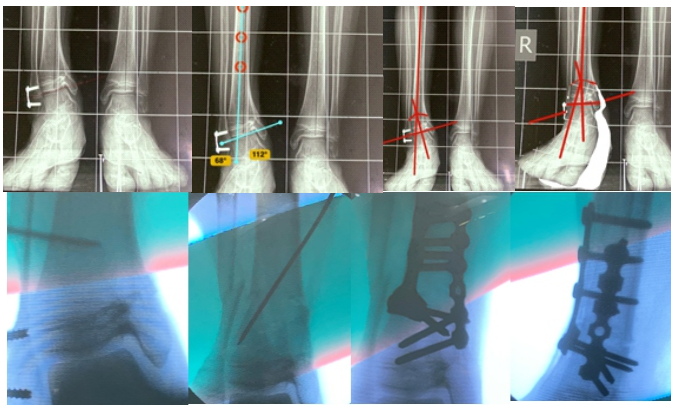

**Figure 3:** An IOS based app used for deformity correction of a patient with a distal femoral physeal arrest causing Ankle Varus.

outcomes of pediatric ankle fractures. Arthroscopy-assisted fracture reduction is gaining popularity for complex fractures, offering enhanced visualization of the joint surface and enabling more precise reduction [7]. The use of bioabsorbable implants has also reduced the need for subsequent hardware removal, minimizing the risk of growth disturbances [9].

For fractures with significant comminution or those involving the articular surface, external fixation may be employed to allow for early weight-bearing while minimizing the risk of physeal injury [10]. In addition, the role of minimally invasive percutaneous fixation continues to expand, particularly for fractures in skeletally immature patients where preserving the growth plate is paramount [5,9].

## Technological Advances: 3D Imaging, 3D Printing, and AI in Fracture Planning

One of the most exciting advancements in the management of pediatric ankle fractures is the incorporation of three-dimensional (3D) imaging and printing into pre-operative planning. 3D CT scans allow for superior visualization of fracture patterns, aiding in the accurate assessment of complex fractures, such as triplane and Tillaux variants [7]. Surgeons can now utilize 3D-printed models to plan osteotomies or screw placement with greater precision, particularly for fractures with complex multi-planar deformities [9].

Artificial intelligence (AI) and machine learning are also making significant strides in fracture diagnosis and management. AI-powered software can now assist in fracture classification and treatment decision-making by analyzing radiographs and predicting outcomes based on large datasets [10]. Several mobile applications have been developed to guide clinical decision-making, offering algorithms that help determine the need for surgery based on patient-specific factors such as age, fracture type, and displacement [8].

## Post-operative care and outcomes

The post-operative management of pediatric ankle fractures focuses on early mobilization and physical therapy to restore range of motion and strength [2]. Growth plate injuries warrant close follow-up to monitor for signs of growth arrest [6]. Long-term outcomes are generally favorable if appropriate reduction is achieved and complications are avoided [7].

## Conclusion

Pediatric and adolescent ankle fractures present unique challenges due to the involvement of the growth plate. Advances in imaging, surgical techniques, and AI are revolutionizing the way these injuries are diagnosed and treated. With the

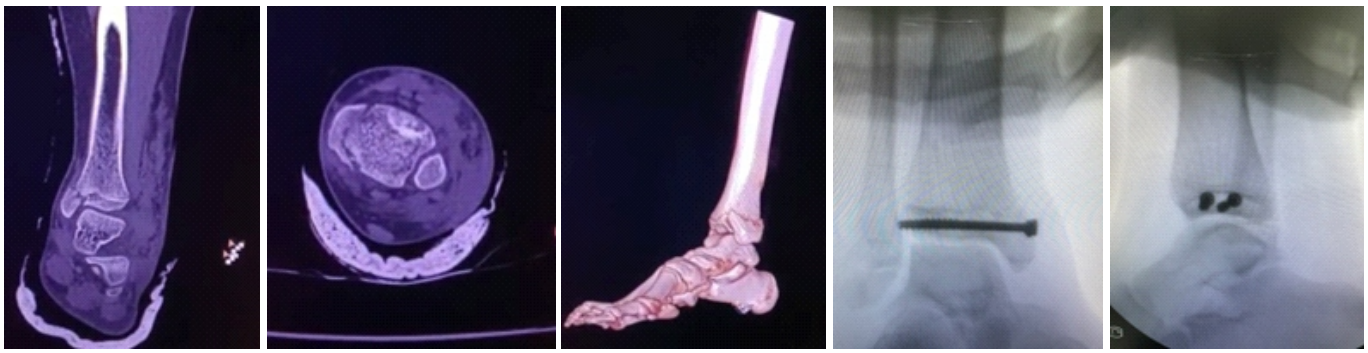

**Figure 2:** A Salter-Harris type 4 injury of the distal tibia, treated by closed internal fixation with screws.

integration of 3D printing and AI-driven applications, surgeons are now equipped with tools that enhance precision in fracture management. Continued research and technological advancements hold the promise of improving outcomes for young patients with these common yet complex injuries.

**Declaration of patient consent:** The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

**Conflict of Interest:** NIL; **Source of Support:** NIL

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