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CORA-Based Single-Stage Double-Level Corrective Osteotomy for Pediatric Distal Tibiofibular Malunion with Multiplanar Valgus Ankle Deformity: A Case Report

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A B S T R A C T

Introduction. Distal tibiofibular malunion in the skeletally immature patient can generate a progressive multiplanar valgus ankle deformity that alters joint mechanics and threatens long-term function. Correction is especially demanding after neglected, non-medical treatment, which remains common in low- and middle-income settings.

Case Presentation. A 13-year-old boy presented with a one-year history of progressive valgus deformity of the right ankle following a road-traffic injury initially managed by a traditional bone setter without radiographs. Imaging confirmed distal tibiofibular malunion with center of rotation of angulation (CORA) values of 16.9° in the coronal plane and 18.1° in the sagittal plane; the tibial anterior surface (TAS) angle was 76.4° and the tibial lateral surface (TLS) angle was 76.0°. A single-stage, CORA-based double-level closing-wedge osteotomy of the distal fibula and distal tibia was performed, stabilized with a one-third tubular plate and a distal tibial T-locking plate. The TAS improved to 93.0° and the TLS to 84.0°. At one-year follow-up the patient showed bony union, improved ankle motion, restored mechanical alignment, and painless ambulation without complications.

Conclusion. CORA-guided single-stage double-level osteotomy with stable internal fixation can restore alignment, ankle congruity, and function in pediatric distal tibiofibular malunion with multiplanar valgus deformity. Early orthopedic evaluation and timely correction are essential to prevent long-term disability.

1. Introduction

Fractures of the tibial and fibular shafts are among the most frequent long-bone injuries of childhood, and they account for a substantial proportion of pediatric lower-extremity fractures. Contemporary practice has moved toward selective operative stabilization whenever acceptable alignment cannot be achieved or maintained by closed means, reflecting an improved understanding that residual deformity in the growing leg is poorly tolerated.[1,2] The mechanism of injury, the fracture configuration, and the presence of an ipsilateral fibular fracture all influence both the risk of acute complications and the likelihood of late deformity; high-energy road-traffic mechanisms and concomitant fibular injury are recognized as features that complicate the clinical course.[3] When reduction is inadequate or treatment is improperly supervised, the fracture may heal in a clinically unacceptable position, producing a malunion with residual angular, rotational, or translational deformity.[4]

The ankle is a tightly constrained, highly loaded joint, and its tolerance for residual malalignment is considerably lower than that of more proximal or upper-extremity sites. Even modest deviations of the distal tibial articular surface from its normal orientation shift the contact stresses borne by the

tibiotalar cartilage, and sustained eccentric loading is a recognized antecedent of pain, instability, and premature degenerative change.[4,5] In the distal tibia and fibula, deformity is frequently multiplanar, combining a coronal-plane component that produces visible varus or valgus with a sagittal-plane component that alters the procurvatum or recurvatum of the plafond.[6] The fibula is not a passive strut: it completes the lateral wall of the ankle mortise and shares load with the tibia, so that fibular shortening or malposition can itself generate or perpetuate a valgus deformity and widen the mortise.[7,8]

Post-traumatic deformity in the pediatric patient is rendered more complex by the simultaneous demands of skeletal growth, joint development, and mechanical loading. A deformity that might be cosmetically and functionally trivial in an adult can progress in a child as remodeling potential interacts with abnormal forces, and the open physis is both an asset for spontaneous correction and a liability for iatrogenic injury during surgery.[9] Valgus ankle deformity arising from distal tibiofibular malunion is comparatively uncommon, but it can lead to progressive instability, gait disturbance, joint incongruity, and early arthrosis if left uncorrected.[5,10] The deformity therefore warrants objective radiographic characterization and timely, anatomically informed correction rather than expectant observation.

From a biomechanical standpoint, the distal tibia and the fibula together form the ankle mortise, a three-sided socket that must remain congruent for load to be transmitted evenly across the dome of the talus. Under physiological conditions the tibiotalar joint distributes the considerable forces of gait over a broad contact area, and small angular deviations of the plafond translate into disproportionate increases in peak cartilage pressure within the overloaded compartment. The relationship between malalignment and joint loading is well established at other weight-bearing joints, where each degree of angular deviation measurably increases the moment borne by the leading compartment, and the same principle governs the ankle.[4,5] A valgus malunion thus concentrates stress on the lateral plafond and lateral talar shoulder while unloading the medial side, establishing the eccentric loading pattern that, over years, drives asymmetric cartilage wear and degenerative arthrosis. Restoration of a neutral mechanical axis and a horizontal, congruent plafond is therefore not a cosmetic refinement but the biomechanical objective on which the durability of the joint depends.

Deformity around the distal tibia is conventionally described by the plane in which it occurs and by its apex, magnitude, and direction. Coronal-plane deformity manifests clinically as varus or valgus, sagittal-plane deformity as procurvatum or recurvatum, and many post-traumatic malunions are multiplanar and may additionally carry a rotational or length component.[4,6] An orderly description of these components, anchored to the apex of the deformity, is the prerequisite for any rational correction, because the level and orientation of the planned osteotomy must be referenced to that apex. The present case exemplifies a multiplanar deformity with substantial components in both the coronal and the sagittal planes, demanding a correction strategy capable of addressing both simultaneously.

A distinctive and clinically important contributor to neglected deformity in many low- and middle-income settings is the continued reliance on traditional bone setters. Although these practitioners are widely consulted and culturally trusted, the absence of radiographic assessment and the use of non-standard immobilization are associated with high rates of malunion, non-union, and in severe cases limb-threatening complications.[11-13] In such circumstances a child may present months after the index injury with an established deformity, having never undergone a definitive fracture diagnosis. This pathway frames both the difficulty and the responsibility of reconstructive correction.

We report a case of neglected pediatric distal tibiofibular malunion presenting with a multiplanar valgus ankle deformity, managed by a single-stage, center of rotation of angulation (CORA)-based double-level corrective osteotomy of the distal tibia and fibula with stable internal fixation. The report illustrates the value of structured radiographic deformity analysis using CORA principles together with the tibial anterior surface (TAS) and tibial lateral surface (TLS) angles, the rationale for addressing both the tibia and the

fibula in a single stage, and the functional and radiological course over one year of follow-up. The novelty of this report lies in the combination of single-stage double-level closing-wedge correction, CORA-based planning validated against both coronal (TAS) and sagittal (TLS) parameters, and angular-stable metaphyseal fixation in a neglected, bone-setter-managed pediatric multiplanar valgus ankle — an uncommon and instructive constellation. The aim of this study is to describe the deformity analysis, surgical strategy, and one-year outcome of this approach, and to underscore the importance of early orthopedic evaluation in preventing avoidable long-term disability.

2. Case Presentation

A 13-year-old boy was referred to our orthopedic department with a progressive valgus deformity of the right ankle that had gradually worsened over the preceding year. The deformity had developed after a motorcycle-related road-traffic injury sustained while the patient was crossing the road. Immediately after the injury he experienced pain and swelling around the right ankle. Rather than seeking formal medical care, the family pursued treatment from a traditional bone setter, where a non-standard splint was applied without radiographic evaluation or a definitive fracture diagnosis. Over the ensuing months the patient reported persistent discomfort during ambulation accompanied by a progressive outward angulation of the ankle.

There was no antecedent history of congenital deformity, systemic illness, metabolic bone disease, or previous orthopedic disorder, and his growth and developmental history were unremarkable. On examination the patient was hemodynamically stable and systemically well. Inspection of the right ankle revealed intact skin without erythema, warmth, or other signs of active inflammation, although a clearly visible valgus deformity of the hindfoot and ankle was apparent on both frontal and lateral views. As shown in Figure 1, the resting alignment of the affected limb demonstrated an obvious outward angulation relative to the contralateral side. Palpation elicited no focal tenderness, and the distal neurovascular status was intact, with normal capillary refill and preserved sensation and motor function in the tibial and peroneal nerve distributions. Both active and passive ankle range of motion were limited, with active motion more restricted than passive motion, a pattern consistent with functional impairment secondary to malalignment and altered ankle biomechanics rather than fixed bony ankylosis. As detailed in Figure 1, the frontal and lateral clinical views demonstrate the outward (valgus) angulation of the right ankle relative to the unaffected contralateral side.

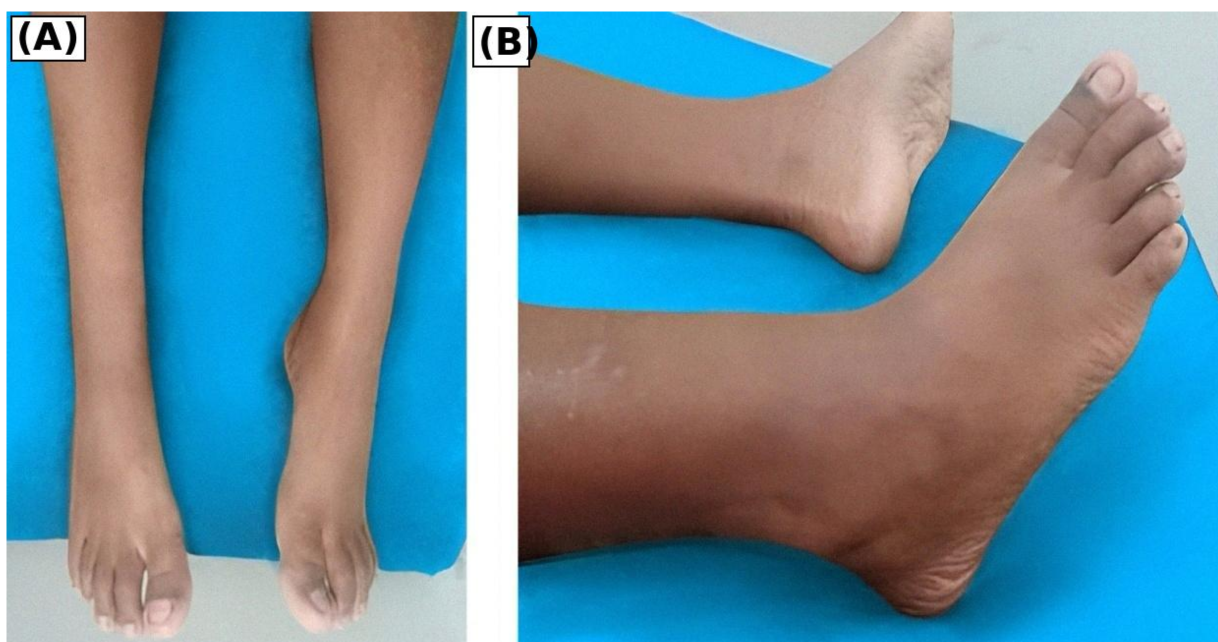

Figure 1. Preoperative clinical photographs of the right lower limb. (A) Frontal view demonstrating outward (valgus) angulation of the right ankle relative to the contralateral side. (B) Lateral view of the right ankle showing the visible deformity with intact, non-inflamed skin.

Plain radiographs of the right lower extremity, including anteroposterior (AP) and lateral views of the leg and ankle, demonstrated malunion of the distal tibia and fibula associated with multiplanar angular deformity. The preoperative radiographic assessment and deformity analysis are presented in detail in Figure 2. The standard views confirmed healed fractures with residual angulation of both bones (Figure 2A), and dedicated ankle views demonstrated obliquity of the distal tibial articular surface (Figure 2B). Deformity analysis using the CORA method quantified 16.9° of coronal-plane angulation and 18.1° of sagittal-plane angulation, locating the apex of the deformity within the distal tibial metaphysis, as shown in Figure 2C. Matching the planned osteotomy level to this apex is a fundamental principle of deformity correction, because an osteotomy performed away from the CORA introduces a secondary translational deformity even when the angular correction is complete.[14]

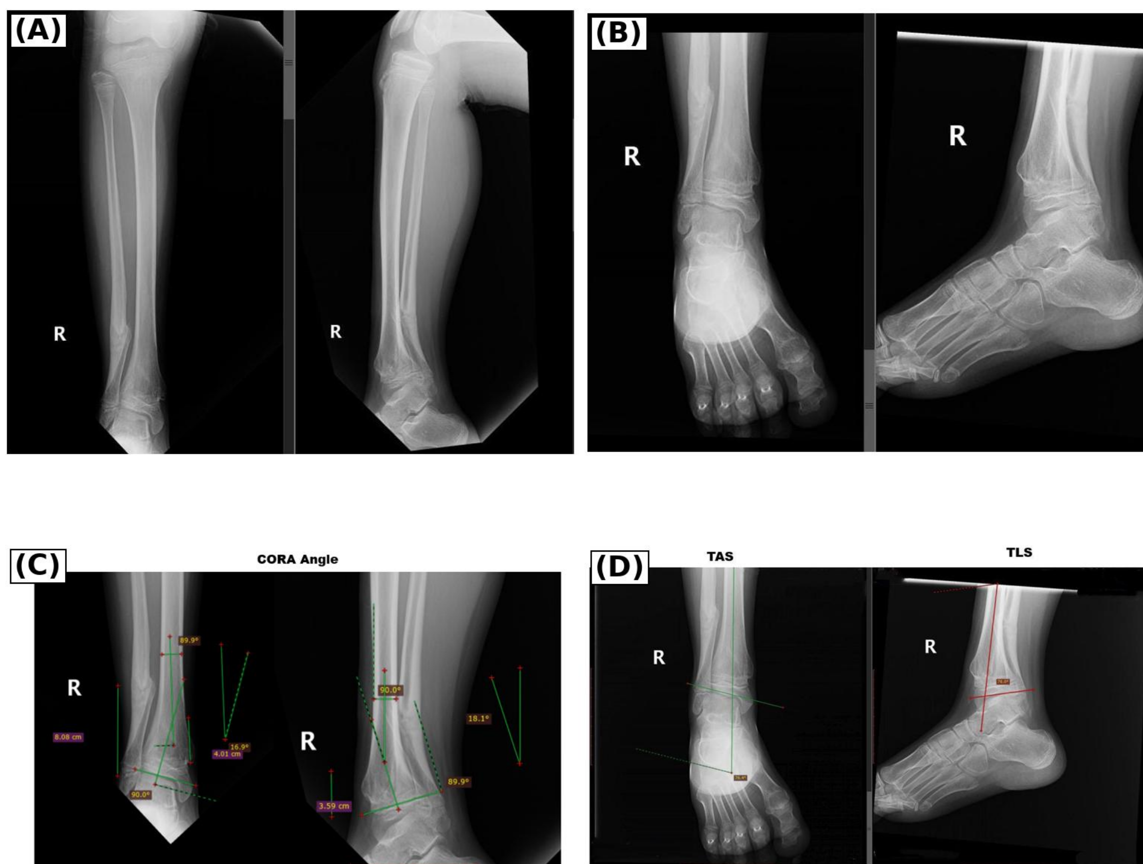

Figure 2. Preoperative radiographic assessment and deformity analysis of the right leg and ankle. (A) Anteroposterior and lateral views of the tibia and fibula showing distal tibiofibular malunion. (B) Anteroposterior and lateral ankle views demonstrating articular-surface obliquity. (C) Center of rotation of angulation (CORA) analysis quantifying 16.9° of coronal-plane and 18.1° of sagittal-plane angulation. (D) Measurement of the tibial anterior surface (TAS, 76.4°) and tibial lateral surface (TLS, 76.0°) angles.

To characterize the deformity with validated periarticular parameters, the TAS angle was measured on the AP radiograph as the angle subtended between the anatomical axis of the tibia and the distal tibial articular surface, and the TLS angle was measured on the lateral radiograph between the tibial anatomical axis and the distal articular surface in the sagittal plane (Figure 2D).[6,15] The TAS angle measured 76.4° and the TLS angle measured 76.0°, both markedly below normal reference values and indicating substantial coronal and sagittal malalignment of the plafond. These radiographic alignment parameters, together with their normal reference ranges and the values obtained at each subsequent time point, are detailed in Table 1.

Table 1. Serial radiographic alignment parameters of the right ankle before and after CORA-based double-level corrective osteotomy, with normal reference ranges.

Radiographic parameter	Normal reference*	Preoperative	Immediate postoperative	One-year follow-up
Coronal-plane angulation (CORA)	≈ 0°	16.9° valgus	Restored to near-neutral	Maintained near-neutral
Sagittal-plane angulation (CORA)	≈ 0°	18.1°	Restored to near-neutral	Maintained near-neutral
Tibial anterior surface (TAS) angle	≈ 88–93°	76.4°	—†	93.0° (Δ +16.6°)
Tibial lateral surface (TLS) angle	≈ 80–84°	76.0°	—†	84.0° (Δ +8.0°)
Bony union	—	Malunion	Fixation stable	United
Ankle range of motion	Full, painless	Limited (active < passive)	Protected	Improved, painless‡

*Notes: CORA, center of rotation of angulation; TAS, tibial anterior surface; TLS, tibial lateral surface; Δ, change from preoperative value. *Normal reference ranges for TAS and TLS are drawn from the periarticular supramalleolar osteotomy literature. †Immediate postoperative TAS and TLS angles were not separately quantified; the values shown were measured at one-year follow-up. ‡Functional improvement was recorded qualitatively; formal goniometric range-of-motion values were not documented in the clinical record.*

The differential diagnosis of a progressive valgus ankle in an adolescent includes post-traumatic malunion, physeal growth disturbance after a previous physeal injury, fibular shortening or insufficiency, and deformities associated with systemic or developmental conditions such as hereditary multiple exostoses, skeletal dysplasias, or neuromuscular disease.[7,16] In this patient the unequivocal history of a discrete traumatic event followed by inadequately supervised non-operative care, the absence of any congenital or systemic disorder, the normal contralateral limb, and the radiographic demonstration of healed fractures with residual angulation together established a post-traumatic distal tibiofibular malunion as the cause. The deformity was fixed rather than dynamic, multiplanar rather than purely coronal, and clearly symptomatic, which framed the indication for an acute, anatomically guided reconstruction. Taken together, the clinical and radiographic findings established a diagnosis of neglected distal tibiofibular malunion with an established, severe, multiplanar valgus ankle deformity. Given the severity of the deformity, its demonstrable progression, and the associated functional limitation, the patient was scheduled for corrective surgery consisting of a single-stage double-level osteotomy and internal fixation.

Surgical technique

Surgery was planned preoperatively on the basis of the CORA analysis to address both the coronal and the sagittal components of the deformity simultaneously, and to restore the TAS and TLS angles toward their normal ranges.[14,15] Planning proceeded by drawing the proximal and distal anatomical axes of the tibia on the orthogonal radiographs, identifying their intersection as the apex of angulation in each plane, and determining the size and orientation of the wedge required to bring the distal articular surface back to its target orientation. The contralateral, uninjured limb served as the template for the intended TAS and TLS, an approach consistent with deformity-correction practice that references the normal side when planning a corrective osteotomy.[17] The fibular and tibial osteotomy levels were selected to coincide with their respective deformity apices so that the angular correction could be achieved without an obligatory secondary translation.

Under general anesthesia, the patient was positioned supine on a radiolucent table with a tourniquet applied to the thigh, and fluoroscopic guidance was used throughout the procedure. The principle of the operation was a staged correction within a single anesthetic: the fibula was addressed first to re-establish lateral column length and the lateral buttress of the mortise, followed by the tibia to achieve the definitive multiplanar correction.

A lateral approach to the distal fibula was used to expose the malunion site while protecting the superficial peroneal nerve. Based on the preoperative CORA planning, a closed wedge osteotomy was performed at the apex of the fibular deformity to

restore lateral column alignment and to correct the valgus malalignment contributed by the fibula. After the wedge was removed and the correction obtained, the fibula was stabilized with a contoured low-profile one-third tubular plate, which provides sufficient stability for the lateral column while respecting the thin local soft-tissue envelope. Restoration of fibular length and alignment is an essential step, because isolated tibial correction that ignores the fibula risks persistent lateral instability, residual joint obliquity, and incomplete correction of the mortise.[7,8]

Attention was then directed to the distal tibia through an anterolateral approach. A closed wedge osteotomy was performed at the level of the deformity apex, according to the preoperative CORA plan, to achieve correction in both the coronal and the sagittal planes while restoring the periarticular alignment parameters. Particular care was taken to preserve the distal tibial physis and the surrounding neurovascular structures during the osteotomy and reduction. After satisfactory realignment was confirmed under fluoroscopy, fixation was achieved with an anatomical distal tibial T-locking plate, which provides angular-stable metaphyseal fixation and resists secondary displacement during healing — a property that is particularly valuable in the relatively soft metaphyseal bone of a skeletally immature patient.[4]

Final intraoperative fluoroscopy confirmed satisfactory restoration of mechanical alignment and correction of the deformity in both planes. The wound was closed in layers, and a below-knee cast was applied. The patient was maintained non-weight-bearing for six weeks, after which a graduated rehabilitation program and serial clinical and radiographic follow-up were undertaken.

Postoperative course and follow-up

Immediate postoperative radiographs demonstrated satisfactory restoration of lower-limb alignment and correction of the valgus deformity, with anatomically positioned implants. Figure 3 shows the immediate postoperative AP and lateral radiographs after the double-level osteotomy and internal fixation. The postoperative course was uneventful: there was no neurovascular compromise, no wound complication, and no early loss of correction. The limb was protected and non-weight-bearing was maintained for six weeks, followed by progressive mobilization.

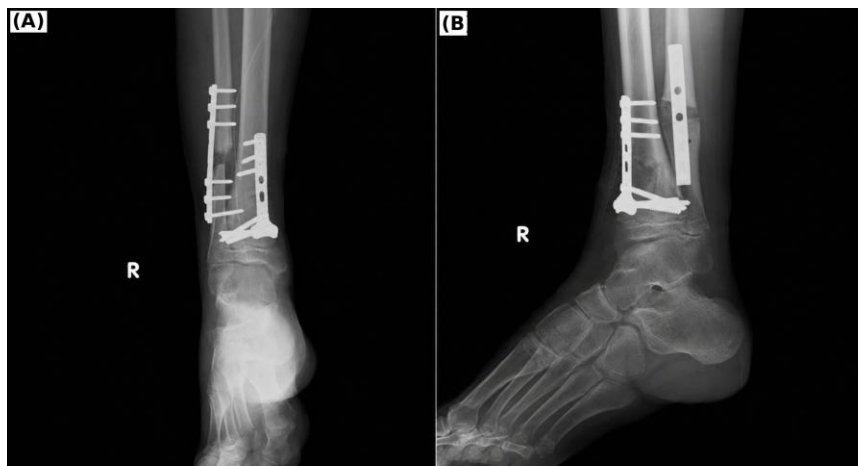

Figure 3. Immediate postoperative radiographs after single-stage double-level corrective osteotomy. (A) Anteroposterior and (B) lateral views demonstrating correction of the valgus deformity, with the distal fibula stabilized by a one-third tubular plate and the distal tibia by an anatomical T-locking plate.

The rehabilitation program was structured around the biology of osteotomy healing and the protection of the correction. For the first six weeks the limb was immobilized and kept strictly non-weight-bearing to allow early consolidation of both osteotomy sites without the risk of displacement, while gentle, pain-limited motion of the toes and protected mobilization were encouraged to limit stiffness and disuse. Once early radiographic union was confirmed, progressive weight-bearing and a graduated program of ankle range-of-motion and strengthening exercises were introduced, advancing as comfort and radiographic

healing permitted. Serial clinical and radiographic review was undertaken to confirm maintenance of alignment, progression of union, and recovery of function. This protocol mirrors the staged, healing-led progression used after corrective osteotomy of the distal tibia, in which a period of protected loading precedes a return to full weight-bearing.[18]

Progressive improvement in ankle alignment and functional mobility was observed throughout rehabilitation. At one-year clinical and radiographic follow-up, the patient demonstrated bony union of both osteotomy sites, improved ankle range of motion, restoration of mechanical alignment, and painless ambulation, with no evidence of recurrent deformity or implant-related complication; formal goniometric range-of-motion values were not separately documented in the clinical record, and the functional gain is reported as the qualitative improvement that was observed. As shown in Figure 4, the one-year assessment documented restored standing alignment (Figure 4A) and a functional, painless deep squat (Figure 4B) together with radiographic union (Figure 4C) and a corrected periarticular profile (Figure 4D). The TAS angle improved from 76.4° preoperatively to 93.0°, and the TLS angle improved from 76.0° to 84.0°, corresponding to corrections of 16.6° and 8.0° respectively, and indicating satisfactory restoration of both coronal and sagittal alignment toward normal reference values. These serial parameters are detailed in Table 1. The magnitude and direction of correction were consistent with the targets reported in contemporary supramalleolar and distal tibial osteotomy series.[19-21]

Ethics approval and consent to participate

The reporting of this case was conducted in accordance with the principles of the Declaration of Helsinki, and institutional approval/exemption for the publication of this case report was obtained in line with local regulations.

Consent for publication

Written informed consent for the publication of this case report and the accompanying clinical images was obtained from the patient's parent/legal guardian. The patient's identity has been protected, and identifying facial features in the clinical photographs have been masked.

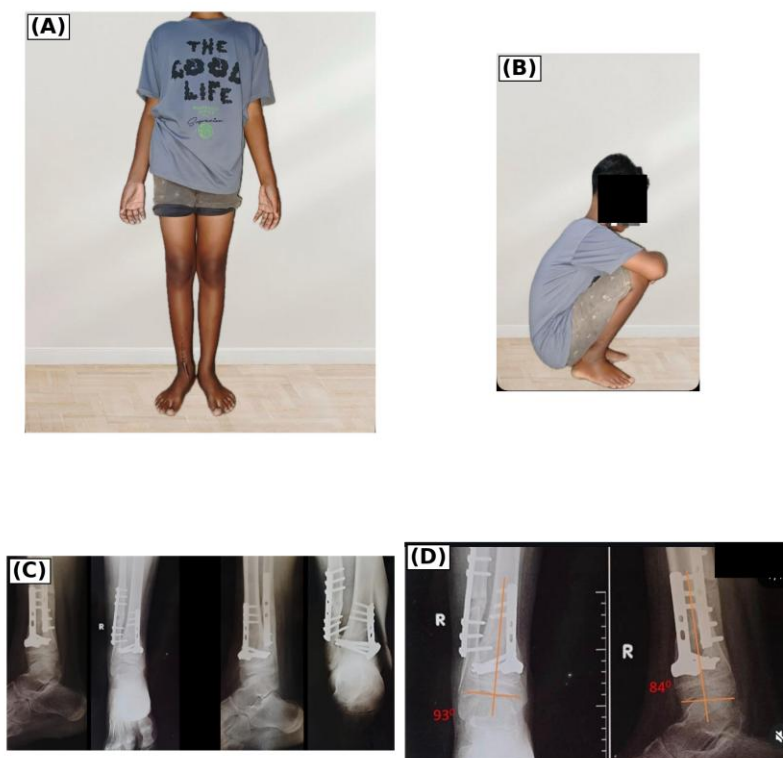

Figure 4. One-year clinical and radiographic follow-up. (A) Standing frontal clinical photograph showing restored limb alignment and a healed surgical scar. (B) Functional deep squat demonstrating improved, painless ankle motion (the patient's face has been masked to protect privacy). (C) Anteroposterior and lateral radiographs demonstrating bony union with maintained alignment. (D) Restored periarticular alignment with the tibial anterior surface angle corrected to 93.0° and the tibial lateral surface angle to 84.0°.

3. Discussion

The correction of post-traumatic deformity in pediatric patients requires careful attention to both anatomical alignment and the long-term biomechanical consequences of malalignment, particularly when a weight-bearing joint such as the ankle is involved. In the present case, malunion of the distal tibia and fibula produced a valgus ankle deformity with multiplanar malalignment, an altered mechanical axis, and joint incongruity. Persistent valgus malalignment increases lateral compartment loading of the tibiotalar joint and predisposes to progressive instability, abnormal gait mechanics, and early degenerative change if it is left untreated.[4,5] The objective of surgical correction was therefore not merely cosmetic realignment but the restoration of a congruent, evenly loaded joint that would protect the articular cartilage over the decades of life ahead of a 13-year-old patient.

A central lesson of this case concerns the pathway by which the deformity arose. The child sustained a road-traffic injury and was taken not to a hospital but to a traditional bone setter, where a splint was applied without any radiographic assessment or definitive diagnosis. The reliance on traditional bone setters is deeply entrenched in many communities because their services are perceived as accessible, affordable, and culturally acceptable, yet the published evidence consistently documents that this practice is associated with high rates of malunion and other complications.[12,13] In one community-based radiographic series, malunion accounted for the majority of complications among patients with fractures treated by bone setters,[12] and a systematic review of the topic catalogued hundreds of complications including limb-threatening sequelae.[11,13] The present patient embodies the more insidious end of this spectrum: not an acute catastrophe, but a slowly progressive deformity that consolidated into a fixed, multiplanar malunion before specialist evaluation was sought. Early recognition, appropriate referral, and timely radiographic diagnosis would very likely have prevented the need for a double-level reconstructive osteotomy altogether.

Radiographic deformity analysis was fundamental to both the diagnosis and the surgical plan. The CORA method, derived from the principles of deformity correction, defines the intersection of the proximal and distal mechanical or anatomical axes as the apex of the deformity and dictates that the osteotomy and its correction axis be referenced to that point.[14] When the osteotomy is performed at the CORA and the correction is angulated about it, angular deformity is corrected without introducing translation; when the osteotomy is performed at a different level, a compensatory translation is mandatory to avoid creating a secondary deformity.[14] In this patient, the apex lay within the distal tibial metaphysis, and matching the osteotomy to that level allowed a clean angular correction in both planes. The deformity was further quantified using the TAS and TLS angles, which are the validated coronal and sagittal descriptors of the distal tibial articular orientation and are widely used to plan and audit periarticular osteotomies around the ankle.[6,15] The preoperative values of TAS 76.4° and TLS 76.0° were well outside the normal range, objectively confirming the severity of the malalignment that was evident clinically.

The surgical literature describes a broad armamentarium for the correction of distal tibial and supramalleolar deformity, and the optimal choice is individualized to the deformity pattern, skeletal maturity, soft-tissue condition, and surgeon experience. Table 2 compares the principal options together with their advantages and limitations. Opening-wedge and closing-wedge supramalleolar osteotomies remain the workhorses for coronal and sagittal correction, each with characteristic trade-offs in limb length and healing.[15,22,23] Plate fixation, including low-profile anatomical and locking constructs, offers immediate angular stability and is well suited to acute single-stage correction,[4,18] whereas circular and computer-assisted hexapod external fixators permit gradual, highly precise multiplanar correction and are particularly valuable for very large, rotational, or length-related deformities or when the soft tissues are compromised.[21,24] Advanced planning techniques such as patient-specific three-dimensional cutting guides and procedures such as the clamshell osteotomy for

multiapical metaphyseal deformity expand the options further.[17,25] For the present patient, in whom the deformity was angular and multiplanar with healthy soft tissues and a single dominant apex, an acute single-stage closing-wedge correction with internal fixation offered a definitive, well-tolerated solution without the prolonged frame time and pin-care burden of external fixation.

Table 2. Principal surgical options for correction of distal tibial / supramalleolar deformity, with relative advantages and limitations.

Technique	Principal advantage	Principal limitation	Typical indication
Closing-wedge osteotomy + internal fixation	Immediate angular stability; single stage; reliable union	Modest limb shortening; requires accurate apex planning	Fixed angular, multiplanar deformity with healthy soft tissues
Opening-wedge osteotomy	Preserves / restores length	Graft or gap healing; risk of delayed union	Coronal deformity where length is to be maintained
Circular / hexapod external fixator	Gradual, precise multiplanar and rotational correction	Prolonged frame time; pin-site care; patient burden	Large, rotational, or length deformities; poor soft tissues
Patient-specific 3D-guided osteotomy	High planning precision	Cost; lead time for guides	Complex multiapical or rotational malunion
Joint-sacrificing (arthrodesis / replacement)	Definitive for end-stage arthrosis	Sacrifices native motion; inappropriate in the young	Salvage of failed reconstruction

Notes: Technique selection is individualized to the deformity pattern, skeletal maturity, soft-tissue condition, and surgeon experience.

The decision to perform a double-level osteotomy, addressing both the tibia and the fibula, deserves emphasis. The fibula is an integral part of the ankle mortise, and its alignment and length govern the position of the lateral malleolus and the integrity of the lateral buttress of the joint. Fibular shortening or malunion is itself a recognized cause of progressive valgus deformity and mortise widening, and restoration of fibular length and alignment can relieve symptoms and protect the cartilage.[7,8] The vulnerability of the mortise to fibular insufficiency is also illustrated, in a different context, by the valgus deformity that may follow harvest or loss of the fibular shaft.[10] Consequently, a tibia-only correction that leaves the fibula malaligned risks persistent lateral instability, residual joint obliquity, and an incomplete or non-durable correction. Performing the fibular osteotomy first, to re-establish lateral column length, and then completing the tibial correction allowed both bones to be realigned in a single anesthetic and produced a balanced, congruent mortise.

Fixation choice was guided by the requirements of the immature metaphysis. The fibula was stabilized with a low-profile one-third tubular plate, which is sufficient for the lateral column and respectful of the thin overlying soft tissues, while the tibia was fixed with an anatomical distal tibial T-locking plate. Locking constructs create a fixed-angle device in which the screws are mechanically coupled to the plate, conferring angular stability that is especially advantageous in soft metaphyseal or osteopenic bone and reducing the risk of secondary loss of correction during healing.[4] Throughout the tibial osteotomy, deliberate care was taken to preserve the distal tibial physis, because iatrogenic physeal injury in a 13-year-old could itself produce a growth-related deformity — the very complication the operation was intended to remedy.[9]

The radiographic outcome of this case compares favorably with the published experience of periarticular osteotomy. The immediate postoperative radiographs confirmed restoration of the mechanical axis with anatomically positioned implants (Figure 3), and at one year the TAS improved from 76.4° to 93.0° and the TLS from 76.0° to 84.0° (a coronal correction of 16.6° and a sagittal correction of 8.0°, as detailed in Table 1 and Figure 4D), bringing both parameters close to or within their normal reference ranges. These

figures are consistent with reported series of supramalleolar osteotomy, in which the TAS is typically restored to the low-90-degree range and the TLS toward the high-70s to mid-80s, accompanied by significant gains in function and pain relief.[15,19] In a dedicated study of supramalleolar osteotomy for traumatic ankle deformity in adolescents, radiographic parameters including TAS and TLS improved significantly and were matched by marked improvements in American Orthopaedic Foot and Ankle Society (AOFAS) scores and ankle range of motion at one year.[20] Comparable improvements in alignment and AOFAS scores have been reported when supramalleolar osteotomy is combined with either internal fixation or a computer-assisted hexapod external fixator, underscoring that the quality of the correction, rather than the specific fixation modality, is the principal determinant of outcome.[21] A systematic review of correction targets after supramalleolar osteotomy, while unable to define a single optimal angle, reinforced the central importance of accurate, individualized realignment.[26] The favorable course in the present patient — union without complication, improved motion, and painless ambulation at one year — is therefore concordant with the broader literature.[4,5] To situate the present case within that experience, Table 3 compares it with selected published reports of corrective osteotomy for distal tibial and tibiofibular malunion and periarticular ankle deformity; as detailed in Table 3, the magnitude of alignment correction and the favorable short-term functional course observed here are consistent with, and in terms of coronal correction toward the upper end of, those reported in comparable series and case reports.[8,15,20,21,25]

Table 3. Comparison of the present case with selected published reports of corrective osteotomy for distal tibial/tibiofibular malunion and periarticular ankle deformity.

Study	Age/population	Etiology and deformity	Procedure and fixation	Key radiographic/functional outcome	Follow-up
Present case	13 y, male	Neglected post-traumatic distal tibiofibular malunion; multiplanar valgus (CORA 16.9°/18.1°)	Single-stage double-level closing-wedge osteotomy (tibia + fibula); one-third tubular + distal tibial T-locking plate	TAS 76.4°→93.0°, TLS 76.0°→84.0°; bony union; painless ambulation	12 months
Gomez-Palomo et al., 2020[8]	23 y, male	Post-traumatic fibular malunion/shortening; progressive valgus	Fibular-lengthening osteotomy + bone graft; compression plate	Restored ankle mortise and joint surface; pain-free; return to sport	6 months
Zhao et al., 2023[20]	32 adolescents	Traumatic ankle varus deformity	Supramalleolar osteotomy; internal fixation	TAS 61.5°→88°, TLS 76.7°→79.3°; AOFAS 65.5→92.3	~20 months (mean)
Stamatis et al., 2003[15]	12 patients (incl. adolescent)	Distal tibial angular deformity ± ankle arthritis	Supramalleolar osteotomy	AOFAS 53.8→87; TAS improved; no arthritic progression	33.6 months (mean)
Yang et al., 2024[21]	44 patients	Distal tibial deformity	Supramalleolar osteotomy with internal fixation vs computer-assisted hexapod fixator	Coronal/sagittal alignment corrected; AOFAS 66→86 (fixator) / 68→79 (plate)	31.7 months (mean)
Darden et al., 2023[25]	49 y, female	Distal tibial metaphyseal malunion	Clamshell osteotomy; internal fixation	Realignment with union; improved gait and quality of life	2.5 years

Notes: CORA, center of rotation of angulation; TAS, tibial anterior surface; TLS, tibial lateral surface; AOFAS, American Orthopaedic Foot and Ankle Society score. Reported series include both varus and valgus periarticular deformities; they are presented for comparison of corrective-osteotomy strategy and alignment/functional outcome rather than of deformity direction.

In the skeletally immature patient, the spectrum of management for ankle valgus also includes growth-modulating techniques, and it is worth situating the present acute correction within that spectrum. Guided growth using a transphyseal screw or plate can gradually correct milder ankle valgus in children with sufficient remaining growth, but it is dependent on an open and responsive physis, it requires close follow-up, and it carries recognized issues including rebound deformity after hardware removal and, occasionally, difficult screw extraction.[16,27] Such techniques are best suited to deformities that are mild to moderate and largely coronal, with adequate growth remaining. For an established, severe, multiplanar post-traumatic malunion such as the present case — in which the deformity was fixed, the apex was clearly defined, and immediate correction of both planes was desirable — acute corrective osteotomy is the more appropriate strategy. The judicious surgeon will choose between growth modulation and acute osteotomy based on the magnitude, plane, and chronicity of the deformity and the patient's remaining growth.

The broader rationale for joint-preserving correction in a young patient is compelling. Arthrodesis and total ankle replacement sacrifice the native joint and are generally inappropriate for an adolescent with salvageable cartilage; realignment osteotomy, by contrast, redistributes load away from the overloaded compartment and may slow or arrest the progression of degenerative change while preserving motion.[5,28] Other joint-preserving strategies, such as ankle distraction arthroplasty, similarly aim to unload and rehabilitate a compromised joint rather than to ablate it, and they reflect the same overarching philosophy of preservation in younger patients.[29] In the present case, restoring the mechanical axis and the periarticular angles re-established a congruent, evenly loaded mortise, which is the most durable protection against premature arthrosis that surgery can offer.

This report is also a reminder of the epidemiological and systemic context of pediatric musculoskeletal trauma. Tibial and ankle fractures are common in children, and although many are managed successfully by closed means, a meaningful minority require operative stabilization to maintain alignment, and a further subset present late with deformity when initial care is inadequate.[1,2] High-energy road-traffic mechanisms, as in this patient, are associated with more severe injury patterns and a higher risk of complications.[3] Distal tibial fractures involving the physis additionally carry a measurable risk of growth disturbance that may not become apparent for years, which is why follow-up to skeletal maturity is recommended after such injuries.[9] These considerations reinforce two practical messages: that timely, radiographically guided care of the index fracture is the most effective way to prevent malunion, and that even after successful correction, continued surveillance of the growing ankle is warranted.

The interplay between deformity and the remodeling potential of the growing skeleton merits particular consideration in a patient of this age. The pediatric bone possesses a capacity for spontaneous correction that depends on the amount of growth remaining, the proximity of the deformity to an active physis, and the plane of the deformity relative to the dominant axis of joint motion. Deformities close to a physis and in the plane of adjacent joint movement remodel most reliably, whereas deformities that are distant from the physis, rotational, or out of the plane of motion remodel poorly. In the present patient, the deformity was established and multiplanar, and at thirteen years of age the remaining growth was insufficient to be relied upon to correct a deformity of this magnitude; furthermore, ongoing eccentric loading of a malaligned mortise risked progressive rather than spontaneous improvement.[1,9] These considerations argued decisively against expectant management and in favor of acute surgical correction, while simultaneously demanding meticulous protection of the distal tibial physis during the osteotomy so that surgery did not exchange one growth-related deformity for another.

The methodology of CORA-based correction deserves fuller exposition because it is the conceptual core of the operation. In the planning framework derived from the principles of deformity correction, the proximal and distal segments of the bone each possess an axis, and the point at which these axes intersect is the center of rotation of angulation. The axis about which the correction is performed — the axis of

correction of angulation — should pass through the CORA; when it does, pure angular correction is achieved with neither residual angulation nor secondary translation. If, for surgical convenience, the osteotomy is made at a level other than the CORA, the surgeon must deliberately add a translation at the osteotomy to avoid creating a new, iatrogenic step-off, and failure to do so produces a secondary translational deformity even though the limb may appear angularly straight.[14] Recognizing the apex within the distal tibial metaphysis in this case allowed the osteotomy to be placed at the CORA, so that a closing wedge produced a clean angular correction in both the coronal and sagittal planes. The same discipline was applied to the fibula, whose apex and correction were planned independently to restore the lateral column.

The TAS and TLS angles warrant emphasis as the practical, reproducible parameters by which periarticular ankle alignment is judged. The TAS angle, measured on the weight-bearing or standard anteroposterior view between the anatomical axis of the tibia and the line of the distal tibial articular surface, normally lies in the high-80-degree to low-90-degree range, with values around 88 to 93 degrees reported as the post-correction target in supramalleolar series.[15,19] The TLS angle, measured in the sagittal plane on the lateral view, normally lies in the region of 80 degrees. Reductions of these angles indicate coronal and sagittal malalignment of the plafond respectively, and their normalization is the radiographic signature of a successful correction. In adolescent series of supramalleolar osteotomy for traumatic ankle deformity, improvements in TAS and TLS have been shown to parallel improvements in validated functional scores, lending these radiographic surrogates genuine clinical meaning.[20,21] In the present patient the correction of the TAS from 76.4 to 93.0 degrees and the TLS from 76.0 to 84.0 degrees therefore represents not merely a change in numbers but a restoration of the loaded surface toward physiological orientation.

Anticipation and avoidance of complications shaped every stage of the procedure. The principal hazards of corrective osteotomy in this region include neurovascular injury, particularly to the superficial peroneal nerve laterally and to the posterior neurovascular bundle; delayed union or non-union at the osteotomy, especially where a wedge resection reduces bony contact; loss of correction before union when fixation is inadequate; wound and soft-tissue problems over a subcutaneous bone; physeal injury with consequent growth disturbance; and recurrence of deformity. Each was specifically addressed: careful soft-tissue handling and protection of the superficial peroneal nerve during the lateral approach; closing-wedge osteotomies that maximize bone-to-bone contact to favor union; angular-stable plate fixation on both the tibia and fibula to prevent secondary displacement; low-profile implants chosen for the thin local envelope; and deliberate preservation of the distal tibial physis.[4,9] The uneventful course in this patient — primary wound healing, no neurovascular deficit, union of both osteotomies, and no loss of correction at one year — is consistent with the low complication rates reported when these principles are observed.

The choice of a single-stage rather than a staged correction also reflects deliberate reasoning. Performing both the fibular and tibial osteotomies under one anesthetic spares the patient a second operation and a second period of immobilization, allows the two bones to be balanced against one another in real time under fluoroscopic control, and shortens the overall rehabilitation timeline. The sequence — fibula first to set lateral column length, then tibia for the definitive multiplanar correction — ensures that the tibial correction is performed against a restored lateral buttress rather than a deficient one.[26-29] Where the deformity is gradual, very large, or accompanied by a substantial length discrepancy or compromised soft tissues, a staged or gradual approach using a circular or hexapod external fixator remains the more prudent option, and the literature documents excellent multiplanar correction with such devices.[21,24] The present case fell clearly into the category amenable to acute single-stage internal fixation, and the outcome supports that judgment.

Beyond the technical narrative, this case carries a public-health message about the prevention of neglected deformity. The persistence of traditional bone-setting in many regions is driven by genuine barriers to formal care — cost, distance, distrust of hospitals, and fear of surgery or amputation — and

simply condemning the practice is neither realistic nor productive.[13] The literature increasingly favors engagement: education and basic training of traditional practitioners, clearer referral pathways for injuries beyond their competence, and integration of bone setters into local musculoskeletal-care networks have been associated with reductions in serious complications.[12,13] For the individual child, the decisive intervention is timely access to a radiograph and a definitive diagnosis after injury; had this been available, a simple closed or minimally invasive treatment of the index fracture would in all likelihood have averted the multiplanar malunion that ultimately required a double-level reconstruction. The reconstructive surgeon and the public-health system are thus complementary: one repairs the established deformity, the other prevents it.

Long-term surveillance and the question of implant removal are further considerations specific to the pediatric patient. Because the distal tibial physis remains active until skeletal maturity, a child who has undergone a periarticular osteotomy should be followed until growth is complete so that any late physeal arrest, recurrent angulation, or limb-length discrepancy can be identified and addressed early. The decision to remove the plates is individualized: hardware that is prominent, symptomatic, or crossing a region of continued growth is more likely to warrant removal, whereas asymptomatic, well-positioned implants may be retained, and the timing of any removal is balanced against the small risks of a further procedure and of refracture through screw holes. The experience with growth-modulating implants, where hardware removal can itself be technically demanding and is occasionally complicated by retained or broken screws, is a reminder that implant removal in children is not a trivial undertaking and should be planned thoughtfully rather than performed reflexively.[16,27] In the present patient, with union achieved and the implants well tolerated at one year, continued observation rather than early routine removal was appropriate, with the plan to reassess as the child approaches skeletal maturity.

Several limitations of this report should be acknowledged. As a single-case report, the findings illustrate a strategy and an outcome but cannot establish generalizable efficacy or define the relative merits of competing techniques. Objective functional instruments such as the AOFAS or the Foot and Ankle Outcome Score (FAOS) were not formally administered, so the functional gains, although clinically evident, are not quantified in a standardized manner. Finally, although one-year follow-up demonstrated union and maintained correction, longer surveillance until skeletal maturity would be valuable to confirm the durability of the correction and to detect any late physeal or growth-related sequelae. Future reports would be strengthened by prospective functional scoring and by longer follow-up of comparable patients.

4. Conclusion

This case demonstrates that a carefully planned, single-stage double-level osteotomy of the distal tibia and fibula, combined with stable internal fixation, can effectively restore alignment, ankle congruity, and function in a child with distal tibiofibular malunion and multiplanar valgus deformity. CORA-based preoperative planning and the restoration of the TAS and TLS alignment parameters were instrumental in achieving an accurate correction, with the TAS improving from 76.4° to 93.0° and the TLS from 76.0° to 84.0°, and with bony union and painless ambulation at one year. Equally important is the preventive message embodied by this case: the deformity was the consequence of a neglected injury managed without radiographs, and early orthopedic evaluation, appropriate referral, and timely definitive treatment remain the most effective means of preventing progressive deformity and long-term disability following pediatric ankle and distal tibial fractures.

5. References

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