

CASE REPORT

Double-Level Closing-Wedge Osteotomy Guided by the Center of Rotation of Angulation for a Neglected Distal Tibiofibular Valgus Malunion in a 13-Year-Old Boy: An Observasional Analytic Case Study

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ABSTRACT

Background: Pediatric distal tibiofibular fractures treated by traditional bone setters without radiographs may heal in multiplanar valgus malunion, with lateral tibiotalar overload and a risk of early arthrosis.

Objective: To describe the deformity analysis, surgical technique, and one-year outcome of single-stage center of rotation of angulation (CORA)-guided double-level closing-wedge osteotomy for a neglected pediatric distal tibiofibular valgus malunion.

Methods: This study describes a 13-year-old boy seen 12 months after a road-traffic injury treated by a traditional bone setter without radiographs. Preoperative analysis showed a coronal valgus CORA of 16.9° (apex 4.01 cm above plafond), a sagittal CORA of 18.1° (apex 3.59 cm above plafond), a resultant oblique angulation (θ_{net}) of 24.1°, a tibial anterior surface (TAS) angle of 76.4°, and a tibial lateral surface (TLS) angle of 76.0°. In one operation, a lateral fibular closing-wedge osteotomy was fixed with a one-third tubular plate and an anterolateral, physeal-sparing tibial closing-wedge osteotomy with a distal tibial T-locking plate. Outcomes were recorded from presentation (T0) to 12 months (T4).

Results: At one year (T4), TAS improved from 76.4° to 93.0° and TLS from 76.0° to 84.0°, and coronal and sagittal angulation were corrected to near neutral. Both osteotomies had united, and the patient walked without restriction and squatted fully without pain. No complications occurred.

Conclusion: In this patient, single-stage CORA-guided double-level closing-wedge osteotomy with physeal-sparing locking fixation restored alignment and painless function at one year; the approach may be considered for neglected pediatric distal tibiofibular malunion.

1. Introduction

Fractures of the tibial and fibular shafts and of the distal tibial metaphysis are a major part of pediatric musculoskeletal trauma and account for approximately 15% of all long-bone injuries in children and adolescents.¹⁻³ Pediatric orthopedic practice has moved toward selective operative stabilization when acceptable axial, rotational, and periarticular alignment cannot be obtained or maintained by closed reduction and casting, because residual multiplanar malalignment near the maturing ankle is poorly tolerated.^{1,2} The energy of the injury, the fracture configuration, and concurrent disruption of the ipsilateral fibula determine both the acute compartment risk and the tendency to late axial deviation; high-energy pedestrian road-traffic collisions and combined distal tibiofibular fractures carry a particularly high risk of secondary displacement and malunion.²⁻⁴ When reduction is omitted or immobilization is not monitored radiographically, the fracture consolidates in an unacceptable position and leaves a fixed malunion with coupled coronal, sagittal, and translational deformity.^{4,5}

Unlike the multiaxial hip and shoulder, the tibiotalar joint is a constrained, highly congruent mortise that transmits compressive loads of more than four to five times body weight during the stance phase of level walking, which makes its

cartilage vulnerable to axial malalignment.^{4,5} Even a modest angular deviation of the distal tibial plafond from its physiological orientation alters the instantaneous axis of tibiotalar rotation, reduces the effective weight-bearing contact area (A_{eff}), and concentrates peak contact stress ($\sigma_c = F/A_{eff}$) in the overloaded compartment.^{5,6} In post-traumatic distal tibial malunion the deformity is rarely confined to one plane; it usually combines coronal valgus or varus deviation with sagittal procurvatum or recurvatum of the plafond.⁷ The distal fibula is not a passive structure. It forms the lateral wall of the bimalleolar mortise, bears approximately 15% to 17% of the axial load of the leg, and deepens the talocrural socket during dorsiflexion.^{7,8} Post-traumatic fibular malunion, valgus bowing, or relative shortening therefore destabilizes the lateral buttress of the ankle, permits lateral talar translation and external rotation, widens the syndesmotic clear space, and can lead to progressive hindfoot and tibiotalar valgus.^{7,8}

In the skeletally immature adolescent, post-traumatic periarticular ankle deformity is further complicated by the interaction between abnormal loading and the remaining growth of the distal tibial and fibular physes.^{9,10} A mild diaphyseal angulation in a young child may remodel

spontaneously if it lies in the plane of joint motion, but an established multiplanar metaphyseal malunion in an older child or an adolescent nearing skeletal maturity often exceeds the capacity for remodeling.^{1,9} Under the Hueter–Volkmann principle, sustained eccentric compression across the lateral part of the distal tibial growth plate inhibits longitudinal chondrocyte hypertrophy in the lateral physal columns while the medial physis is unloaded, which may turn a static malunion into a progressive valgus deformity.^{9,10} Left uncorrected, severe pediatric distal tibiofibular valgus malunion leads to lateral subfibular impingement, attenuation of the medial deltoid ligament, antalgic gait, and premature post-traumatic tibiotalar osteoarthritis in early adulthood.⁵

In low- and middle-income countries (LMICs), a common socioeconomic and cultural cause of neglected pediatric fracture malunion is reliance on traditional bone setters (TBS) as the first providers of musculoskeletal trauma care.^{11–13} Traditional practitioners are embedded in rural and peri-urban communities because they are perceived as affordable, close, and culturally familiar, yet their management involves no diagnostic radiography, empirical manual manipulation, and non-standard bamboo or wooden splints.^{11,12} Systematic and clinical studies report high rates of complex malunion, pseudarthrosis, joint contracture, and ischemic complications after unsupervised TBS treatment.^{11,12} When an adolescent reaches a tertiary orthopedic center a full year after TBS treatment with a consolidated multiplanar distal tibiofibular malunion, the surgeon has to perform a geometrically precise, physal-sparing osteotomy that restores both the lateral fibular column and the biplanar orientation of the tibial plafond.^{14,15}

We report the case of a 13-year-old boy with a neglected, progressive multiplanar valgus ankle deformity caused by a distal tibiofibular malunion that had been managed by a traditional bone setter without radiographs. The deformity was corrected in one stage by a center of rotation of angulation (CORA)-guided double-level closing-wedge osteotomy of the distal fibula and distal tibia with angular-stable internal fixation. The case shows how biplanar CORA planning, which located the coronal (16.9° valgus) and sagittal (18.1°) apices within the distal tibial metaphysis to satisfy Paley's zero-translation rule ($d_{trans} = 0.0$ mm), was combined with lateral-first restoration of the fibular buttress using a contoured one-third tubular plate and with physal-sparing distal tibial T-locking plate fixation in an adolescent ankle neglected after bone-setter treatment. We describe the preoperative three-dimensional deformity geometry, the single-stage technique, and the one-year radiographic and functional course measured with the tibial anterior surface (TAS) and tibial lateral surface (TLS) angles, and we discuss what the case implies for referral from traditional bone setters in resource-limited settings.^{14–16}

2. Methods

Case design and reporting framework

This case report describes one patient followed longitudinally after correction of a neglected post-traumatic pediatric distal tibiofibular malunion at the Pediatric Division, Department of Orthopaedic and Traumatology, Faculty of Medicine, Universitas Sebelas Maret / Dr. Moewardi Regional General Hospital, a tertiary academic referral center in Surakarta, Central Java, Indonesia, and is reported according to the CARE guideline. The report combines orthogonal radiographic measurement, trigonometric analysis of the multiplanar deformity, and serial clinical and functional assessment over a 24-month timeline that comprises the 12-month interval of prehospital neglect (T–12m to T0) and 12 months of prospective postoperative

follow-up (T1 to T4). Planning, surgery, and follow-up followed the department's standard pediatric orthopedic reconstruction protocols.

Case setting and patient information

The patient was a skeletally immature adolescent with radiographically open distal tibial and fibular physes and an established, symptomatic, fixed post-traumatic malunion of the distal third of the tibia and fibula after non-medical initial fracture care. The deformity was multiplanar: the coronal-plane CORA angulation (COR_{cor}) and the sagittal-plane angulation (COR_{sag}) each exceeded 10°, and both periarticular orientation angles were below their lower reference limits (TAS below 88° and TLS below 80°).¹⁵ The soft-tissue envelope was intact, and distal neurovascular function was preserved. Preoperative radiographs and examination showed no hematogenous or post-traumatic osteomyelitis, neuropathic (Charcot) arthropathy, congenital skeletal dysplasia, hereditary multiple exostoses, neuromuscular disease, or transphysal bony bar involving more than 50% of the distal tibial physal cross-section.^{9,16}

Data collection and diagnostic assessment

Clinical findings and orthogonal anteroposterior (AP) and lateral radiographs of the right leg and ankle were recorded at each time point, and the deformity was analyzed with the CORA method on both projections.¹⁴ Reference values came from the patient's uninjured left lower limb and from published periarticular standards: COR_{cor} and $COR_{sag} \approx 0.0^\circ$ (tolerance $\leq 2.0^\circ$), TAS 88.0°–93.0°, and TLS 80.0°–84.0°.¹⁵ Because a single patient was studied, no inferential tests (Student's t-test, analysis of variance, Mann–Whitney U test, χ^2 test, or p-values) were applied. Each continuous radiographic parameter X was reported at preoperative baseline (T0) and at one-year follow-up (T4), with the absolute change $\Delta X = X_{T4} - X_{T0}$. The true oblique-plane angulation (θ_{net}) and its orientation relative to the coronal plane (φ) were derived from the orthogonal projections as $\theta_{net} = \arctan[\sqrt{\tan^2(COR_{cor}) + \tan^2(COR_{sag})}]$ and $\varphi = \arctan[\tan(COR_{sag})/\tan(COR_{cor})]$.¹⁴ The secondary translation produced when an osteotomy lies at a distance L from the CORA apex was modeled with Paley's relation $d_{trans} = 2 \cdot L \cdot \sin(\theta/2)$.¹⁴

The chosen technique, acute closing-wedge osteotomy with internal locking fixation of both columns, was compared with five alternative strategies: supramalleolar opening-wedge osteotomy with structural bone graft, circular Ilizarov or computer-assisted hexapod external fixation, patient-specific three-dimensional (3D)-printed cutting-guide osteotomy, medial malleolar transphysal guided growth (hemiepiphyseodesis), and joint-sacrificing arthrodesis or arthroplasty.^{16–21} The baseline deformity, angular correction (ΔTAS and ΔTLS), time to union, and complications were compared with published series and case reports of distal tibiofibular malunion and supramalleolar osteotomy.^{5,7,8,15,17,21,22} Complications were recorded throughout follow-up and graded with the Clavien–Dindo classification.

Intervention and follow-up

Clinical and radiographic data were recorded at six time points anchored to the operation: T–12m (retrospective baseline at month –12, day –365: the motorcycle-related pedestrian road-traffic collision and the start of bone-setter splinting); T0 (preoperative tertiary referral baseline at month 0, day 0: clinical inspection, neurovascular examination, and orthogonal AP and lateral radiographs of the right leg and ankle); T1 (day 1 after the single-stage CORA-guided double-level closing-wedge

osteotomy, dual-plate internal fixation, and application of a below-knee cast); T2 (postoperative week 6, day 42: end of strict non-weight-bearing [NWB] immobilization, radiographic check of early metaphyseal callus, cast removal, and start of graduated partial weight-bearing [PWB] and active-assisted ankle range-of-motion [ROM] exercises); T3 (postoperative month 3, week 12, day 90: progression to unassisted full weight-bearing [FWB] plantigrade walking); and T4 (one-year follow-up at month 12, week 52, day 365: standing lower-limb photographs, deep-squat assessment, orthogonal union radiographs, and final measurement of the TAS and TLS angles).¹⁵

Ethical approval and consent

The study was approved by CMHC Research Center Ethics Committee, Indonesia (protocol No. 2026/0425), with institutional clinical governance endorsement from the Department of Orthopaedic and Traumatology, Dr. Moewardi Regional General Hospital / Faculty of Medicine, Universitas Sebelas Maret, Surakarta, Indonesia. Diagnostic, surgical, and photographic procedures complied with the 1964 Declaration of Helsinki and its 2013 Fortaleza amendment and with the International Committee of Medical Journal Editors (ICMJE) recommendations for the protection of research participants. Before surgery, written informed consent for surgical

reconstruction, follow-up, and publication of clinical data and photographs was obtained from the patient's parents and legal guardians, together with the assent of the patient.

3. Results

Prehospital course, presentation, and clinical examination

A 13-year-old boy was referred to our tertiary pediatric orthopedic service (T0) with progressive outward angulation of the right ankle and persistent mechanical discomfort on weight-bearing that had developed over the preceding 12 months. Twelve months earlier (T-12m), he had sustained a high-energy road-traffic injury when a motorcycle struck him as he crossed the street, with immediate severe pain, periarticular swelling, and inability to bear weight on the right leg. Instead of seeking hospital care or radiography, the family consulted a local traditional bone setter, who manipulated the leg and applied a non-standard splint without radiographic assessment or a definitive diagnosis. Over the following year, as the swelling subsided and the child walked again unaided, the family noticed increasing lateral deviation of the right foot and ankle, together with activity-limiting lateral ankle pain and an asymmetric limp. The clinical, radiographic, and functional course from the injury to the one-year postoperative review is summarized in Table 1.

Table 1. Clinical, radiographic, and functional course of the right ankle from injury (T-12m) to 12 months after surgery (T4).

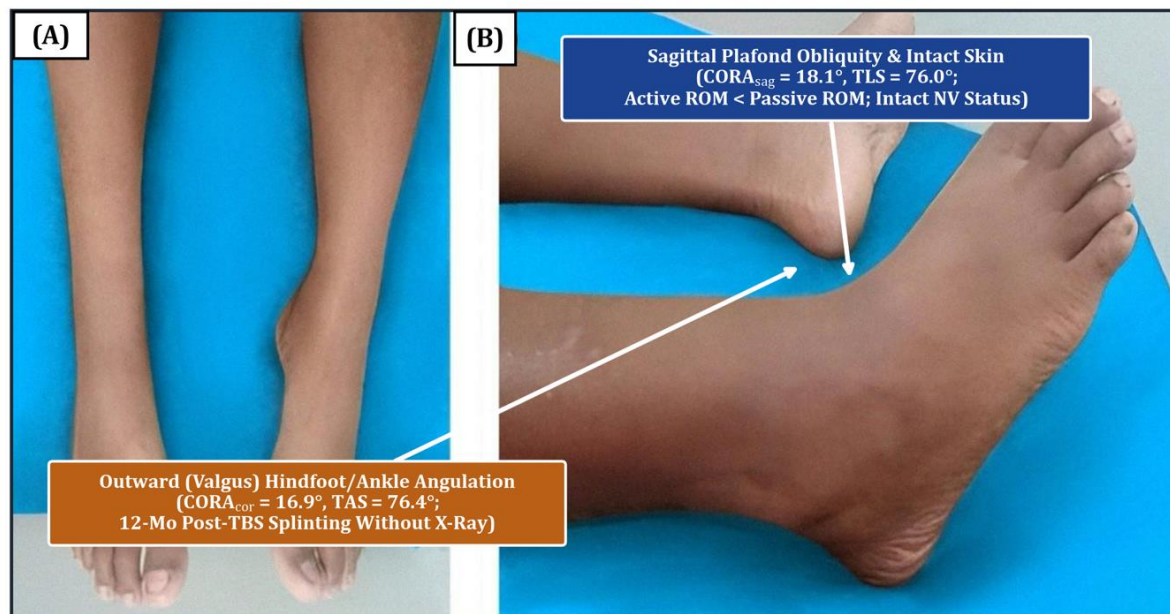
Parameter	Normal reference*	Injury (T-12m)	Preoperative (T0, day 0)	Postoperative (T1, day 1)	Protected union (T2, week 6)	Full weight-bearing (T3, month 3)	One year (T4, month 12)	Absolute change (Δ)
Coronal-plane angulation (CORA _{cor})	$\approx 0.0^\circ$ ($\leq 2.0^\circ$ tolerance)	Acute displaced fracture (not imaged)	16.9° valgus	Near-neutral ($\approx 0.3^\circ$)	Near-neutral ($\approx 0.3^\circ$)	Near-neutral ($\approx 0.3^\circ$)§	Near-neutral ($\approx 0.3^\circ$)	$\Delta = -16.6^\circ$ (to neutral zone)
Sagittal-plane angulation (CORA _{sag})	$\approx 0.0^\circ$ ($\leq 2.0^\circ$ tolerance)	Acute displaced fracture (not imaged)	18.1° apex angulation	Near-neutral ($\approx 0.0^\circ$)	Near-neutral ($\approx 0.0^\circ$)	Near-neutral ($\approx 0.0^\circ$)§	Near-neutral ($\approx 0.0^\circ$)	$\Delta = -18.1^\circ$ (axis neutralized)
Resultant oblique angulation (θ_{net})	$\approx 0.0^\circ$ ($\leq 2.8^\circ$ vector limit)	Progressive malunion under TBS splint	24.1° ($\phi = 47.1^\circ$ plane)	Near-neutral ($\approx 0.3^\circ$)	Near-neutral ($\approx 0.3^\circ$)	Near-neutral ($\approx 0.3^\circ$)§	Near-neutral ($\approx 0.3^\circ$)	$\Delta = -23.8^\circ$ (plafond vector $\Delta\theta = 18.4^\circ$)
Tibial anterior surface (TAS) angle (coronal)	88.0°–93.0° (LLN 88.0°)	Not radiographed at TBS facility	76.4° (11.6° below LLN)	Realigned on fluoroscopy†	Maintained on serial AP view†	Maintained†	93.0°	$\Delta = +16.6^\circ$ (deficit resolved)
Tibial lateral surface (TLS) angle (sagittal)	80.0°–84.0° (LLN 80.0°)	Not radiographed at TBS facility	76.0° (4.0° below LLN)	Realigned on fluoroscopy†	Maintained on serial lateral view†	Maintained†	84.0°	$\Delta = +8.0^\circ$ (deficit resolved)
Radiographic osseous and metaphyseal status	Intact bicortical continuity	Acute distal tibiofibular fracture	Established multiplanar malunion	Double-level osteotomy; stable plates	Early bridging callus; cast removed	Progressive cortical maturation	Complete bicortical union (tibia and fibula)	Union at both levels; no secondary loss (0.0°)
Ankle range of motion‡	Full, symmetrical, painless arc	Painful, swollen ankle	Limited ROM (active < passive)	Immobilized in below-knee cast	Graduated active ROM started	Not reported	Improved, painless motion; full squat	Qualitative normalization; painless deep squat
Weight-bearing and walking	Unrestricted plantigrade gait	Non-standard TBS bamboo splint	Progressive valgus gait and pain	Strict NWB (weeks 0–6)	Progressive PWB to FWB (weeks 6–12)	Unassisted FWB plantigrade walking	Unrestricted, painless FWB walking	Full functional recovery; no complications

CORA, center of rotation of angulation; TAS, tibial anterior surface; TLS, tibial lateral surface; TBS, traditional bone setter; LLN, lower limit of normal; AP, anteroposterior; ROM, range of motion; NWB, non-weight-bearing; PWB, partial weight-bearing; FWB, full weight-bearing; Δ , absolute change from T0 to T4. *Reference ranges for TAS (88.0°–93.0°) and TLS (80.0°–84.0°) are those of published supramalleolar osteotomy standards. †TAS and TLS at T1–T3 were verified intraoperatively and radiographically as near-normal; the quantitative values (93.0° and 84.0°) were measured at T4. ‡Range of motion was documented qualitatively in the clinical record. §TAS angulation values were read from the serial alignment chart.

Medical, developmental, and family histories revealed no congenital lower-limb anomaly, skeletal dysplasia, hereditary multiple exostoses, rickets, metabolic bone disease, or previous injury to either lower limb. At T0 the patient was hemodynamically stable, afebrile, and systemically well. Inspection of the right lower limb, supine and standing, showed an intact skin envelope without erythema, induration, sinus tracts, warmth, or inflammation and a pronounced outward (valgus) angulation of the distal leg, ankle, and hindfoot compared with the straight left limb. Palpation over the distal tibial metaphysis, both malleoli, and the syndesmotic ligaments elicited no focal bony tenderness or crepitus, which indicated clinical consolidation of the malunited fragments. The distal

neurovascular examination was normal, with capillary refill under 2 s, symmetrical dorsalis pedis and posterior tibial pulses, and intact sensory and motor function in the tibial and the deep and superficial peroneal nerve distributions. Ankle dorsiflexion–plantarflexion and subtalar inversion–eversion were restricted, with active motion more limited than passive motion; we attributed this pattern to mechanical impingement and altered muscle–tendon lever arms from the bony malalignment rather than to intra-articular fibrous or bony ankylosis. The preoperative frontal and lateral appearance and a schematic of the corresponding tibiotalar loading are shown in Figure 1.

(a) Preoperative Clinical Photographs of the Right Lower Limb (Frontal [A] & Lateral [B])



(b) Bimalleolar Mortise Load-Sharing & CORA Double-Level Realignment Mechanics

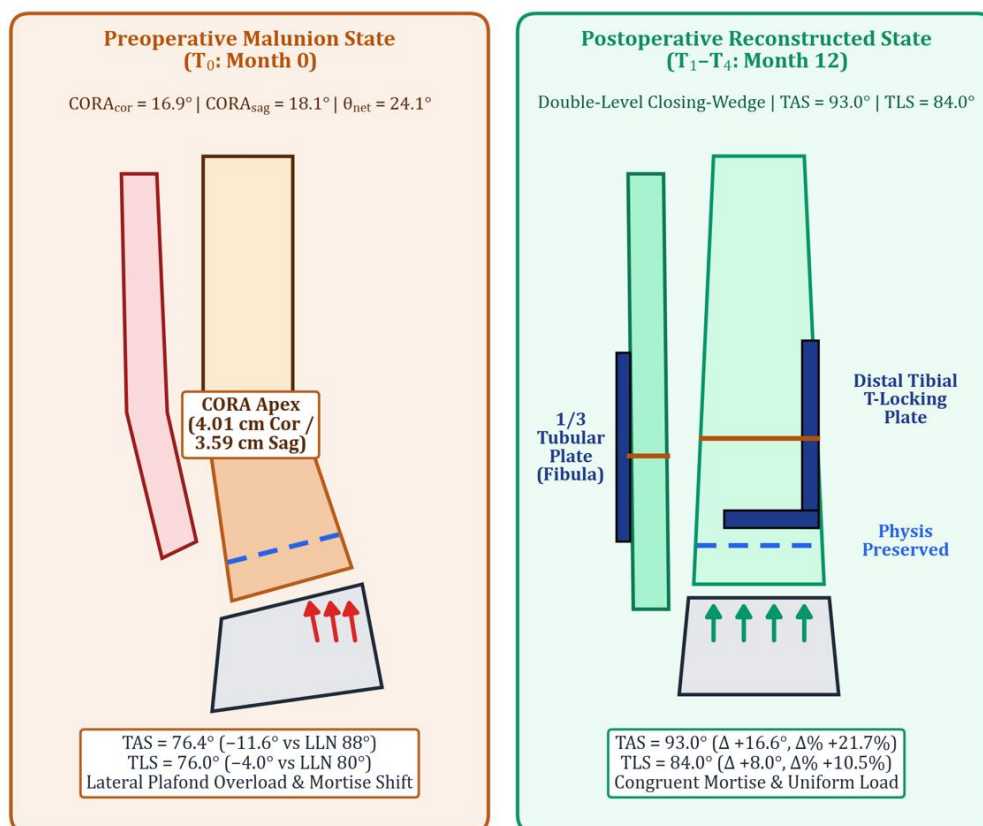


Figure 1. Preoperative clinical presentation (T₀) and schematic of tibiotalar loading. (a) Preoperative clinical photographs of the right lower limb in frontal [A] and lateral [B] views showing marked outward (valgus) angulation of the right ankle compared with the unaffected left side, with an intact, non-inflamed skin envelope after 12 months of unsupervised traditional bone-setter splinting. (b) Schematic (not to scale) comparing eccentric lateral plafond loading and the shortened fibular buttress in the preoperative malunion (T₀: $CORA_{cor} = 16.9^\circ$, $CORA_{sag} = 18.1^\circ$, $\theta_{net} = 24.1^\circ$, $TAS = 76.4^\circ$, $TLS = 76.0^\circ$) with uniform tibiotalar load distribution and restored bimalleolar mortise containment after single-stage double-level closing-wedge osteotomy and physseal-sparing dual-plate fixation (T₁-T₄: $TAS = 93.0^\circ$, $TLS = 84.0^\circ$); contact stress was not measured.

Preoperative deformity analysis

Orthogonal radiographs of the right leg and ankle mortise at T₀ showed a fully consolidated malunion of the distal third of the tibia and fibula with severe multiplanar angulation and lateral tilt of the tibiotalar articular surface. CORA analysis on the AP

radiograph identified a proximal tibial anatomical axis segment of 8.08 cm and a distal metaphyseal segment of 4.01 cm (referenced at 89.9° and 90.0° to the proximal and distal epiphyseal-metaphyseal baselines), which intersected at a coronal-plane valgus CORA ($CORA_{cor}$) of 16.9° within the distal

tibial metaphysis, 4.01 cm proximal to the tibiotalar plafond. On the lateral radiograph, the proximal and distal tibial anatomical axes (referenced at 90.0° and 89.9°) intersected at a sagittal-plane apex (CORA_{sag}) of 18.1°, 3.59 cm proximal to the plafond.

The multiplanar CORA parameters, the geometry of the double-level closing-wedge osteotomy, and the fixation are summarized in Table 2.

Table 2. Preoperative multiplanar CORA deformity, double-level closing-wedge osteotomy, and dual-column internal fixation.

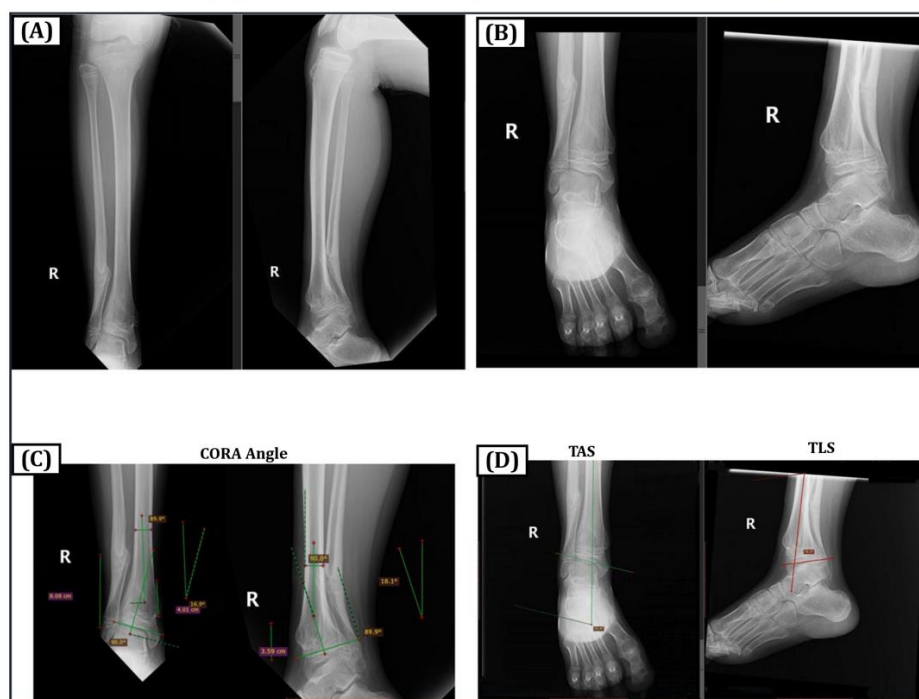
Anatomical domain	Preoperative deformity (T0)	Osteotomy level and wedge geometry (T1)	Implant construct and fixation	Postoperative realignment and outcome (T4)
Lateral column (distal fibula)	Healed malunion with relative shortening and valgus angulation; loss of lateral mortise buttress	Stage 1 (lateral approach): closing-wedge osteotomy at the fibular CORA apex; superficial peroneal nerve protected	Contoured low-profile 3.5-mm one-third tubular plate; bicortical neutralization screws respecting the thin lateral soft-tissue envelope	Fibular length and lateral malleolar buttress restored; talar lateral shift and syndesmotic widening prevented
Medial-central column (distal tibia, coronal plane)	CORA _{cor} = 16.9° valgus; TAS = 76.4° (proximal axis 8.08 cm; distal metaphyseal apex 4.01 cm above the plafond; references 89.9°/90.0°)	Stage 2 (anterolateral approach): medial-based biplanar closing-wedge resection at the tibial metaphyseal CORA (planned ΔTAS +16.6°)	Anatomical distal tibial T-locking plate; fixed-angle locking screws in the distal metaphyseal segment proximal to the open physis	TAS restored to 93.0° (Δ = +16.6°); CORA _{cor} corrected to ≈ 0.3°; osteotomy at the CORA (planned d _{trans} = 0.0 mm)
Medial-central column (distal tibia, sagittal plane)	CORA _{sag} = 18.1° angulation; TLS = 76.0° (sagittal metaphyseal apex 3.59 cm proximal to the plafond; references 90.0°/89.9°)	Sagittal closing-wedge component incorporated in the single tibial metaphyseal osteotomy (planned ΔTLS +8.0°)	Fixed-angle distal locking cluster resisting sagittal bending and secondary procurvatum or recurvatum	TLS restored to 84.0° (Δ = +8.0°); sagittal plafond tilt within the 80.0°–84.0° window
Resultant 3D oblique deformity and ACA alignment	θ _{net} = 24.1° oriented at φ = 47.1° from the coronal plane; lateral tibiotalar contact-stress overload	Osteotomy plane and axis of correction of angulation (ACA) matched to the metaphyseal CORA intersection	Dual-column construct (fibular one-third tubular plate + tibial T-locking plate) + 6-week below-knee cast	Resultant plafond realignment Δθ _{plafond} = 18.4°; uniform tibiotalar load distribution restored
Distal tibial and fibular physes	Open, viable distal tibial and fibular physes in a 13-year-old boy; insufficient remaining growth for spontaneous remodeling	Subperiosteal dissection and saw cuts kept proximal to the undulating growth plate	Distal T-plate locking screws placed parallel to and above the physis without transphyseal violation	Physes open at 12 months (T4); no radiographic physeal bar or secondary growth arrest

CORA, center of rotation of angulation; ACA, axis of correction of angulation; TAS, tibial anterior surface angle; TLS, tibial lateral surface angle; d_{trans}, secondary translational step-off. Placing the osteotomy at the metaphyseal CORA satisfies Paley's rule 1 of deformity correction (d_{trans} = 0.0 mm)¹⁴ and maximizes cancellous bone contact across the closing-wedge interface.

Combining the coronal (16.9°) and sagittal (18.1°) projections ($\theta_{\text{net}} = \arctan[\sqrt{(\tan^2(16.9^\circ) + \tan^2(18.1^\circ))}] = \arctan[\sqrt{(0.3038^2 + 0.3269^2)}] = \arctan[0.4463]$) gave a true oblique-plane angulation of $\theta_{\text{net}} = 24.1^\circ$, oriented at $\phi = 47.1^\circ$ from the coronal plane. The effect of the malunion on the orientation of the tibiotalar joint line was measured with periarticular angles on the preoperative ankle radiographs. The TAS angle, formed in the coronal plane by the tibial anatomical axis and the distal tibial plafond, measured 76.4°, which is 11.6° below the lower limit of the reference range (88.0°–93.0°) and 16.6° below its upper limit. The TLS angle, formed in the sagittal plane by the tibial anatomical axis and the distal articular surface, measured 76.0°, 4.0° below the lower limit of the reference range (80.0°–84.0°) and 8.0° below its upper limit. The ipsilateral distal fibula

had healed in valgus with relative shortening of the lateral column, which weakened the lateral malleolar buttress and allowed lateral talar tilt within the mortise. Templating followed Paley's first rule of osteotomy: when both the osteotomy and the axis of correction of angulation (ACA) pass through the CORA, the angular deformity is corrected without a secondary translational step-off ($d_{\text{trans}} = 2 \cdot L \cdot \sin(\theta/2) = 0.0$ mm when $L = 0.0$ mm), whereas an osteotomy placed 20.0 or 30.0 mm proximal to the metaphyseal CORA without compensatory translation would introduce a translational deformity of 8.3 to 12.5 mm.¹⁴ The preoperative radiographs, the CORA intersections, the baseline TAS and TLS measurements, and the translation curves are shown in Figure 2.

(a) Orthogonal Radiographs [A,B], CORA Analysis [C: 16.9° / 18.1°], & TAS/TLS Angles [D: 76.4° / 76.0°]



(b) Multiplanar Deformity Vector Synthesis & Osteotomy Offset Rule

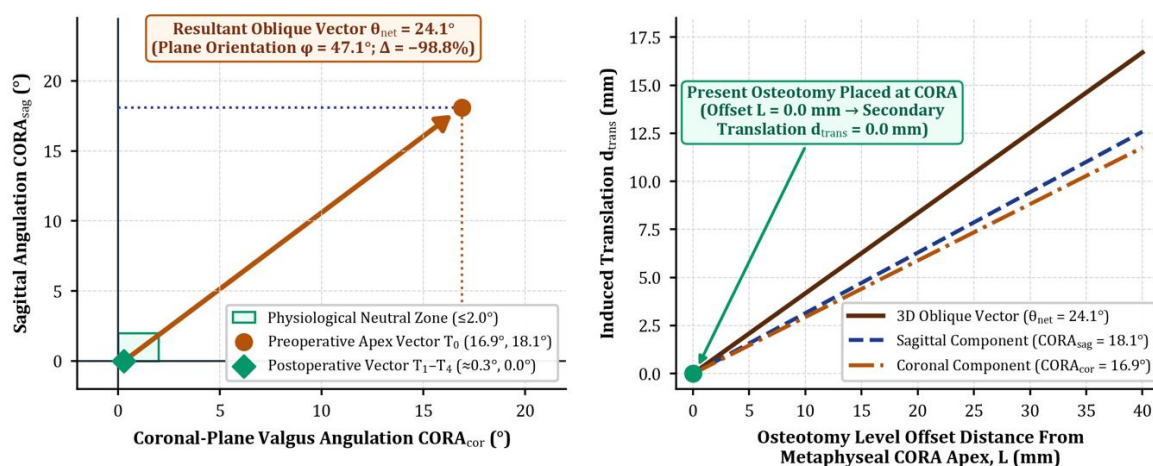


Figure 2. Preoperative radiographic deformity analysis (T0) and multiplanar CORA osteotomy planning. (a) Preoperative orthogonal radiographs of the right tibia and fibula [A] and ankle mortise [B] showing distal tibiofibular malunion and articular-surface obliquity; center of rotation of angulation (CORA) analysis [C] showing 16.9° of coronal valgus angulation (apex 4.01 cm above the plafond; proximal axis 8.08 cm) and 18.1° of sagittal angulation (apex 3.59 cm above the plafond); and baseline periarticular measurements [D] showing a tibial anterior surface (TAS) angle of 76.4° and a tibial lateral surface (TLS) angle of 76.0°. (b) Coronal-sagittal deformity vector synthesis showing the resultant 24.1° oblique angulation ($\phi = 47.1^\circ$), and Paley's rule 1 secondary translation curve ($d_{trans} = 2 \cdot L \cdot \sin(\theta/2)$), which shows why placing the osteotomy at the metaphyseal CORA (offset L = 0.0 mm) gives pure angular realignment without secondary translation ($d_{trans} = 0.0$ mm).

Single-stage double-level closing-wedge osteotomy and fixation

Non-traumatic causes of adolescent ankle valgus were excluded, including congenital fibular hemimelia, hereditary multiple exostoses, post-infectious physal arrest, metabolic bone disease, and neuromuscular valgus hindfoot collapse, on the basis of the clear history of high-energy road-traffic trauma followed by 12 months of unsupervised bone-setter splinting, the normal left limb, the absence of osteochondromas or systemic skeletal stigmata, and the healed fracture callus visible at the tibial and fibular deformity apices. Because the 24.1° resultant deformity was fixed, progressive, and beyond the remodeling capacity of a 13-year-old physis, the patient

underwent acute, single-stage CORA-guided double-level closing-wedge osteotomy of the distal fibula and distal tibia with internal plate fixation.

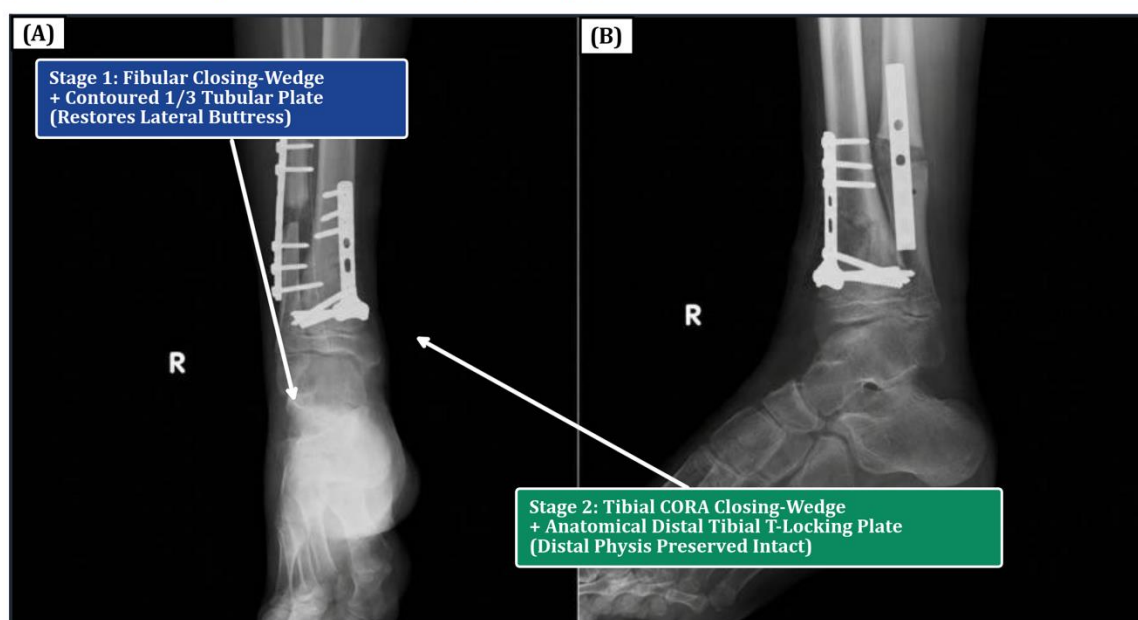
With the patient supine on a radiolucent table under general anesthesia and with a proximal thigh tourniquet, continuous C-arm fluoroscopy was used throughout. In stage 1, a longitudinal lateral approach was made over the distal fibula, and the superficial peroneal nerve was identified and gently retracted. A closing-wedge osteotomy was performed at the apex of the fibular malunion, removing a cortical-cancellous wedge to straighten the lateral column and restore fibular length and lateral mortise containment. The fibular osteotomy was fixed with a contoured, low-profile 3.5-mm one-third tubular plate

and bicortical screws, which supported the lateral column while respecting the thin subcutaneous soft-tissue envelope.

In stage 2, the distal tibia was exposed through an anterolateral approach that protected the anterior tibial neurovascular bundle, with the extensor tendons retracted medially. The undulating contour of the open distal tibial physis was located fluoroscopically and protected from thermal and mechanical injury. At the level of the distal tibial metaphyseal CORA (4.01 cm coronal and 3.59 cm sagittal proximal to the plafond), a biplanar closing-wedge osteotomy was made with a cooled oscillating saw, resecting a pre-calculated medial- and sagittal-based metaphyseal wedge planned to provide a 16.6° coronal correction (TAS from 76.4° to 93.0°) and an 8.0° sagittal correction (TLS from 76.0° to 84.0°). Closing the wedge brought

broad, well-vascularized cancellous surfaces into direct compression without secondary cortical translation ($d_{trans} = 0.0$ mm). Definitive fixation used an anatomically pre-contoured distal tibial T-locking plate placed proximal to the distal tibial growth plate, with fixed-angle locking screws in the distal metaphyseal segment above the physis and bicortical shaft screws in the proximal diaphyseal segment. Final intraoperative fluoroscopy and the radiographs on day 1 (T1) confirmed a horizontal, congruent tibiotalar plafond, a normal bimalleolar mortise width, and near-neutral coronal ($COR_{cor} \approx 0.3^\circ$) and sagittal ($COR_{sag} \approx 0.0^\circ$) mechanical axes. The immediate postoperative AP and lateral radiographs of the construct and the 12-month course of periarticular alignment from T0 to T4 are shown in Figure 3.

(a) Immediate Postoperative AP [A] & Lateral [B] Radiographs After Double-Level Osteotomy



(b) Serial Periarticular Realignment (TAS/TLS) & Deformity Neutralization

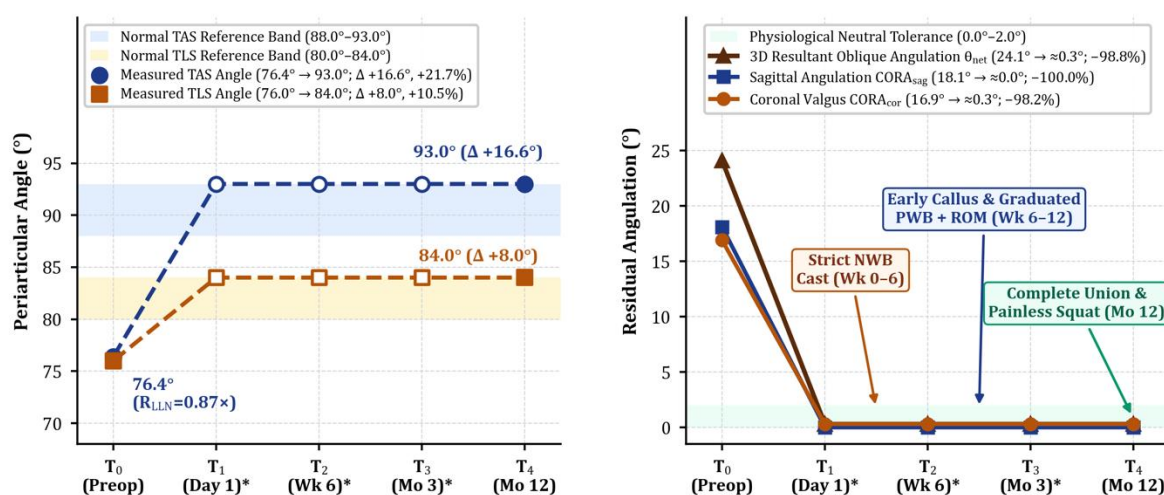


Figure 3. Immediate postoperative construct (T1) and 12-month alignment course (T0 to T4). (a) Immediate postoperative anteroposterior [A] and lateral [B] radiographs showing acute correction of the multiplanar valgus deformity, with the lateral fibular closing-wedge osteotomy fixed with a contoured low-profile one-third tubular plate and the distal tibial metaphyseal closing-wedge osteotomy fixed with an anatomical distal tibial T-locking plate proximal to the open distal tibial physis. (b) Course of the TAS (76.4° → 93.0°, $\Delta = +16.6^\circ$) and TLS (76.0° → 84.0°, $\Delta = +8.0^\circ$) angles relative to shaded reference bands (left) and of coronal (16.9° → $\approx 0.3^\circ$), sagittal (18.1° → $\approx 0.0^\circ$), and resultant 3D (24.1° → $\approx 0.3^\circ$) angulation across the rehabilitation timeline (right).

Postoperative course and choice of technique

The early postoperative course was uneventful: capillary refill remained under 2 s, active toe flexion and extension were full, sensation in the superficial peroneal, deep peroneal, and tibial nerve territories was intact, and the wounds healed primarily without hematoma, dehiscence, or surgical site infection. Under our biology-led rehabilitation protocol, the right leg was kept in a below-knee cast without weight-bearing for the first 6 weeks (T1 to T2), with active isometric quadriceps exercises, hip and knee mobilization, and gentle pain-free toe movement to prevent disuse atrophy and venous stasis. At the 6-week visit (T2, day 42), radiographs showed a stable fixed-angle construct without screw back-out or plate bending and early endosteal-metaphyseal bridging callus at both osteotomies. The cast was removed, and physiotherapy began with graduated partial weight-bearing on crutches and progressive active and active-assisted dorsiflexion, plantarflexion, subtalar inversion-eversion, and proprioceptive exercises. By postoperative month 3 (T3, week 12, day 90), progressive cortical maturation allowed unassisted full weight-bearing with a normal, plantigrade foot progression angle.

Table 3. Comparison of surgical options for distal tibial and supramalleolar deformity correction in skeletally immature and adolescent patients.

Surgical option	Principal biomechanical and clinical advantage	Principal technical or biological limitation	Physcal and axial length effect	Indication and relevance to the present case
Double-level closing-wedge osteotomy + internal locking fixation (present strategy)	Immediate fixed-angle biplanar stability; single-stage correction; direct cancellous bone contact promoting union	Modest focal wedge shortening; requires exact preoperative localization of the CORA apex to avoid secondary translation	Physcal-sparing metaphyseal placement; balances the lateral fibular and medial tibial columns simultaneously	Suited to fixed, severe, multiplanar post-traumatic tibiofibular malunion (CORA 16.9°/18.1°) with healthy soft tissues
Supramalleolar opening-wedge osteotomy + structural graft	Preserves or restores distal tibial column length; adjustable coronal correction by wedge distraction	Requires autograft or allograft gap healing; higher risk of delayed union, graft collapse, or skin tension	Maintains length; requires an intact or osteotomized fibula to allow angular distraction of the plafond	Preferred in uniplanar coronal deformity with a shortened ipsilateral tibial segment
Circular Ilizarov or computer-assisted hexapod external fixator	Gradual, precise six-axis multiplanar, rotational, and axial correction by distraction osteogenesis	Prolonged frame time (frame index 48.9 days/cm ²⁰); pin-tract infection risk; high psychosocial and nursing burden in adolescents	Allows concurrent limb lengthening; avoids deep internal hardware in scarred envelopes	Reserved for extreme multiplanar deformity, large limb-length discrepancy (> 2.5 cm), or compromised soft tissues
Patient-specific 3D-printed cutting-guide osteotomy	Submillimeter transfer of virtual 3D contralateral-templated planning to the intraoperative saw cuts	High cost, CT radiation exposure, and a 2–4-week fabrication time not available in many LMIC public hospitals	High geometric accuracy near the physis; depends on exact intraoperative guide seating	Useful for complex rotational or multiplanar diaphyseal-metaphyseal malunion where 3D printing is available
Medial malleolar guided growth (transphyseal screw, eight-plate, or U-staple)	Minimally invasive; gradual physiological angular correction (0.4°–0.68° per month) with early mobilization	Slow correction; risk of rebound valgus after removal; difficult screw extraction; ineffective for severe sagittal deformity	Requires ≥ 2–3 years of open physeal growth; tethered hemiepiphysiodesis principle	Indicated for mild-to-moderate, purely coronal ankle valgus in younger children; insufficient for a fixed 16.9°/18.1° malunion at 13 years
Joint-sacrificing procedures (tibiotalar arthrodesis or total ankle replacement)	Definitive pain relief in end-stage tibiotalar osteoarthritis with complete cartilage loss	Abolishes native tibiotalar motion; transfers load to the subtalar and midfoot joints; prosthesis loosening in young patients	Contraindicated across open physes; permanently sacrifices joint kinematics	Salvage only, for end-stage adult arthrosis; inappropriate in a 13-year-old with viable articular cartilage

CORA, center of rotation of angulation; CT, computed tomography; LMIC, low- and middle-income country. The choice of technique depends on deformity magnitude, multiplanarity, soft-tissue condition, and remaining skeletal growth.

Outcome at one year and comparison with published series

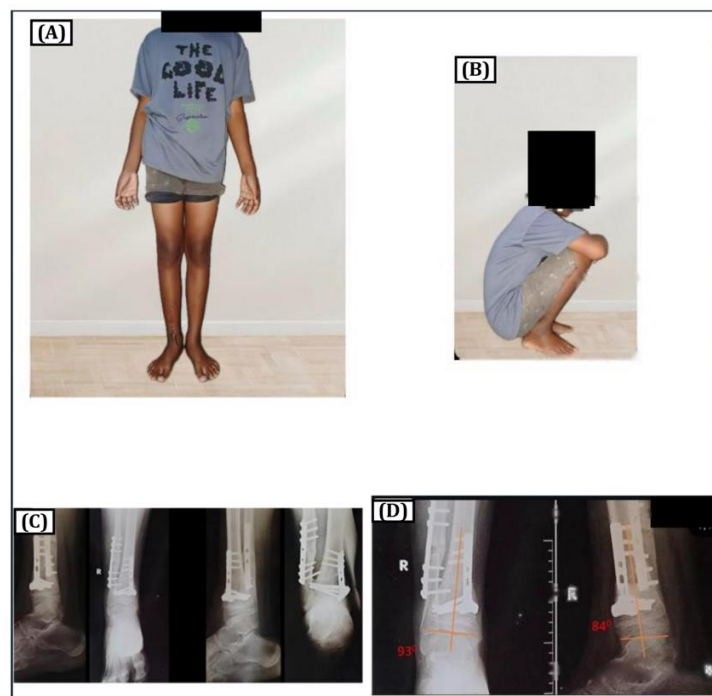
No complications occurred during the 12 months of follow-up. There were no wound, neurovascular, or hardware problems, no loss of reduction, and no adverse reactions to the general anesthetic, the prophylactic intravenous cephalosporin, or the postoperative multimodal analgesia.

At the one-year review (T4, month 12, day 365), standing frontal inspection showed symmetrical lower-limb alignment, a well-healed, non-adherent anterolateral scar, and no residual hindfoot-ankle valgus. Ankle motion was clearly improved and painless, and the patient could perform a full, deep, flat-footed squat without heel lift, lateral instability, or pain. AP and lateral radiographs at T4 showed union across all four cortices with

Six main options for correcting distal tibial deformity in children and adolescents were weighed before this single-stage closing-wedge strategy was chosen. Medial malleolar guided growth (transphyseal screw, tension-band eight-plate, or U-shaped staple hemiepiphysiodesis) corrects coronal ankle valgus gradually, at about 0.4° per month¹⁶ to 0.65°–0.68° per month,^{23,24} which would have required roughly 25 to 42 months of remaining growth to correct a 16.9° coronal deformity and would have left the 18.1° sagittal deformity uncorrected; the double-level closing-wedge osteotomy corrected both planes in one operation. Compared with circular Ilizarov or computer-assisted hexapod external fixation, for which a frame index of 48.9 days/cm has been reported in distal tibial lengthening in children²⁰ and which requires prolonged pin-site care,¹⁷ acute closing-wedge osteotomy with low-profile internal locking fixation provided immediate fixed-angle metaphyseal stability, direct cancellous compression, and consolidation without the morbidity of an external frame. The advantages, limitations, effects on the physis, and indications of the six options are compared in Table 3.

trabecular remodeling at both the distal fibular and the distal tibial osteotomy, open and viable distal tibial and fibular physes, and no radiographic evidence of premature physeal bar formation, hardware loosening, or recurrent angulation. Radiographic measurement at T4 showed that the TAS angle had improved from 76.4° at T0 to 93.0° (Δ TAS = +16.6°), within the 88.0°–93.0° reference interval, and that the TLS angle had improved from 76.0° to 84.0° (Δ TLS = +8.0°), within the 80.0°–84.0° reference interval. The resultant plafond realignment was $\Delta\theta_{\text{plafond}} = \sqrt{(16.6^2 + 8.0^2)} = 18.4^\circ$, and the net multiplanar shaft angulation decreased from $\theta_{\text{net}} = 24.1^\circ$ to $\approx 0.3^\circ$. The one-year photographs, the deep squat, the union radiographs, the final TAS and TLS measurements, and the comparison with published series are shown in Figure 4.

(a) 1-Year Standing Alignment [A], Deep Squat [B], Union [C], & TAS 93° / TLS 84° [D]



(b) Benchmark of Periarticular Angular Restoration Across Published Series

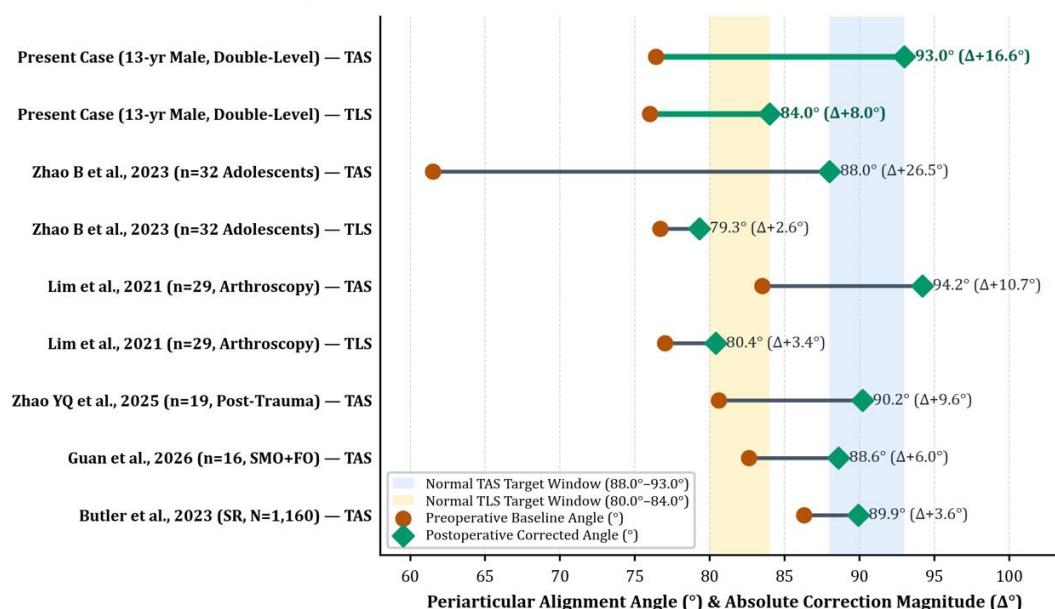


Figure 4. One-year clinical and radiographic outcome (T4) and comparison with published supramalleolar osteotomy series. (a) One-year assessment showing restored standing lower-limb alignment and a healed anterolateral scar [A], a painless full deep squat showing recovery of ankle dorsiflexion [B], anteroposterior and lateral radiographs showing complete bicortical union of both osteotomies with maintained alignment [C], and final radiographic measurement of the TAS (93.0°) and TLS (84.0°) angles [D]. (b) Comparison of preoperative and postoperative TAS and TLS angles (and absolute corrections, Δ°) in the present case with published supramalleolar osteotomy series.

Compared with published series and case reports of distal tibiofibular malunion and supramalleolar osteotomy, the coronal correction in this patient ($\Delta\text{TAS} = +16.6^\circ$, from 76.4° to 93.0°) and the sagittal correction ($\Delta\text{TLS} = +8.0^\circ$, from 76.0° to 84.0°) are within the range reported. The postoperative TAS of 93.0° and TLS of 84.0° are comparable with the results of the series of 29 ankles with medial (varus) ankle osteoarthritis reported by Lim et al.¹⁵ (mean TAS from 83.5° to 94.2° [$\Delta +10.7^\circ$] and TLS from 77.0° to 80.4° [$\Delta +3.4^\circ$]), the cohort of 32 adolescents with traumatic ankle varus deformity reported by Zhao et al.²² (mean TAS from 61.5° to 88.0° and TLS from 76.7°

to 79.3° , with American Orthopaedic Foot and Ankle Society [AOFAS] scores rising from 65.5 to 92.3), the study by Yang et al. of 44 patients aged 15–62 years with distal tibial deformity¹⁷ (AOFAS from 68.3 to 79.4 with internal plate fixation and from 66.0 to 86.1 with hexapod fixation), the systematic review by Butler et al. of 1,160 patients⁵ (weighted mean TAS from 86.3° to 89.9°), the metaphyseal clamshell osteotomy reported by Darden et al.,²¹ and the periarticular ankle reconstructions reported by Shin et al.⁷ and Poulos et al.⁸ The demographic profile, deformity geometry, fixation, and one-year outcome of this patient are compared with these studies in Table 4.

Table 4. Comparison of the present case with published series and case reports of distal tibiofibular malunion and supramalleolar osteotomy.

Study	Sample and population	Etiology and preoperative deformity	Surgical strategy and fixation	Key radiographic and functional outcomes	Follow-up
Present case (Siswanto et al.)	n = 1 (13-year-old boy, Indonesia)	Post-traumatic distal tibiofibular malunion neglected for 1 year after TBS treatment; multiplanar valgus (CORA 16.9°/18.1°, θ_{net} 24.1°; TAS 76.4°, TLS 76.0°)	Single-stage CORA-guided double-level closing-wedge osteotomy (fibula + tibia); one-third tubular plate + distal tibial T-locking plate	TAS 76.4° → 93.0° (Δ +16.6°); TLS 76.0° → 84.0° (Δ +8.0°); complete union; painless deep squat and walking	12 months
Shin et al., 2025 ⁷	n = 1 (57-year-old adult, Belgium)	Post-traumatic tibiofibular malunion with fibular shortening, lateral talar tilt, and hindfoot valgus osteoarthritis	Fibular Z-lengthening osteotomy with corticocancellous graft + medializing calcaneal osteotomy	Restored ankle mortise balance and tibiotalar congruence; resolved lateral-dorsal impingement and chronic pain	24 weeks
Poulos et al., 2025 ⁸	n = 1 (12-year-old boy, USA)	Delayed presentation of a displaced pediatric distal tibial physeal (Salter-Harris III) ankle injury with articular incongruity	Open transfracture reduction and internal fixation preserving distal tibial physeal vitality	Anatomical union, restored ankle joint congruity, and no premature physeal arrest or angular deformity	24 months
Zhao et al., 2023 ²²	n = 32 adolescents, mean age 14.9 years (China)	Traumatic ankle varus deformity (mean preoperative TAS 61.5°, TLS 76.7°)	Supramalleolar osteotomy with medial locking plate and iliac bone graft; fibular osteotomy in some patients	TAS 61.5° → 88.0° (Δ +26.5°); TLS 76.7° → 79.3° (Δ +2.6°); AOFAS 65.5 → 92.3; ankle ROM increased	20.3 months (mean)
Yang et al., 2024 ¹⁷	n = 44 patients aged 15–62 years (China)	Distal tibial multiplanar post-traumatic and developmental angular deformities	Supramalleolar osteotomy: internal plate fixation vs. computer-assisted hexapod external fixator	100% union; coronal deviation reduced to 3.7° (plate) and 5.9° (hexapod); AOFAS 68.3 → 79.4 (plate) and 66.0 → 86.1 (hexapod)	31.7 months (mean)
Darden et al., 2023 ²¹	n = 1 (49-year-old woman, USA)	Complex multiapical distal tibial metaphyseal malunion with coronal and sagittal angulation	Metaphyseal clamshell corrective osteotomy with anatomical internal plate fixation	Complete radiographic union and mechanical axis realignment; normalized gait mechanics and quality of life	30 months (2.5 years)
Lim et al., 2021 ¹⁵	n = 29 ankles (South Korea)	Medial (varus) ankle osteoarthritis (preoperative TAS 83.5°, TLS 77.0°)	Supramalleolar osteotomy without marrow stimulation + second-look arthroscopic evaluation	TAS 83.5° → 94.2° (Δ +10.7°); TLS 77.0° → 80.4° (Δ +3.4°); AOFAS 60.5 → 88.3; tissue regeneration in 89.7% at second-look arthroscopy	34.8 months (2.9 years)
Butler et al., 2023 ⁵	N = 1,160 patients (24 studies)	Systematic review of supramalleolar osteotomy (78.8% post-traumatic etiology; weighted mean TAS 86.3°)	Supramalleolar opening- or closing-wedge tibial ± fibular osteotomy with plate or frame fixation	Weighted mean TAS 86.3° → 89.9°; AOFAS 52.6 → 78.1; non-union 1.6%; overall complication rate 5.1%	50.4 months (mean)

CORA, center of rotation of angulation; TAS, tibial anterior surface angle; TLS, tibial lateral surface angle; AOFAS, American Orthopaedic Foot and Ankle Society ankle-hindfoot score; TBS, traditional bone setter; ROM, range of motion. The series of Zhao et al. and Lim et al. concern varus deformity or varus ankle osteoarthritis, and Butler et al. pooled mainly post-traumatic ankle osteoarthritis; differences in deformity direction, age, and etiology limit comparison with the present valgus case.

4. Discussion

Pathophysiology of the deformity

Reconstruction of a neglected post-traumatic periarticular deformity in a skeletally immature patient requires attention to three-dimensional osteotomy geometry, bimalleolar joint mechanics, and growth-plate biology.^{4,5,9} In this case, a 13-year-old boy presented 12 months after a motorcycle-related road-traffic injury that had been managed only by a traditional bone setter without radiographs, with a severe, progressive multiplanar valgus ankle deformity (CORA_{cor} = 16.9°, CORA_{sag} = 18.1°, θ_{net} = 24.1°, TAS = 76.4°, TLS = 76.0°). When a distal-third tibiofibular fracture consolidates in valgus and sagittal malalignment under an unmonitored bamboo splint, the mechanical axis of the limb shifts laterally relative to the center of the talar dome, and uniform joint compression becomes an eccentric lateral stress concentration.^{4–6}

Mechanically, the intact ankle mortise is a congruent, three-sided osteoligamentous socket formed by the distal tibial plafond above, the medial malleolus medially, and the distal fibula laterally, held together by the anterior inferior tibiofibular, posterior inferior tibiofibular, and interosseous syndesmotomic ligaments.^{5,7,8} With neutral alignment (TAS 88.0°–93.0°, TLS 80.0°–84.0°), the ground-reaction force during stance is spread over a broad tibiotalar contact area (approximately 350 to 450 mm²), keeping peak cartilage contact pressure within tolerable limits (1.5 to 3.0 MPa); these values are literature-based estimates, not measurements in this patient.^{5,6} When the plafond tilts into valgus (TAS 76.4°) and sagittal obliquity (TLS 76.0°), the line of action of the ground-reaction

force moves laterally and creates an external valgus moment about the tibiotalar center of rotation.^{5,6,15} Cadaveric pressure-sensor and finite-element studies of supramalleolar malalignment suggest that each 5° to 10° of coronal or sagittal plafond tilt reduces the effective tibiotalar contact area by 25% to 40% and raises peak contact stress on the lateral plafond and lateral talar shoulder by more than 50%.^{5,6,25} In our patient, this sustained lateral overload, together with sagittal incongruity that shifts contact anteriorly, may have contributed to the greater restriction of active than passive ankle motion at T0, and it supported surgical realignment to reduce the risk of irreversible cartilage damage and early post-traumatic osteoarthritis.^{5,15,18}

Remodeling potential and Hueter-Volkman growth modulation are equally important at 13 years of age.^{1,9,10} In young children, malunions near an active growth plate that lie in the sagittal plane of ankle motion have a substantial capacity for spontaneous remodeling.^{1,2} This capacity has limits: coronal valgus-varus deformities remodel less well than sagittal ones, rotational malalignment does not remodel, and remodeling potential declines sharply after 10 to 12 years of age as the distal tibial physis approaches closure, which typically occurs between 14 and 16 years in boys.^{1,9} In our patient, the remaining growth could not correct a 24.1° multiplanar deformity, and the eccentric lateral compression imposed by the 16.9° valgus alignment may have slowed longitudinal growth in the lateral columns of the distal tibial physis (Hueter-Volkman principle), favoring progression of the valgus angulation.^{9,10,16} The pathophysiological, biomechanical, and surgical sequence from T–12m to T4 is summarized schematically in Figure 5.

Integrative 5-Tier Mechanistic Architecture: From Prehospital Bone-Setter Neglect (T_{-12m}) to CORA Double-Level Realignment and 1-Year Joint Preservation (T_4)



Figure 5. Pathophysiological, biomechanical, and surgical sequence in neglected pediatric distal tibiofibular malunion. The schematic summarizes the clinical course from Tier I (motorcycle-pedestrian injury at T_{-12m} , traditional bone-setter splinting without radiographs, and 12-month malunited consolidation), through Tier II (multiplanar malunion geometry at T_0 : $COR_{cor} = 16.9^\circ$, $COR_{sag} = 18.1^\circ$, $\theta_{net} = 24.1^\circ$, $TAS = 76.4^\circ$, $TLS = 76.0^\circ$, and shortening of the fibular buttress) and Tier III (eccentric lateral tibiotalar contact stress $\sigma_c = F/A_{eff}$, asymmetric lateral physseal compression under the Hueter-Volkman principle, and greater restriction of active than passive motion), to Tier IV (single-stage CORA-guided double-level closing-wedge osteotomy at T_1 with lateral fibular one-third tubular plating and physseal-sparing distal tibial T-locking fixation satisfying Paley's zero-translation rule) and Tier V (6 weeks of NWB cast immobilization, graduated PWB/FWB rehabilitation, complete bicortical union and functional recovery at T_4 , and referral integration in LMICs).

CORA planning and fibular correction

A central technical element of this case is the use of Paley's CORA method to plan and perform a single-stage biplanar correction without secondary translation.^{14,26} By drawing the proximal and distal tibial anatomical axes on the AP and lateral radiographs, we located the coronal apex (16.9° valgus) 4.01 cm and the sagittal apex (18.1°) 3.59 cm proximal to the plafond, both within the distal tibial metaphyseal flare. According to Paley's rules, when the osteotomy and the ACA pass through the CORA ($L = 0.0$ mm), angular closure brings the proximal and distal mechanical axes into collinear alignment without secondary translation ($d_{trans} = 2 \cdot L \cdot \sin(\theta/2) = 0.0$ mm).¹⁴ If the osteotomy is

placed away from the CORA without a compensatory shift of the distal fragment, a residual translational step-off remains even when the axes are made parallel.¹⁴ Placing the anterolateral tibial closing-wedge osteotomy at the metaphyseal CORA corrected the TAS from 76.4° to 93.0° and the TLS from 76.0° to 84.0° while cortical continuity was maintained.

We corrected the distal fibula first, through a lateral approach, and the distal tibia second because of the role of the fibula in mortise stability.^{7,8,27-30} In combined distal tibiofibular malunion, the healed, malaligned fibula acts as a rigid lateral tether that blocks angular closure or rotation of the tibial plafond; an isolated supramalleolar tibial osteotomy without

division and realignment of the fibula either prevents full coronal correction or forces the distal tibiofibular syndesmosis open and malreduces the talus.^{7,8,27,31} Series in adults with varus ankle osteoarthritis by Liang et al.,²⁷ Guan et al.,²⁸ Choi et al.,²⁹ and Choi et al.³⁰ suggest that adding a fibular osteotomy to supramalleolar tibial osteotomy improves talar tilt reduction, normalizes the tibiofibular clear space, limits medial or lateral talar displacement, and may improve functional scores compared with isolated tibial osteotomy. The reconstructions reported by Shin et al.⁷ and Poulos et al.⁸ likewise indicate that restoring periarticular and lateral column anatomy helps to prevent progressive ankle valgus and lateral impingement. Correcting the fibula first and fixing it with a contoured low-profile one-third tubular plate restored lateral column length and a rigid lateral malleolar buttress, against which the tibial closing-wedge osteotomy could then be reduced and locked.^{7,27,28}

Fixation and physeal protection

Implant choice and physeal protection were matched to the adolescent distal tibial metaphysis.^{4,32–36} Distal tibial malalignment is a recognized complication when distal-third tibiofibular fractures lack stable multiplanar fixation during healing, as reported by Chaudhry et al.,³² Daas et al.,³³ and Mannan et al.³⁴ In our patient, fixation of the tibial closing-wedge osteotomy with an anatomically pre-contoured distal tibial T-locking plate gave a fixed-angle construct, with the screw heads locked into the plate, that resists cantilever bending, shear, and rotation in the relatively soft metaphyseal cancellous bone of a 13-year-old boy.^{4,35} During subperiosteal exposure, the saw cuts, and insertion of the distal locking screws, fluoroscopy confirmed that neither hardware nor heat breached the open distal tibial physis.^{9,36} Xiao et al.,³⁶ Steiger et al.,³ and Blondin et al.⁹ showed that iatrogenic or post-traumatic physeal bars in the distal tibia carry a high rate of secondary angular deformity and leg-length discrepancy that may require bar resection. External fixation, Ilizarov frames, and intramedullary nails are valuable in pediatric tibial trauma and lengthening.^{37,38} and calcaneal, subtalar, or proximal fibular osteotomies and salvage arthrodesis are used in advanced adult ankle arthritis;^{39–42} in this patient, however, the intact articular cartilage and the focal metaphyseal CORA made acute, physeal-sparing double-level internal fixation a suitable joint-preserving option.

Tibiotalar contact mechanics and subtalar compensation

Supramalleolar malunion in a child also changes the three-dimensional load distribution across the tibiotalar and subtalar joints during stance.^{4–6,15,25} With physiological alignment (TAS 88.0°–93.0° and TLS 80.0°–84.0°), the tibiotalar joint behaves as a congruent cylindrical mortise in which the ground-reaction force ($F_{GRF} \approx 4\text{--}5 \times \text{body weight}$ from mid-stance to push-off) passes through the center of the talar dome and produces a nearly uniform contact stress ($\sigma_c = F_{GRF}/A_{eff} \approx 1.8\text{--}2.6 \text{ MPa}$ over an effective contact area of 360–440 mm²); as above, these are literature-based estimates.^{5,6,15} In our patient at T0, the 16.9° coronal valgus CORA (TAS 76.4°) combined with the 18.1° sagittal CORA (TLS 76.0°) produced a resultant oblique angulation of $\theta_{net} = 24.1^\circ$ at $\varphi = 47.1^\circ$ to the coronal plane.¹⁴

With the plafond 11.6° (TAS) and 4.0° (TLS) beyond the lower limits of normal, the instantaneous center of tibiotalar rotation shifts laterally and anteriorly toward the anterolateral shoulder of the talar dome.^{5,6,18} Because the ipsilateral distal fibula had healed short and in valgus, the lateral malleolus no longer formed a rigid lateral wall of the mortise.^{7,8,27–30} Under axial load, the talus translates laterally and rotates externally within the widened mortise, concentrating compressive and shear stress over the lateral 30% to 35% of the plafond and the

fibulotalar facet while unloading the medial compartment and placing chronic tensile strain on the deep and superficial deltoid ligament.^{7,8,29,30} Weight-bearing computed tomography and second-look arthroscopic studies by Burssens et al.,²⁵ Zhang et al.,³⁹ and Lim et al.¹⁵ show that the subtalar joint first compensates for supramalleolar deformity by inversion or eversion of the calcaneopedal unit; once the coronal plafond deviation exceeds 12° to 15°, this reserve is exhausted, with fixed hindfoot valgus, lateral subfibular impingement, and accelerated cartilage fibrillation as the result.^{5,25,39}

Restoring the TAS from 76.4° to 93.0° and the TLS from 76.0° to 84.0° with the single-stage double-level osteotomy reversed this loading pattern in both planes.^{15,17–19,22} The stage 1 fibular osteotomy and one-third tubular plate restored lateral column length and alignment, closing the widened lateral mortise and centering the talus under the tibial anatomical axis, while the stage 2 biplanar tibial osteotomy leveled the plafond in both projections (resultant plafond realignment $\Delta\theta_{plafond} = 18.4^\circ$).^{7,8,27,28} In the second-look arthroscopic series of Lim et al., tissue regeneration of the medial compartment was seen in 89.7% of ankles after supramalleolar osteotomy for medial ankle osteoarthritis, with the TAS corrected to 94.2° and the TLS to 80.4°.¹⁵ Restoring physiological alignment in a 13-year-old with viable hyaline cartilage may therefore preserve the joint and lower the risk of later salvage arthrodesis, although longer follow-up is needed to confirm this.^{5,15,18,42}

Consolidation and physeal preservation

Both osteotomies consolidated without complications, which reflects the combined effect of metaphyseal closing-wedge geometry and angular-stable locking fixation.^{4,14,17,35} According to Perren's interfragmentary strain theory ($\epsilon = \Delta L/L_{gap}$), direct bone healing and early endosteal-metaphyseal bridging occur when interfragmentary strain stays below about 2% and periosteal and endosteal blood supply is preserved.^{4,35,43} Medial or lateral opening-wedge supramalleolar osteotomies create a wedge-shaped gap that needs structural autograft or allograft and carries risks of graft resorption, delayed union, and necrosis of the overlying skin, whereas a closing-wedge osteotomy in the broad, well-vascularized cancellous bone of the distal tibial metaphysis brings two congruent, bleeding cancellous surfaces into direct contact.^{15,17,19}

Because the tibial osteotomy lay at the intersection of the proximal and distal anatomical axes (the metaphyseal CORA, 4.01 cm proximal to the plafond on the AP view and 3.59 cm on the lateral view), closing the biplanar wedge satisfied Paley's first rule ($d_{trans} = 2 \cdot L \cdot \sin(\theta/2) = 0.0 \text{ mm}$ at $L = 0.0 \text{ mm}$).^{14,26} Maximizing cortical-cancellous contact may favor early bridging, as seen at week 6 (T2), and lets the bone share axial load with the implants, which reduces the risk of implant fatigue failure.^{4,17,35} On the lateral column, the contoured low-profile 3.5-mm one-third tubular plate neutralized the fibular osteotomy without prominent hardware under the thin lateral malleolar skin.^{7,8,28} On the medial-central column, the anatomical distal tibial T-locking plate acted as an internal fixed-angle construct: locking the distal metaphyseal screw cluster into the cross-arm of the plate created a frame that resists sagittal bending and coronal varus-valgus shear in immature bone without relying on plate-bone friction, which could strip soft metaphyseal cortex or compromise periosteal perfusion.^{4,34,35}

Performing an acute double-level osteotomy at 13 years meant balancing too little remaining growth for guided-growth correction against the vulnerability of the open physis to iatrogenic arrest.^{9,16,24,36} Studies of medial malleolar

hemiepiphyodesis with transphyseal screws, tension-band eight-plates, or U-shaped staples by Macneille et al.¹⁶ and Hu et al.²⁴ report average coronal correction rates of about 0.4° to 0.68° per month. A 13-year-old boy approaching closure of the distal tibial physis, which begins centrally and medially at about 14–15 years, therefore lacks the roughly 25 to 42 months of growth needed to correct a 16.9° coronal valgus deformity, and guided growth cannot correct the concurrent 18.1° sagittal deformity or the fibular shortening.^{9,16,24} Because the distal tibial physis was open and active at T0, breaching it with a saw blade or transphyseal locking screws could have caused a physeal bar and secondary angular or longitudinal growth disturbance, as documented in pediatric ankle studies by Steiger et al.³ and Xiao et al.³⁶ Placing the tibial osteotomy and the distal locking screws proximal to the undulating physis under fluoroscopy kept the physis open, without radiographic bar formation, through 12 months of follow-up (T4).

Traditional bone setters and referral

Beyond its surgical aspects, this case has public-health implications for preventing neglected pediatric musculoskeletal disability in Indonesia and comparable LMICs.^{11–13,44–46} The severe multiplanar deformity was not an unavoidable consequence of the original road-traffic injury but the preventable result of a 12-month delay in diagnosis and treatment caused by reliance on a traditional bone setter who immobilized an unstable distal tibiofibular fracture without radiography.^{11,12} Studies from LMIC trauma and pediatric orthopedic settings, including those of Garikapati et al.,¹¹ Adesina et al.,¹² Adje et al.,¹³ Abang et al.,⁴⁴ Prasetya et al.,⁴⁵ and Kim et al.,⁴⁶ indicate that use of traditional bone setters is driven by socioeconomic barriers, fear of hospital surgery, and misperceptions about healthcare costs, while modern pediatric internal fixation can shorten hospital stay and reduce secondary procedures. Rather than relying only on late reconstructive osteotomy, orthopedic societies and health authorities could establish educational and referral partnerships with community practitioners, with early radiographic assessment of all pediatric periarticular and long-bone injuries, so that index fractures receive timely, anatomically supervised care.^{11–13}

From a health-system perspective, the progression from an uncomplicated road-traffic fracture at T–12m to a disabling multiplanar ankle malunion at T0 reflects a gap in prehospital care across LMICs.^{11–13,44–46} Pediatric tibial and ankle fractures treated promptly with closed reduction and molded casting or minimally invasive fixation unite without residual deformity in more than 90% to 95% of cases.^{1–3,38,46} When families bypass hospital emergency departments in favor of traditional bone setters, the absence of radiography, analgesia, and anatomical reduction leads to malunion, the most frequent complication in a systematic review of bone-setter treatment (144 of 691 complications, 20.8%),¹¹ as well as non-union, chronic osteomyelitis, Volkmann ischemic contracture, and limb gangrene.^{11–13}

Studies from Indonesia, sub-Saharan Africa, and South Asia by Garikapati et al.,¹¹ Adesina et al.,¹² Adje et al.,¹³ and Prasetya et al.⁴⁵ suggest that caregivers rarely prefer traditional bone setters out of ignorance alone; their choice reflects geographic distance to tertiary hospitals, perceived out-of-pocket costs, fear of surgical implants or amputation, cultural trust in community healers, and limited awareness that pediatric trauma care and diagnostic radiography are covered by national social health insurance schemes such as Indonesia's Jaminan Kesehatan Nasional (JKN).^{11–13,45} Punitive prohibition of traditional bone setting has therefore proved ineffective, whereas structured collaboration, with basic musculoskeletal red-flag training for

traditional practitioners and direct, non-punitive referral pathways to district hospitals for radiographic screening of all pediatric periarticular injuries, open fractures, and high-energy road-traffic injuries, may reduce the incidence of late neglected malunion.^{11–13}

Rehabilitation and surveillance

The follow-up protocol described here may guide rehabilitation and long-term surveillance after periarticular osteotomy around the adolescent ankle.^{9,16,22} Protecting the double-level osteotomy in a below-knee cast without weight-bearing for 6 weeks (T1 to T2) limited cyclic micromotion across the fresh metaphyseal surfaces during the inflammatory and soft-callus phases, and the change at week 6 to graduated partial weight-bearing with active-assisted dorsiflexion, plantarflexion, and proprioceptive exercises aimed to use Wolff's law of functional trabecular remodeling and to prevent periarticular capsular stiffness.^{17,22,43} At 12 months (T4), complete union, restored TAS (93.0°) and TLS (84.0°), and a painless deep squat allowed the low-profile plates to be retained without routine early removal, with annual clinical and radiographic surveillance planned until physeal closure at skeletal maturity.^{9,16,46}

Limitations

This report has limitations. First, it describes a single patient: the result shows that CORA-guided double-level closing-wedge osteotomy is feasible in neglected pediatric ankle valgus, but it cannot show that the technique is superior to others, which would require prospective multicenter cohorts. Second, recovery of motion was recorded qualitatively in the clinical notes (painless ankle motion and a full deep squat at 12 months), without goniometry or standardized patient-reported outcome instruments such as the AOFAS score or the Foot and Ankle Outcome Score (FAOS). Third, although complete union and maintained TAS (93.0°) and TLS (84.0°) alignment without physeal arrest were confirmed at 12 months, surveillance until skeletal maturity (16–18 years) is still needed to detect late problems of physeal closure and to guide the decision to retain or remove the hardware.^{9,16,46}

5. Conclusion

In this patient, single-stage CORA-guided double-level closing-wedge osteotomy of the distal fibula and distal tibia, fixed with a contoured one-third tubular plate and a physeal-sparing anatomical distal tibial T-locking plate, restored bimalleolar mortise congruity, mechanical alignment, and painless function in a neglected pediatric distal tibiofibular valgus malunion. With the osteotomies placed at the coronal (16.9° valgus; 4.01 cm above the plafond) and sagittal (18.1°; 3.59 cm above the plafond) metaphyseal apices ($\theta_{\text{net}} = 24.1^\circ$), the deformity was corrected without secondary translation ($d_{\text{trans}} = 0.0$ mm): the TAS improved from 76.4° to 93.0° and the TLS from 76.0° to 84.0°, both osteotomies united, the patient squatted fully without pain, and no complications occurred at one year. The case also shows the need for early radiographic diagnosis, community education, and structured referral links with traditional bone setters in low- and middle-income countries to prevent avoidable post-traumatic disability in children.

6. Declarations

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of CMHC Research Center, Indonesia (protocol No.2026/0425), with institutional approval from Dr. Moewardi Regional General Hospital / Faculty of Medicine, Universitas Sebelas Maret, Surakarta, Indonesia. Written

informed consent for participation was obtained from the patient's parents and legal guardians, together with the assent of the patient.

Consent for Publication

Written informed consent for publication of this report and of all accompanying clinical photographs and radiographs was obtained from the patient's parents and legal guardians, and identifying features have been masked.

Availability of Data and Materials

All clinical, radiographic, geometric, and longitudinal data supporting the findings are presented in the text, Tables 1–4, and Figures 1–5. De-identified source records are available from the corresponding author on reasonable request.

Artificial Intelligence Use Statement

No artificial intelligence tools were used in the preparation of this article.

Author Contribution Statement

T.S.: Conceptualization, Investigation, Supervision. U.H.N.: Investigation, Validation, Writing – review & editing. M.R.A.: Data curation, Formal analysis, Investigation, Writing – original draft. All authors reviewed and approved the final version of the manuscript.

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Conflict of Interest / Competing Interests

The authors declare that they have no financial or non-financial competing interests.

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