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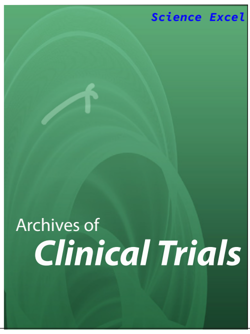
Case Report



Geometric Determinism in Pediatric Femoral Head Osteonecrosis: High-Degree Valgus Redirection Osteotomy as a Boundary-Condition Reset for Self-Organized Remodeling with Instrumented Gait Restoration

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Abstract

Background *Pediatric femoral neck fractures complicated by nonunion and femoral head osteonecrosis may enter a mechanically self-reinforcing collapse phenotype, in which varus malalignment and a high Pauwels angle bias interfragmentary motion toward destructive shear, perpetuating resorption and growth disturbance. Conventional fixation can stabilize implants yet leave the adverse load-transfer geometry—the underlying mechanical "algorithm"—unchanged.*

Methods: *We treated a 10-year-old girl with femoral neck nonunion and osteonecrosis after failed pinning using a high-degree valgus redirection osteotomy fixed with a compression hip screw/angled plate. Conceptually, the osteotomy served as a boundary-condition reset: it reduced the effective Pauwels angle, converted shear-dominant input into axial compression, and redirected the weight-bearing arc away from necrotic sectors toward viable cartilage and apophyseal reserve. Serial radiographs and intraoperative fluoroscopy documented correction, fixation, and healing. Instrumented gait analysis (pre- vs post-operative) provided an objective functional endpoint.*

Results: *Union was achieved with restoration of alignment and without hardware migration. During longitudinal follow-up, the femoral head remodeled toward a more spherical, congruent articulation consistent with load-directed remodeling (Wolff's Law). Gait kinematics normalized, including resolution of Trendelenburg pelvic drop and recovery of stance-phase hip extension and ankle dorsiflexion toward normative traces.*

Conclusion: *In pediatric femoral neck nonunion with osteonecrosis, high-degree valgus redirection osteotomy can be interpreted as an engineering intervention that reprograms mechanical inputs. By resetting boundary conditions from destructive shear to constructive compression and reassigning the weight-bearing arc to viable tissue, the procedure can enable self-organized remodeling corroborated by objective gait restoration.*

Introduction

Pediatric femoral neck fractures (Delbet II/III) carry high risks of nonunion, coxa vara and avascular necrosis (AVN) [1-3]. Valgus redirection osteotomy (intertrochanteric or trochanteric level) lowers the Pauwels angle, converts shear to compression across the fracture plane, and reorients the load-bearing arc to viable head. However, functional outcomes are seldom quantified with instrumented gait. This report integrates radiographic endpoints with gait analysis to demonstrate recovery of hip mechanics.

Mechanical Rationale

Let g be the effective interfragmentary gap. Interfragmentary strain (IFS) is defined as $IFS = \sqrt{[(\Delta x)^2 + (\Delta y)^2]} / g$, where Δx is axial micromotion and Δy is transverse shear. Axial micromotion within limits is osteogenic, whereas transverse shear impedes mineralization. By increasing the neck–shaft angle, a valgus osteotomy decreases the Pauwels angle and the shear component at the interface; it also lengthens the abductor lever arm and redistributes joint reaction over a viable arc, which should translate into normalized pelvic obliquity and hip moments on gait analysis.

Case and Surgical Technique

A 10-year-old girl presented with nonunion and AVN after failed pinning of a femoral neck fracture, with varus malalignment and limb-length discrepancy (Figure 1). A high-degree valgus redirection osteotomy was planned and executed with fluoroscopic guidance (Figure 2) and stabilized using a compression hip screw/angled plate.

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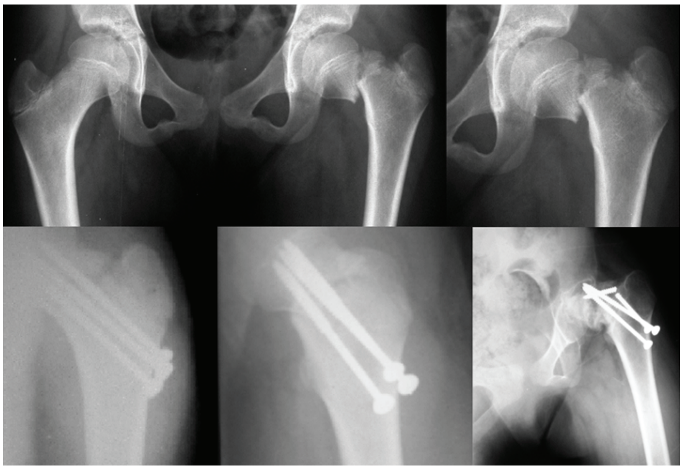

Figure 1. *Preoperative radiographs and failed pinning.*
AP pelvis and affected-side hip (top row) show varus malalignment with persistent fracture line and features of osteonecrosis; magnified views (bottom row) demonstrate hardware migration and loss of reduction.

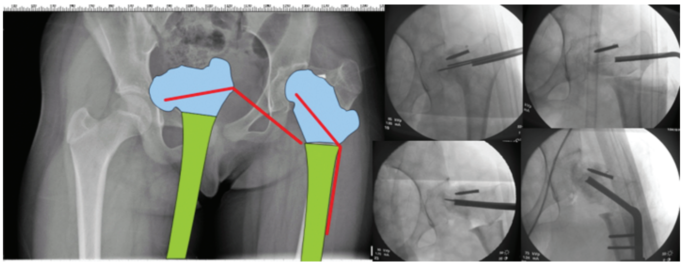

Figure 2. *Surgical planning schematic and intraoperative fluoroscopy sequence.*
Left: schematic overlay illustrating valgus redirection converting a shear-dominant interface into compression and reorienting the weight-bearing arc; Right: fluoroscopic frames demonstrating guide-wire placement and implant insertion at the corrected angle.

Intraoperative imaging confirmed correction of the Pauwels angle and secure implant trajectory.

Instrumented Gait Analysis Methods

Standard marker-based gait analysis was performed pre-operatively and at follow-up using a multi-camera optical system and force plates. Kinematics were sampled at ≥100 Hz and low-pass filtered; events were defined by force-plate heel strike/toe-off. Primary readouts were pelvic obliquity, hip/knee/ankle sagittal kinematics and stance-phase symmetry. Traces were time-normalized to the gait cycle with ensemble averaging of multiple trials.

Results

Immediate postoperative radiographs confirmed alignment restoration and stable fixation (Figure 3). At follow-up, union was achieved without hardware migration. Instrumented gait traces demonstrated resolution of compensatory pelvic drop and improved ankle dorsiflexion during stance with recovery of stance-phase hip extension toward normative patterns (Figure 4). These functional improvements aligned with the mechanical rationale and radiographic healing.

Discussion

This longitudinal case suggests that valgus redirection osteotomy acts as more than a fixation strategy: it rewrites load

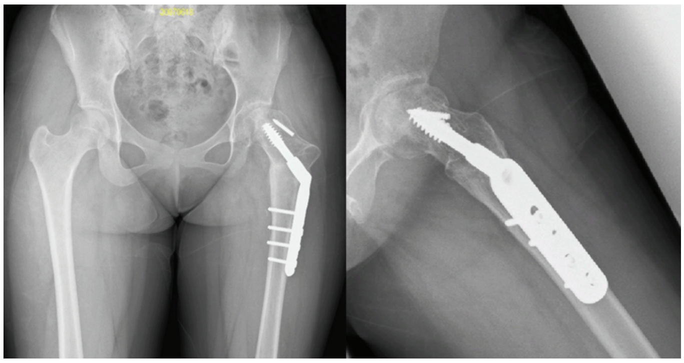

Figure 3. *Immediate postoperative alignment and fixation.*
AP pelvis and lateral hip after valgus intertrochanteric osteotomy fixed with a compression hip screw/angled plate; the construct restores Pauwels angle, length and offset.

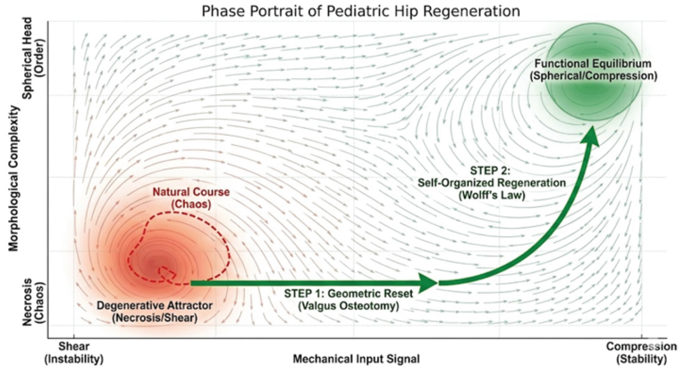

Figure 4. *Instrumented gait analysis: pre- vs post-operative.*
Representative kinematic traces (ankle/knee/hip sagittal and pelvic obliquity) demonstrate correction of Trendelenburg pattern and normalization of stance-phase dorsiflexion and hip extension at follow-up.

transmission across the proximal femur. In pediatric femoral neck nonunion complicated by osteonecrosis, varus collapse increases the effective Pauwels angle and biases interfragmentary motion toward transverse shear, a mechanical environment that impedes mineralization and sustains a cycle of resorption. By increasing the neck–shaft angle, the osteotomy decreases the shear component, increases the compressive component at the interface, and can redistribute the joint reaction force toward a viable load-bearing arc, thereby restoring a mechanical context compatible with union and remodeling.

Morphological Computation and the Escape from Irreducibility

From the perspective of computational morphogenesis, the developing skeleton can be framed as a distributed system in which global form emerges from simple local update rules, principally mechano-transduction (Wolff's Law) and mechanostat concepts [5,6]. In Wolfram's language, such systems resemble cellular automata: uncomplicated local rules can generate complex macroscopic structures once boundary conditions are specified [4]. Here, the initial injury and varus malalignment effectively trapped the femoral head in a maladaptive state in which shear-dominant stress within the weight-bearing cone became the governing input, mathematically predisposing the output toward

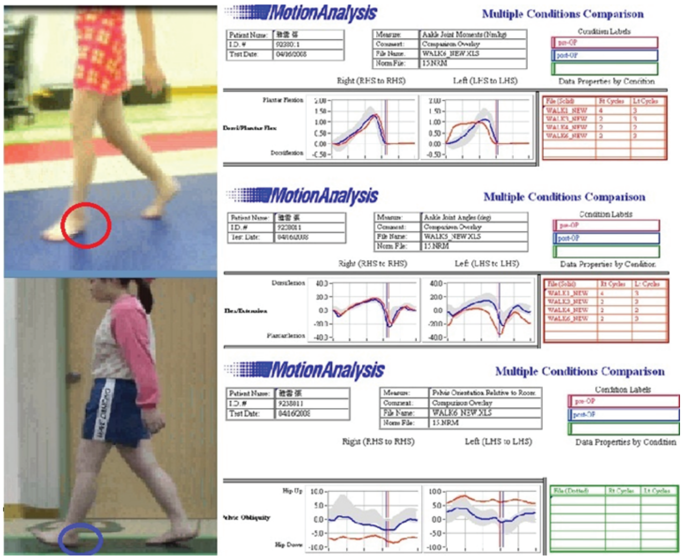

Figure 5. *Phase portrait: boundary-condition reset and remodeling trajectory.*

Conceptual phase portrait with the horizontal axis representing mechanical input (shear-dominant instability → compressive stability) and the vertical axis representing morphological complexity (collapse/necrosis → spherical, functional articulation). The osteotomy is modeled as a horizontal state jump (geometric reset/bit swapping) that changes the input signal without immediate morphological recovery; subsequent growth follows a trajectory toward a stable functional equilibrium under Wolff's Law.

collapse, resorption, and growth arrest. Our high-degree valgus osteotomy can be interpreted as a physical "bit-swap" operation: by rotating the biological hardware, the load-bearing stress cone was reassigned from corrupted sectors (necrotic bone) to viable sectors (trochanteric apophysis and adjacent cartilage reserve). Once this geometric boundary condition was reset, the system's intrinsic remodeling algorithm switched from a degenerative cycle to a regenerative one. The subsequent re-formation of a spherical, congruent head was therefore not a stochastic event but a convergence toward a stable morphological attractor under compressive loading. The normalization of gait parameters (Figure 4) provides functional corroboration that the limb likewise converged to a stable, low-energy kinematic state; the corresponding boundary-condition reset and remodeling trajectory are conceptualized in the phase portrait (Figure 5).

Clinically, this framing emphasizes why "stability" alone may be insufficient when the preoperative geometry continues to encode shear at the nonunion interface and concentrates loading onto necrotic regions. Instrumented gait analysis strengthens the image-to-function narrative by quantifying recovery of pelvic control and sagittal-plane kinematics, not merely radiographic consolidation. The principal limitation remains the single-case design, and the computational analogy is offered as a testable conceptual model rather than a literal mechanistic proof. Future prospective series should predefine gait endpoints and correlate them with radiographic remodeling metrics to determine whether the observed attractor-like recovery generalizes across osteonecrosis phenotypes.

Conclusion

Valgus redirection osteotomy can restore mechanics and promote union in pediatric femoral neck nonunion with AVN. Integrating gait analysis with imaging offers a rigorous, transferable outcome framework.

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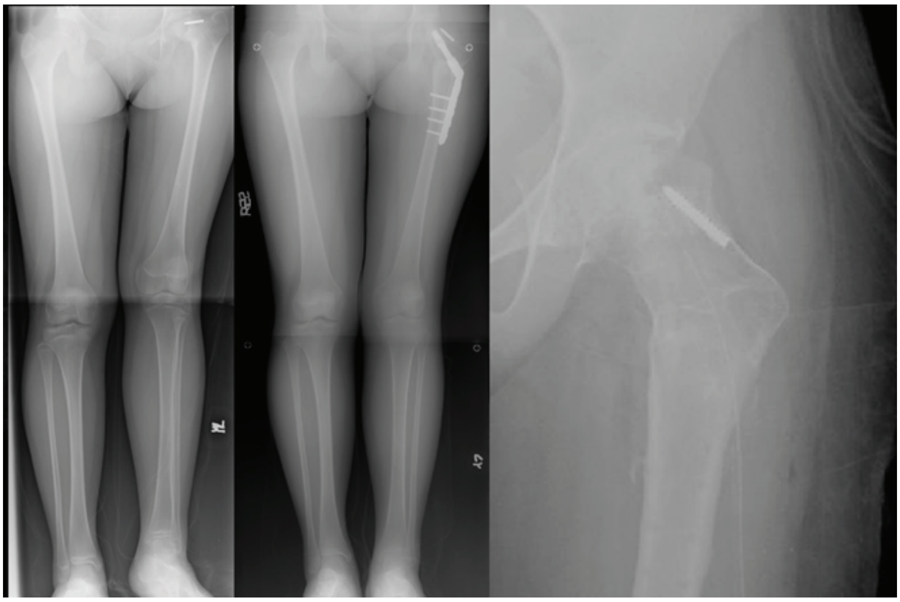
Supplementary Data



Supplementary Figure: *Standing long-film alignment and lateral hip remodeling image (provided as a separate 300-dpi TIFF).*