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The vertical growth plate of the proximal femur: distinguishing developmental coxa vara from trauma in a three-year-old female

Abstract

Developmental coxa vara (DCV) is a rare paediatric hip deformity characterized by a progressive reduction in the femoral neck-shaft angle (NSA) and marked verticalization of the proximal femoral physis. Accurately differentiating DCV from traumatic physeal injuries or neglected femoral neck fractures is critical in toddlers presenting with an isolated, unilateral limp to avoid irreversible bio-mechanical failure. We present the case of a 3-year-old female who presented with a four-month history of a painless limp and 1.5 cm of left lower limb shortening. Radiographic evaluation revealed a reduced left femoral neck-shaft angle and a pathognomonic Hilgenreiner-Epiphyseal (H-E) angle of 86°, accompanied by a characteristic inverted Y-shaped radio-lucency and an inferior-medial triangular bone fragment. The absolute absence of trauma combined with these distinct, chronic structural changes definitively excluded an acute or neglected fracture mal-union. Given that an H-E angle of 86° represents extreme biomechanical shear instability; representing abnormal abductor mechanism. This serves as an absolute indication for surgical correction via valgus proximal femoral osteotomy to restore tension to the abductor mechanism, improve hip stability, and prevent progressive limb shortening and early joint degeneration.

Keywords: developmental coxa vara, femoral neck-shaft angle, hilgenreiner-epiphyseal angle, growth plate, vertical physis, abductor mechanism, limb length discrepancy

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Introduction

Developmental coxa vara (DCV) is an uncommon structural anomaly characterized by a pathological reduction in the proximal femoral neck-shaft angle to less than 120°.[1] While historically classified under the broad umbrella of congenital coxa vara, modern anatomical and orthopaedic consensus differentiates developmental or infantile coxa vara from true congenital variants. Congenital cases are present at birth as manifestations of altered embryogenesis, frequently co-occurring with major skeletal dysplasias such as proximal femoral focal deficiency. Conversely, developmental coxa vara represents a post-natal architectural deviation where the proximal femoral physis dynamically reorients in response to mechanical shear forces during early weight-bearing.[2] Consequently, the condition typically remains clinically silent until the onset of ambulation and physiological loading. While its exact pathogenesis is considered idiopathic, it is hypothesized to stem from a localized cartilaginous or metabolic failure isolated to the medial segment of the proximal femoral physis.[3] This micro-architectural flaw impairs regular endochondral ossification. Consequently, normal axial and shear forces experienced during upright posture drive a progressive verticalization of the growth plate, deviating from its physiological horizontal plane.[4] In unilateral presentations, a diagnostic dilemma arises because the gross structural changes closely replicate those observed in an unrecognized paediatric femoral neck fracture or an acute traumatic proximal femoral physeal slip.[5] However, distinguishing between these entities is critical because their natural histories, mechanical stabilities, and management strategies deviate significantly.[6] This case report outlines the clinical presentation, meticulous radiological differentiation, and therapeutic rationale for a 3-year-old female presenting with unilateral DCV.

Case presentation

Clinical evaluation

A 3-year-old female presented to our paediatric orthopaedic clinic with a four-month history of a painless, progressive limp affecting her left lower extremity. The parents reported a completely uneventful perinatal history, normal developmental milestones, and an absence of any history of trauma. Physical examination revealed an active toddler with a prominent, uncompensated left-sided Trendelenburg gait. Clinical measurements demonstrated a true limb length discrepancy, with the left lower extremity measuring 1.5 cm shorter than the right side. On palpation, the left greater trochanter was noted to be abnormally prominent and high-riding compared to the contralateral side. Range of motion testing of the left hip revealed a terminal restriction of abduction and internal rotation as compared to contralateral side. However, rest of the movements were within normal limits and painless. The right hip and lower limb examination was entirely unremarkable, demonstrating physiological symmetry and full range of motion.

Radiological evaluation

Anteroposterior (AP) radiograph of pelvis including both hips revealed a severe varus deformity isolated to the left proximal femur. The left femoral neck-shaft angle was critically decreased. The proximal femoral physis on the left side demonstrated a striking, vertically oriented trajectory, yielding a calculated Hilgenreiner-Epiphyseal (H-E) angle of 76.4° (Figure 1a). Furthermore, a distinct, inverted Y-shaped radio-lucency was noticed within the femoral neck, which effectively demarcated a characteristic triangular bony fragment at the inferior-medial aspect of the neck (Figure – 2a & b). Severe chronic adaptive remodeling was also present, characterized

by a shortened, thickened left femoral neck and a high-riding greater trochanter that extended superior to the apex of the femoral head. Conversely, radiographic evaluation of the contralateral right hip remained within normal physiological limits. Serial radiographic monitoring over a three-month interval revealed acute, progressive verticalization of the proximal femoral physis. During this period, the calculated Hilgenreiner-Epiphyseal (H-E) angle accelerated from an initial 76.4° to a highly unstable 86.0° (Figures 1a & 1b). To restore anatomical hip biomechanics, a corrective valgus osteotomy was performed (Figure 3). Postoperatively, both the femoral neck-shaft angle (NSA) and the spatial orientation of the proximal femoral growth plate were successfully restored to normal physiological parameters.

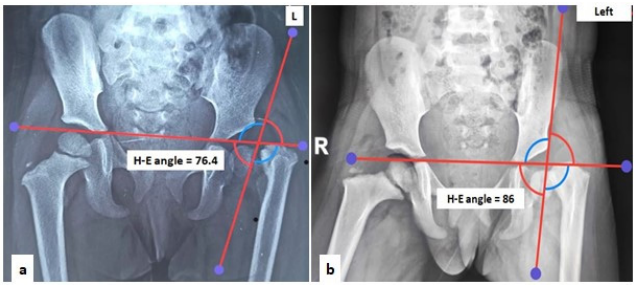

Figure 1 Serial radiographic progression of proximal femoral physis verticalization. Anteroposterior radiographs of the pelvis obtained over a three-month interval demonstrate progressive verticalization of the right proximal femoral physis. The calculated Hilgenreiner-Epiphyseal (H-E) angle increased from an initial 76.4° (left) to a highly unstable 86.0° (right), signifying severe instability and high risk for progressive coxa vara.

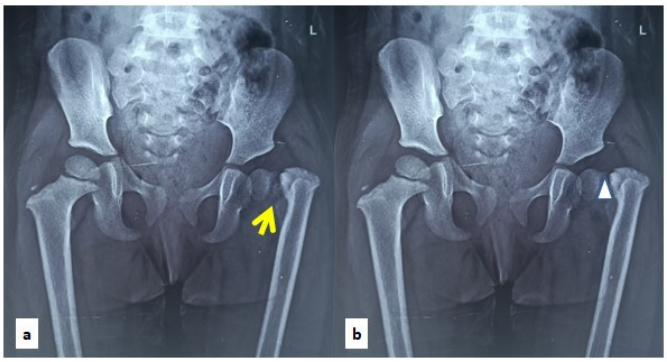

Figure 2 Initial radiographic evaluation of the proximal femoral physis. (a) Anteroposterior pelvis radiograph demonstrating a vertical physis with a distinct triangular radio-lucency at the inferior neck margin is indicated by the arrow. (b) Identical radiographic view with a superimposed triangular overlay highlighting the exact boundaries of the unstable bone fragment.

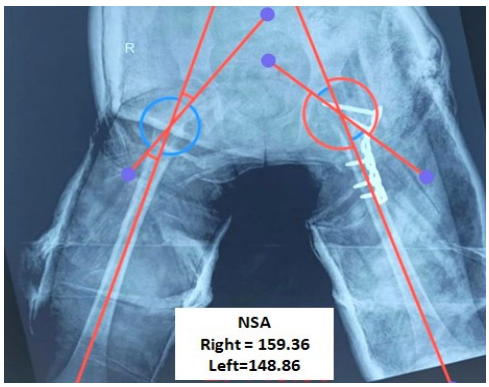

Figure 3 Post-operative radiograph following a valgus osteotomy showing the neck-shaft angle and the spatial orientation of the proximal femoral growth plate were successfully restored to normal physiological parameters.

Discussion

Differentiating unilateral developmental coxa vara from traumatic or acquired pathologies in a 3-year-old is a primary diagnostic obstacle.[6] The conditions that must be definitively excluded are a proximal femoral physeal injury (Salter-Harris Type I) and a mal-united or neglected paediatric femoral neck fracture corresponding to Delbet Types I, II, or III.[7]

The role of the H-E angle in differentiation

The Hilgenreiner-Epiphyseal (H-E) angle represents the foremost objective parameter used to differentiate developmental aetiology from trauma, while simultaneously establishing a clear prognosis.[6] In normal paediatric populations, the Hilgenreiner-Epiphyseal (H-E) angle routinely measures less than 25°.[1] Angles between 45° and 60° occupy a biomechanical grey zone that warrants close longitudinal observation. The literature confirms that an H-E angle exceeding 60°, such as the extreme 86 degree vertical orientation, as observed in our patient, is pathognomonic for progressive, structurally unstable developmental coxa vara.[4] This pathologically vertical orientation of the physis converts the normal compressive forces of axial weight-bearing and physiological loading into distractive mechanical shear forces across the cartilaginous matrix, driving the progressive acceleration of the varus deformity. This mechanical deterioration was clearly documented in our patient by serial radiographs obtained three months apart, which demonstrated a rapid, unstable verticalization shift (Figure 1a & 1b). In contrast, an acute paediatric femoral neck fracture or a traumatic physeal slip can instantly alter the spatial alignment of the femoral physis, but it cannot acutely verticalize the cellular architecture of the growth plate itself to 86° without a catastrophic, clinically obvious musculo-skeletal failure following high fall of trauma.[5]

Pathognomonic structural clues

The presence of the inferior-medial triangular bone fragment, bordered by the inverted Y-shaped radio-lucent line, serves as a definitive marker of DCV (Figure 2).[3] This triangular fragment does not represent an avulsed bony fragment or a reactive healing callus; rather, it is an established area of delayed endochondral ossification unique to the dysplastic cartilaginous tissue of developmental coxa vara.[2] Additionally, the extensive osseous remodeling seen in our patient, specifically the short, broad femoral neck and the superiorly migrated greater trochanter, provides clear anatomical evidence of a long-standing, chronic adaptive process under altered weight-bearing mechanics.[1] To exhibit this degree of adaptive osseous remodeling, a mal-united traumatic fracture or physeal injury would require many months of neglected, painful, and weight-bearing symptoms following a verified, high-energy fall. Such a scenario is incompatible with the patient's history of a completely painless limp and an absence of injury.

Biomechanical rationale and therapeutic intervention

Left untreated, an H-E angle of 86° carries an absolute certainty of clinical progression, leading to severe limb length discrepancy, worsening the gait profile, premature closure of the physis, and consequently an early-onset osteoarthritis of the hip joint.[4] Because the angle exceeds the critical 60° threshold, surgical intervention for correction was absolutely indicated in our patient.[6] The primary objective of surgical intervention is to restore the normal abductor mechanism by altering local biomechanics, effectively converting detrimental vertical shear forces into physiological compressive forces. This correction is achieved through a valgus proximal femoral

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osteotomy, which realigns the femoral neck-shaft angle and reduces the Hilgenreiner-Epiphyseal (H-E) angle to a physiological baseline.[1] By transforming these local shear forces into compressive loads, the valgus osteotomy facilitates the reliable healing of the pathological physis, resolution of the inverted Y-sign, and restoration of normal ossification.[4]

A structured, step-by-step clinico-radiological algorithm designed to differentiate progressive unilateral developmental coxa vara in toddlers from traumatic or acquired hip pathologies is summarized in Table 1.

Step	Clinico-Radiological Parameter	Developmental coxa vara (DCV)	Traumatic injury (Fracture/Physeal Slip)	Biomechanical rationale
1	Onset & Pain	Insidious; progressive painless limp; no trauma history.	Acute; severe, disabling pain following high-energy trauma.	DCV is a gradual micro-architectural failure; trauma is acute, macro-structural disruption.
2	Gait	Trendelenburg gait	Antalgic gait	Compromised abductor mechanism in DCV
3	Limb & Trochanter	True shortening; undue prominent, high-riding greater trochanter.	Acute shortening based on displacement; Normal trochanter anatomy.	Progressive proximal migration of trochanter in DCV due to gradual varus collapse under weight-bearing.
4	Range of Motion	Restricted abduction/ internal rotation; painless flexion/extension.	Global, painful restriction of movements in all planes; voluntary muscle guarding.	In DCV, restrictions are mechanical due to trochanteric impingement against the lateral ilium.
5	Neck-Shaft Angle	Uniformly reduced.	Variable; normal or altered by fracture displacement.	Focal endochondral ossification failure in DCV, forces femoral neck into pathologically acute angle.
6	Physeal Lucency	Pathognomonic, smooth inverted Y-shaped lucency in femoral neck.	Linear, irregular radiolucent fracture line or physeal split.	The inverted Y-sign is a chronic developmental cartilage tracking defect, not an acute fracture line
7	Metaphyseal Fragment	Isolated triangular bone fragment at inferior-medial femoral neck.	Absent; structural fracture fragments only.	Fragment results from abnormal, delayed endochondral ossification native to DCV.
8	Physis orientation	Vertical physis; high (H-E) angle (>60° threshold).	Normal horizontal or slightly inclined physis; normal H-E angle.	Excessive shear forces reorient the dysplastic physis into an unstable vertical plane.
9	Angular Dynamics	Rapid disease progression; serial radiographs over a 3- months show increase in H-E angle from 76.4° to 86.0°.	Static; alignment do not display progressive verticalization.	Chronic loading across the defective physis forces the weak cartilage to continuously reorient.
10	Osseous Remodeling	Short, broad femoral neck; no periosteal reaction.	Acute bone margins or irregular callus formation; cortical step-offs.	Wide femoral neck reflects chronic, slow-moving adaptive remodeling unique to DCV

Conclusion

This case highlights how to diagnose and treat progressive unilateral developmental coxa vara in toddlers. It emphasizes using a step-by-step clinico-radiological approach to distinguish it from traumatic or acquired hip issues. The calculated Hilgenreiner-Epiphyseal (H-E) angle serves as the definitive objective anchor for diagnosis and surgical decision-making. An initial H-E angle above the threshold value with documented rapid deterioration displays hip instability and compromised abductor mechanism. Left untreated, an 86 degree deformity carries a definitive poor prognosis. Valgus osteotomy realigns hip and thus effectively restores proper abductor mechanism, eliminates the pathognomonic inverted Y-sign, and allows normal endochondral ossification to resume.

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None.

Conflicts of interest

The author declares that there are no conflicts of interest.

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