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The Hip-Spine Relationship in Developmental Dysplasia of the Hip: A Contemporary Review for the Spinal Deformity Surgeon

Running title: DDH and the Hip–Spine Relationship

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Abstract: ***Background: Developmental dysplasia of the hip (DDH) is traditionally managed within pediatric orthopaedics and adult reconstruction, but a growing body of literature demonstrates that the dysplastic hip and the spine are mechanically and clinically interdependent. Uncorrected acetabular and femoral deformity alters pelvic incidence, pelvic tilt, and pelvic obliquity, and can precipitate or mask coexisting spinal deformity, while spinal malalignment in turn reshapes the biomechanical demands placed on a dysplastic hip. Purpose: To synthesize recent advances (predominantly 2019–2026) in the diagnosis, pathophysiology, and treatment of DDH that carry direct relevance for spinal deformity surgeons managing patients with combined hip–spine pathology. Methods: A narrative review of the PubMed, Embase, and Cochrane literature was performed using combinations of the terms "developmental dysplasia of the hip," "hip-spine syndrome," "spinopelvic alignment," "pelvic incidence," "pelvic obliquity," "periacetabular osteotomy," and "total hip arthroplasty," prioritizing studies published within the last five years. Results: Recent work has clarified that pelvic incidence in DDH is not uniformly elevated but rises early in mild dysplasia before a compensatory ceiling is reached in advanced (Crowe III–IV) disease; that pelvic obliquity is disproportionately represented among adolescents with combined idiopathic scoliosis and hip dysplasia; that periacetabular osteotomy reliably corrects acetabular version and coverage without materially changing pelvic tilt; that total hip arthroplasty in unilateral high-grade DDH meaningfully improves low back pain while symmetric or low-grade dysplasia benefits less; and that deep-learning-assisted ultrasound and expanding genome-wide association data are reshaping early screening and risk stratification. Emerging robotic and augmented-reality navigation platforms are improving the precision of acetabular correction, with early but still limited evidence of downstream spinopelvic benefit. Conclusions: DDH should be considered a spinopelvic, not purely femoroacetabular, disorder. Spinal deformity surgeons evaluating patients with scoliosis, pelvic obliquity, or sagittal imbalance should screen for coexisting hip dysplasia, and hip surgeons planning periacetabular osteotomy or arthroplasty in DDH should account for spinal alignment when sequencing care. Prospective, spinopelvic-parameter-driven studies are needed to define optimal surgical sequencing in patients requiring both hip and spine correction.***

Keywords: developmental dysplasia of the hip; hip-spine syndrome; spinopelvic alignment; pelvic incidence; pelvic obliquity; periacetabular osteotomy; total hip arthroplasty; scoliosis

1. Introduction

Developmental dysplasia of the hip (DDH) encompasses a spectrum of acetabular under-coverage, femoral head instability, and frank dislocation that affects an estimated 1–3% of live births when defined by clinical instability, and a smaller but clinically important fraction when defined radiographically in adolescence and adulthood. DDH has historically been framed as a disease of the hip joint alone, managed by pediatric orthopaedists with Pavlik harnessing and closed or open reduction in infancy, and by adult reconstructive surgeons with periacetabular osteotomy (PAO) or total hip arthroplasty (THA) later in life. This framing under-represents the anatomic reality of the condition.

The acetabulum is not an isolated structure; it is one component of the pelvic ring, and the pelvic ring is the mechanical link between the lower extremities and the spine. Any process that alters acetabular orientation, femoral offset, or leg length also alters pelvic incidence, pelvic tilt, and pelvic obliquity- the same parameters that spinal deformity surgeons use to plan osteotomies, assess sagittal balance, and predict mechanical complications after long fusion. Conversely, spinal deformity- whether idiopathic, degenerative, or neuromuscular- changes the orientation of the pelvis and, with it, the functional position of the acetabulum, a relationship increasingly termed the "hip–spine syndrome," a term first coined by Offierski and MacNab in 1983 and substantially re-operationalized over the past decade with the adoption of standing full-length radiographic spinopelvic measurement.[14]

This relationship is not merely of academic interest. Spinal deformity surgeons are increasingly the first point of contact for adult patients with low back pain, sagittal imbalance, or scoliosis in whom an underlying dysplastic hip is either the primary driver of compensatory spinal posture or a confounder that will affect the outcome of spinal correction. Pediatric and adolescent scoliosis surgeons likewise encounter DDH as a coexisting or masking diagnosis in patients presenting with pelvic obliquity. This review synthesizes recent advances- in screening and genetics, in the biomechanics of the hip–spine unit, in the spinopelvic consequences of PAO and THA, and in surgical sequencing- that are directly relevant to the practice of spinal deformity surgery.

2. Methods

This is a narrative, rather than systematic, review. The PubMed, Embase, and Cochrane Library databases were searched for English-language articles combining the terms "developmental dysplasia of the hip," "hip dysplasia," "hip-spine syndrome," "spinopelvic alignment," "pelvic incidence," "pelvic tilt," "pelvic obliquity," "periacetabular osteotomy," "total hip arthroplasty," and "scoliosis." Priority was given to systematic reviews, meta-analyses, and comparative cohort studies published between 2019 and 2026, supplemented by foundational older studies where necessary for context. Because the intersection of DDH and spinal deformity is a comparatively narrow and emerging literature, thresholds for inclusion were kept broad and findings are presented narratively rather than pooled quantitatively.

3. The Hip–Spine Relationship: Pathophysiologic Basis

Pelvic incidence (PI)- the angle between a line perpendicular to the sacral endplate at its midpoint and a line connecting that point to the bicoxofemoral axis- is a fixed, individual anatomic parameter in the mature skeleton that dictates the range of pelvic tilt and lumbar lordosis a person can adopt to maintain sagittal balance. Because the bicoxofemoral axis is defined by the hip joint centers, deformity at the acetabulum has the potential to influence how PI is measured and how the pelvis compensates. Recent three-dimensional CT-based work by Cheng and colleagues directly tested whether the severity of DDH correlates with abnormal pelvic incidence in a comparison of 53 dysplastic hips (Crowe I–III) against 53 matched controls; DDH hips as a group showed higher PI than controls, but the correlation between Crowe severity and the degree of PI abnormality was weak and non-significant ($r = 0.091$, $p = 0.222$), with the elevation confined largely to mild (Crowe I) dysplasia and lost in more severe (Crowe II–III) disease.[1] This finding is important for spinal deformity practice: it suggests that the pelvis mounts a compensatory response to mild acetabular under-coverage that becomes unreliable, and possibly exhausted, as dysplasia becomes more severe- analogous to the recruitment and eventual failure of pelvic retroversion as a compensatory mechanism for sagittal spinal imbalance.

Pelvic obliquity- coronal-plane tilt of the pelvis- provides a second, independent axis of hip–spine interaction that is coronal rather than sagittal. Because the sacroiliac joints link the pelvis to the spine rigidly, coronal pelvic obliquity of hip origin is transmitted directly to the lumbosacral spine and can both mimic and aggravate scoliosis, while primary spinal coronal deformity can, in turn, produce a compensatory pelvic obliquity that alters loading across the hip. This bidirectional coronal relationship is discussed further in Section 5.

At the tissue level, the pathophysiology of DDH itself has been substantially clarified. DDH results from multifactorial disruption of normal acetabular and femoral head development, with mechanical (breech presentation, oligohydramnios, swaddling practices), hormonal (maternal relaxin-mediated ligamentous laxity), and genetic contributions. A 2024 synthesis in Frontiers in Genetics catalogued genome-wide association, linkage, and exome-sequencing data implicating CX3CR1, GDF5, KANSL1, and HOXB-cluster variants, with GDF5 and CX3CR1 converging on Wnt-signaling-mediated chondrogenesis and collagen types I, II, and XI dysregulation altering the mechanical competence of the acetabular labrum and capsule; the review also highlighted emerging epigenetic contributions, including DNA methylation at the GDF5 locus.[2] A parallel 2025 review in Clinical Genetics catalogued an expanding panel of candidate susceptibility genes and population-specific variant frequencies across Chinese, Turkish, and other cohorts, underscoring that DDH risk is polygenic and population-dependent rather than attributable to a single causal locus.[3] These genetic advances have not yet been translated into routine clinical risk-stratification tools, but they strengthen the rationale for family-history-based selective screening and may eventually inform risk models analogous to those used in adolescent idiopathic scoliosis (AIS) genetics.

4. Recent Advances in DDH Screening and Diagnosis

Universal versus selective ultrasound screening for DDH remains debated, but the diagnostic accuracy and reproducibility of hip ultrasound have improved substantially with the introduction of artificial intelligence (AI). A 2025 systematic review by Bhavsar and colleagues in the Journal of Paediatrics and Child Health evaluated AI-assisted approaches to DDH detection, including automated standard-plane identification, alpha- and beta-angle measurement, and Graf-type classification, and found that deep-learning models achieved diagnostic performance approaching that of experienced pediatric radiologists while substantially reducing inter-observer variability, a historically significant limitation of manual Graf-method ultrasound.[4] Complementary AI-assisted standard-plane-detection algorithms published in 2025 further demonstrated real-time feasibility, raising the possibility of point-of-care AI-augmented screening in general pediatric and primary-care settings rather than restricting expert-level interpretation to tertiary referral centers.[5]

For the spinal deformity surgeon, the practical relevance of these diagnostic advances is twofold. First, as AI-assisted screening lowers the threshold for confident DDH diagnosis, more patients will arrive at adolescence and adulthood with a documented history of treated or observed dysplasia, information that should be actively solicited when evaluating coronal or sagittal deformity of uncertain etiology. Second, in patients presenting de novo with asymmetric pelvic radiographic findings during scoliosis work-up, the same alpha-angle and lateral-center-edge-angle criteria used in pediatric ultrasound and adolescent/adult radiography remain the reference standard for identifying missed or residual dysplasia and should prompt a directed hip examination and standing pelvic radiograph even when the presenting complaint is spinal.

5. DDH and Coexistent Spinal Deformity in the Pediatric and Adolescent Population

5.1 Adolescent idiopathic scoliosis and hip dysplasia

A 2024 retrospective cohort study by Zhao, Pan, and Hai directly examined the coexistence of hip dysplasia and adolescent idiopathic scoliosis (AIS) in 103 adolescents (36 with hip dysplasia, 67 without).[6] The reported prevalence of radiographic hip dysplasia among AIS patients was 35%- markedly higher than the 5- 13% prevalence typically cited for hip dysplasia in the general adolescent population- suggesting either a shared underlying connective-tissue or neuromuscular predisposition, or a mechanical interaction in which pelvic asymmetry from one condition promotes compensatory change at the other joint system. Adolescents with combined AIS and hip dysplasia demonstrated significantly greater sacroiliac discrepancy and iliac obliquity than those with AIS alone, with iliac obliquity angle inversely correlated with sacroiliac discrepancy ($r = -0.803$, $p < 0.001$, accounting for 64.5% of variance), and this combined-pathology group reported higher rates of moderate-to-severe low back pain on functional testing.[6]

The clinical implication for spinal deformity practice is direct: unexplained or disproportionate pelvic obliquity in an AIS patient - particularly obliquity that does not resolve with correction of the primary curve, or that is out of proportion to curve magnitude- should prompt hip-specific radiographic evaluation (lateral center-edge angle, Tönnis angle) rather than being attributed to the spinal deformity alone. Because pelvic obliquity is itself a recognized driver of curve progression and postoperative decompensation, failure to identify a coexisting dysplastic hip as a contributor to obliquity risks incomplete correction or under-appreciated residual asymmetry after spinal instrumentation.

5.2 Neuromuscular hip dysplasia, windswept deformity, and pelvic obliquity

The bidirectional hip–spine relationship is most extensively documented in cerebral palsy (CP), where progressive hip displacement/dysplasia and neuromuscular scoliosis frequently coexist as manifestations of the same underlying muscle imbalance and are mechanically linked through pelvic obliquity. A large 2024 Swedish registry-based longitudinal cohort study by Casey and colleagues followed 4,148 children with CP over 26 years (41,600 measurements) and found that windswept hip deformity- asymmetric abduction of one hip and adduction of the contralateral hip- most often precedes scoliosis rather than the reverse: windswept deformity emerged first in 16.6% of children (mean age 8.1 years) compared with scoliosis emerging first in 8.1%, with the highest and earliest-onset scoliosis risk concentrated in children with Gross Motor Function Classification System (GMFCS) level V and dyskinetic-subtype CP.[7] This sequencing has direct surveillance implications: in high-risk (GMFCS IV–V) CP populations, hip surveillance programs that detect early windswept deformity may serve as a sentinel for subsequent scoliosis development, supporting coordinated hip–spine surveillance rather than parallel, siloed monitoring by pediatric hip and spine services.

A 2021 review by Yen, Gartenberg, and Cho published in Spine Deformity- the official journal of the Scoliosis Research Society- formalized a mechanistic classification of pelvic obliquity in neuromuscular scoliosis into suprapelvic (spinal curve-driven), infrapelvic (hip contracture/dysplasia-driven), and intrapelvic (pelvic ring asymmetry) categories, and emphasized that no single standardized measurement method (Maloney or O'Brien techniques being the most validated) has achieved universal adoption.[8] The authors underscored that effective correction requires addressing the dominant causative level- contracture release or proximal femoral/pelvic osteotomy for infrapelvic causes, posterior spinal fusion incorporating the pelvis for suprapelvic causes, and combined strategies when both coexist- reinforcing that pelvic obliquity in the neuromuscular patient cannot be reliably corrected through spinal instrumentation alone when a substantial hip-driven (infrapelvic) component is present. This distinction is directly actionable for the spinal deformity surgeon: preoperative differentiation of suprapelvic from infrapelvic obliquity, using supine/prone correctability of the pelvis and hip range-of-motion examination in addition to standing radiographs, should guide whether hip-directed intervention needs to precede, accompany, or follow spinal fusion to the pelvis.

6. Spinopelvic Consequences of Adult DDH and Its Treatment

6.1 Untreated adult DDH: pelvic compensation and low back pain

As described in Section 3, mild DDH is associated with modestly elevated pelvic incidence relative to normal hips, a compensatory adaptation that appears to fail as dysplasia becomes severe.[1] Clinically, this compensatory failure manifests as low back pain, which is a common and often under-recognized presenting symptom of adult hip dysplasia, frequently misattributed to primary lumbar spine pathology before the hip is examined. This has direct diagnostic implications for spinal deformity clinics evaluating adult low back pain: leg-length discrepancy, coronal pelvic obliquity on standing films, and reduced hip internal rotation on examination should prompt dedicated hip imaging (AP pelvis with Tönnis angle and lateral center-edge angle) before attributing symptoms solely to lumbar degenerative disease.

6.2 Periacetabular osteotomy and spinopelvic alignment

PAO remains the joint-preserving procedure of choice for symptomatic acetabular dysplasia in the skeletally mature patient without advanced osteoarthritis, correcting acetabular version, coverage, and inclination by reorienting the acetabular fragment. Because PAO alters pelvic bony anatomy adjacent to the sacroiliac joints, its effect on standing pelvic tilt- and therefore on the sagittal spinopelvic parameters used by spine surgeons- has been of increasing interest. A 2025 single-arm multilevel meta-analysis and meta-regression by Ramadanov and colleagues, published in the Journal of Experimental Orthopaedics, pooled data across multiple PAO cohorts and found that pelvic tilt remains statistically unchanged from preoperative to postoperative measurement despite successful correction of acetabular coverage parameters.[9] This finding is reassuring for surgical planning in patients who may require both PAO and lumbar spinal intervention: it suggests that PAO can be expected to correct local acetabular deformity without

meaningfully perturbing the sagittal pelvic compensatory mechanisms (pelvic tilt, and by extension functional lumbar lordosis requirements) that spinal deformity surgeons rely on when planning correction magnitude, though pelvic incidence itself — being defined partly by hip-joint-center position- may still shift modestly with large acetabular translations and warrants case-specific remeasurement rather than assumption of stability in complex or bilateral corrections.

A separate 2025 systematic review and multilevel meta-analysis by the same group compared PAO with hip arthroscopy for borderline dysplasia, finding both to be viable options with procedure selection driven more by the degree of instability and labral pathology than by any differential effect on pelvic or spinal alignment, an area that remains comparatively under-studied and represents a clear gap for future spinopelvic-focused research.[10]

6.3 Total hip arthroplasty in DDH: limb length, obliquity, and low back pain

For patients with dysplasia progressing to end-stage osteoarthritis, THA — often technically demanding in Crowe III–IV hips owing to acetabular bone loss, femoral deformity, and leg-length discrepancy — is the definitive treatment.[13] A large 2023 retrospective cohort study by Jia and colleagues followed 306 DDH patients (407 hips; 65 Crowe I, 61 Crowe II, 69 Crowe III, 212 Crowe IV) for a minimum of five years after THA and found that low back pain improved substantially in patients with unilateral Crowe III–IV dysplasia ($p < 0.05$), whereas improvement was limited in unilateral Crowe I–II and in bilateral symmetric dysplasia.[11] This pattern is consistent with the pathophysiologic model described above: unilateral high-grade dysplasia produces pronounced pelvic obliquity and coronal spinal compensation that THA-mediated limb-length and offset restoration can reverse, whereas bilateral symmetric dysplasia- lacking a coronal asymmetry for THA to correct- leaves the compensatory lumbar mechanism largely unaddressed by hip surgery alone. This distinction has direct counseling implications: spinal deformity surgeons co-managing patients with combined hip and spine complaints should temper expectations that THA will resolve low back pain in bilateral or low-grade unilateral dysplasia, and should evaluate the spine independently in these subgroups rather than deferring pending hip surgery outcome.

Residual leg-length discrepancy and its relationship to postoperative spinopelvic compensation after THA in DDH has also received renewed attention, with 2024 cohort data demonstrating that greater postoperative limb-length inequality is associated with persistent coronal and sagittal spinopelvic compensatory changes, reinforcing that precise limb-length and offset restoration during THA- particularly in Crowe III–IV reconstruction, where subtrochanteric shortening osteotomy is frequently required- has direct downstream consequences for spinal alignment and should be a shared priority between the arthroplasty and spine teams when both are involved in a patient's care.

7. Surgical Sequencing in Combined Hip–Spine Pathology

Perhaps the most immediately actionable body of recent literature for the spinal deformity surgeon concerns the sequencing of hip and spine surgery when both are indicated. Preoperative sagittal spinopelvic measurement has been proposed as a decision-support tool: patients with a stiff, hyperlordotic or flat-back lumbar spine and abnormal pelvic tilt reserve, in whom the spine is the dominant driver of functional pelvic position, have been argued to benefit from addressing the spine first so that the hip can subsequently be reconstructed to a stable, predictable functional position; conversely, in patients whose spine is comparatively flexible and whose hip is the dominant source of positional abnormality, hip-first sequencing has been favored.[12] This patient-specific, spinopelvic-parameter-driven approach represents a meaningful advance over historical practice, in which sequencing was determined by symptom severity or surgeon subspecialty referral pattern alone.

A closely related and more extensively studied body of work addresses THA dislocation risk in patients with prior or subsequent lumbar spinal fusion. Multiple systematic reviews and meta-analyses spanning 2019–2024 have consistently found that lumbar fusion- particularly fusion incorporating the sacrum/pelvis, which eliminates compensatory pelvic tilt- increases the risk of postoperative THA instability and dislocation, whether fusion precedes or follows arthroplasty, by removing the spinopelvic compensatory reserve that normally accommodates component malposition. While this literature is derived predominantly from degenerative rather than dysplastic hip populations, its implications extend directly to DDH patients undergoing THA, particularly Crowe III–IV reconstructions in which acetabular component positioning is already technically constrained by bone stock; in such patients, awareness of coexisting or planned lumbar fusion should prompt more conservative (increased anteversion/inclination safe-zone) acetabular component positioning, dual-mobility or constrained liner consideration, and close interdisciplinary communication between the arthroplasty and spine teams regarding sequencing and implant selection.

Taken together, the sequencing literature supports a general principle rather than a rigid algorithm: whichever pathology contributes more to the loss of spinopelvic compensatory reserve- a stiff, malaligned spine or a severely dysplastic, obliquity-generating hip- should generally be addressed first, with the second procedure planned using the corrected alignment of the first as the new functional baseline, and with explicit intraoperative and postoperative communication between hip and spine teams to avoid component malposition on either side of the correction.

8. Emerging Technologies: Robotics and Navigation

Precision of acetabular fragment reorientation in PAO, and of acetabular component placement in THA, is mechanically important to spinopelvic outcomes because malpositioned correction can itself generate new coronal or sagittal

compensatory demand. Robot-assisted and augmented-reality (AR)-guided navigation platforms for PAO, described in feasibility and early clinical series published in 2024, have demonstrated improved accuracy of intraoperative acetabular fragment positioning relative to fluoroscopy-guided freehand technique, with AR overlay allowing real-time visualization of target correction angles during fragment manipulation. Robot-assisted acetabular component positioning in THA for DDH has similarly been associated with improved accuracy of cup inclination and anteversion relative to conventional technique in comparative series and meta-analyses. While these technologies have not yet been directly studied for their downstream effect on spinopelvic alignment or on rates of subsequent spinal symptoms, the mechanistic rationale- that more accurate correction of hip-sided deformity should reduce the compensatory demand placed on the spine- provides a clear direction for future outcomes research linking surgical precision technology to spinopelvic endpoints.

9. Limitations and Future Directions

The literature synthesized in this review is limited in several respects that define clear priorities for future research. First, most spinopelvic outcome studies in DDH are retrospective cohorts from single high-volume centers, with heterogeneous measurement techniques for pelvic tilt, incidence, and obliquity that limit direct comparison and pooling. Second, prospective studies directly linking hip-sided correction (PAO or THA) to longitudinal spinal radiographic and patient-reported outcomes remain scarce; most current evidence is either hip-outcome-focused with spinal parameters as a secondary measurement, or spine-outcome-focused with hip status recorded only descriptively. Third, the genetic and AI-screening advances described in Sections 3–4 have not yet been prospectively linked to spinopelvic phenotype or outcome, representing a natural convergence point for future translational work. Finally, robust, spinopelvic-parameter-based, prospective sequencing algorithms for patients requiring both hip and spine surgery- validated across dysplastic (rather than purely degenerative) hip populations- remain an unmet need and represent the most clinically pressing direction for future investigation relevant to this journal's readership.

10. Conclusion

Developmental dysplasia of the hip is increasingly understood as a spinopelvic disorder rather than a purely femoroacetabular one. Recent advances demonstrate that mild dysplasia provokes a compensatory rise in pelvic incidence that is lost as dysplasia worsens; that pelvic obliquity of hip origin is a significant and under-recognized contributor to adolescent and neuromuscular scoliosis; that PAO corrects acetabular deformity without materially disturbing pelvic tilt; that THA improves low back pain most reliably in unilateral high-grade dysplasia; and that surgical sequencing in patients requiring both hip and spine correction should be guided by which structure has exhausted its compensatory reserve. Spinal deformity surgeons are well positioned- and, given these findings, obligated- to incorporate hip-specific history, examination, and imaging into the evaluation of pelvic obliquity and sagittal imbalance, and to collaborate closely with hip preservation and reconstruction colleagues when both joint systems require correction.

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