

Acetabular Index in Developmental Dysplasia of the Hip: Imaging Assessment and Clinical Decision-Making

Gamal Mutwakil Gamal Ahmed, Mohammad Abdelaziz Ghieth, Ahmed Mohammad Abdel-Wahab, Yamen Safwat Abdel-Daym, Ahmed Mohamed Ismail Elkatcha

Orthopedic Surgery Department, Faculty of Medicine, Zagazig University, Egypt

***Corresponding author:** Gamal Mutwakil Gamal Ahmed,

Abstract

Background: Developmental dysplasia of the hip is a common pediatric orthopedic condition with an estimated incidence of 1.4–80 cases per 1000 births, reported incidence varies considerably according to diagnostic method, population, and the age at assessment. Acetabular dysplasia is characterized by a shallow, immature acetabulum and may present with or without hip instability or dislocation⁽¹⁾. Instability of the hip causes superior and lateral migration of the femoral head that increases localized contact pressure, which eventually leads to degenerative changes. The severity of subluxation of the femoral head has an inverse relation to the time it takes for symptoms to develop.

Objective: There is still no uniform standard for the surgical timing and indications of RAD, so if some predictors can be identified to accurately assess and forecast the developmental prognosis after treatment, it can help to guide the timing of correction or avoid unnecessary surgery.

Conclusion: The treatment goal in developmental dysplasia of hip is to obtain stable congruous reduction either by closed or open methods to promote normal hip development. Many authors have reported that concentric reduction is the main factor affecting the acetabular development, and all acetabulae with DDH may develop satisfactorily if concentric reduction is obtained. Failure to sufficiently remodel results in residual acetabular dysplasia which may need additional surgeries.

Keywords: Developmental dysplasia of the hip; acetabular index; radiography; acetabular dysplasia; arthrography; magnetic resonance imaging.

Introduction

Developmental dysplasia of the hip is a common pediatric orthopedic condition with an estimated incidence of 1.4–80 cases per 1000 births, reported incidence varies considerably according to diagnostic method, population, and the age at assessment. Acetabular dysplasia is characterized by a shallow, immature acetabulum and may present with or without hip instability or dislocation⁽¹⁾. Instability of the hip causes superior and lateral migration of the femoral head that increases localized contact pressure, which eventually leads to degenerative changes. The severity of subluxation of the femoral head has an inverse relation to the time it takes for symptoms to develop⁽²⁾.

Several radiographic measurements have been described over the years to assess for developmental dysplasia or dislocation of the hip, including the Shenton line, center-edge angle, neck-shaft angle, and the acetabular index. The acetabular index is an objective measurement of acetabular dysplasia and can be used to determine the severity of dysplasia and efficacy of treatment⁽³⁾.

Acetabular Development and Remodeling

In hip dysplasia the acetabulum is shallower than normal. The lip or limbus antero-superiorly is progressively flattened outwards. If dislocation occurs and the femoral head crosses the lip, the limbus

posteriorly turns into the joint. The acetabulum is triangular with the base toward the obturator foramen and the apex pointing upwards and backwards. The cavity is to a large extent filled by cartilage and a fibro-fatty overgrowth of the haversion pad⁽²⁾.

Following reduction of a dislocated hip, the acetabulum begins to remodel in response to the pressure exerted by the femoral head. Usually this results in gradual deepening of the acetabulum and reduction of the obliquity of the acetabular roof. Many times, however, this process is incomplete and the acetabulum will remain shallow and the roof inclined.

The development of the sourcil (or eyebrows) is a reliable indicator of acetabular development⁽⁴⁾.

The goal of treatment at any age in patients with DDH is to establish normal biomechanical forces about the hip joint, such that remodeling of the joint will occur. It is well recognized that the potential for remodeling is profound in the neonatal time period, but the potential for remodeling in older children has been long debated. Salter & Dubos⁽⁵⁾ believed the potential for remodeling begins to decline at birth and is significantly reduced by 18 months of age. On the other hand, Harris⁽⁶⁾, concluded that 4 years was the maximum age after which hip congruence could not be established without surgical intervention.

Radiological Diagnosis

Plain Radiography

Plain radiography of the pelvis is obtained in the frontal projection with the legs in the neutral position. Line measurements made on the anteroposterior radiograph help in determining the relationship of the femoral head with the acetabulum⁽⁷⁾.

The acetabular index; which is determined by drawing the Hilgenreiner's line, and a second line connecting the superolateral and inferomedial margins of the acetabular roof (i.e. tangent to the acetabular roof). The normal acetabular index angle is approximately 28° at birth. The acetabular angle often is increased in DDH because maturation and ossification of the acetabulum are abnormal and delayed. It cannot alone be diagnostic of dysplasia; however, values greater than 30° are considered abnormal and indicative of impending dislocation⁽⁸⁾.

The Shenton line; in a normal hip, the Shenton line is a smooth unbroken arc that bridges the medial femoral metaphysis and the inferior edge of the superior pubic ramus. Displacement of the femoral head out of the joint space and disruption of the Shenton line is suggestive of DDH⁽⁹⁾.

The center edge (CE) angle of Wiberg⁽¹⁰⁾; Determination of this angle is most useful after full ossification of the femoral head, since its relationship to the acetabulum is then fully established, so it is useful in older children and adults⁽⁷⁾.

Metaphyseal/teardrop distance: This is a quick measurement to make and gives reliable information about lateral movement of the femoral head in the acetabulum⁽⁹⁾.

Lateralization of the femoral head; is measured by the distance between the medial edge of the femoral head and the ilioischial line, and cranialization of the femoral head is measured by the distance of the inferior edge of the femoral head and the most postero-inferior edge of the acetabulum. Lateralization and cranialization of the femoral head is compared preoperatively with the opposite side in patients with a normal contra-lateral hip, and postoperatively with the measurements obtained at last follow-up of the hip that underwent osteotomy⁽⁷⁾.

Delayed ossification of the capital femoral epiphysis; which is observed in the unstable hip. The ossification center first appears between three and six months of life, and a delay in its appearance should be viewed as an indication of DDH. A false acetabulum eventually develops secondary to molding of the displaced ossification center against the bony pelvis⁽¹¹⁾.

Ultrasonography

The use of ultrasonography in the diagnosis and management of children with DDH remains controversial. Many proponents strongly recommend that ultrasonography be used as a routine screening tool in the newborn nursery and that it be used extensively in the management of all DDH problems⁽¹²⁾.

Ultrasonography can be used in two basic ways to evaluate the child with DDH: morphologic assessment and dynamic assessment⁽¹³⁾. The morphologic assessment, as pioneered by Graf, focuses primarily on critical evaluation of the anatomic characteristics of the hip joint⁽¹⁴⁾.

Computed Tomography

Computed tomography (CT) is necessary to define any associated lesions in DDH and to quantify the acetabular deficiency more accurately and will further determine the type and degree of correction required for each hip because no two dysplastic hips are quite the same. Hip dysplasia represents a spectrum of complex deformities on both sides of the joint⁽¹⁵⁾.

Three-dimensional reconstruction of CT (3D CT) is of utmost importance for precise definition of direction, magnitude of displacement and bony configuration of the acetabulum and the proximal femur with their relationship to complicated and/or neglected congenital hip dislocations⁽¹¹⁾.

Computed tomography plays a role in evaluating concentricity of reduction, especially if the clinical findings or the radiographs raise the possibility of a hip not concentrically reduced. CT can accurately display the relation of the proximal femoral metaphysis to the acetabulum. Dislocation of the femur may occur posteriorly or laterally. Normal acetabular development in DDH depends upon early and maintained congruent reduction.

CT can detect osseous blocks to relocation, as well as iliopsoas tendon capsule constriction, a thick ligamentum teres, and fibrofatty pulvinar hypertrophy.

The axial CT of the hip should routinely include images of the femoral neck and selected sections through the distal femur to evaluate femoral anteversion. By constructing an axial line through the femoral head and neck and another line through the transcondylar plane of the distal portion of the femur, the exact angle of anteversion can be obtained. Anterior inclination of the axis of the femoral neck to the transcondylar plane is defined as anteversion, and posterior inclination is retroversion. It is helpful in planning the amount of derotation necessary for intertrochanteric or subtrochanteric osteotomy⁽¹¹⁾.

The transverse plane anatomy seen on 2-dimensional (2 D) CT gives the best preoperative evaluation of the degree of anteversion or retroversion of the acetabulum. The acetabular anteversion can be determined by evaluating the angle formed by a tangent to the anterior and posterior lip of the acetabulum in relation to a perpendicular line through the triradiate cartilage. In adult the average angle measures 16.5° degree, but in the newborn the average angle being only 6.5° degree. The acetabulae of the dislocated hips were found to be significantly more anteverted than the normal⁽¹¹⁾.

Sarban et al.⁽¹⁶⁾ found that the acetabular anteversion was increased on the dislocated side in each patient and found no retroverted acetabulum. It was concluded that confirming anteversion of the acetabulum and the femoral neck by two-dimensional computed tomography is needed in treatment planning of early walking age patients with developmental hip dysplasia.

The sum of the femoral anteversion and acetabular anteversion is the instability index. The stability of the hip joint is influenced by the relationship between femoral torsion and acetabular torsion. The instability index ranges from 20° to 58° degree.

If the reciprocal relationship between femoral and acetabular torsion broke down and the combination of these readings was greater than 60° degree, then instability would result⁽¹⁵⁾.

Two angles were defined to quantitate acetabular shape and orientation by drawing three lines on a transpelvic CT scan. The first line was drawn across the pelvis connecting the centre of the triradiate cartilage.

The second line was drawn from the anterolateral corner of the triradiate cartilage to the anterior bony tip of the concave acetabulum. The third line was drawn from the posterolateral corner of the triradiate cartilage to the posterior bony tip of the concave acetabulum. Angle 1 and 2 were formed by the intersection of these lines. Angle 1 is a function of anterior acetabular development and /or torsion. Angle 2 is a function of posterior acetabular development and /or torsion. The sum of angles 1 and 2 measures acetabular depth, with increasing values indicating shallowness⁽¹¹⁾.

Three-dimensional images become increasingly important. However, measurements and angles numbers are not as applicable to 3 D images as to standard CT images and radiographs. It's evident through the study of 3D CT images that acetabular dysplasia is more than just a maldirection or malrotation. It's a combination of acetabular maldirection, margin erosion, torsion, hypoplasia (focal or global), abnormal shape, and altered acetabular surface area⁽¹⁷⁾.

Acetabular sector angle measurements are more specific to the presence of hip dysplasia. Anterior and posterior acetabular sector angles (AASA and PASA) reflect the degree of both anterior and posterior acetabular support. The sector angles are determined by measurement of the angle drawn between the center of the femoral head and the anterior and posterior acetabular rim relative to the horizontal axis of the pelvis. A normal anterior angle is greater than 50° and a normal posterior angle is greater than 90°. These angles are reduced in DDH which reflects decreased acetabular support⁽¹⁸⁾.

When surgery is contemplated, computed tomography (CT) is useful to better determine the anterior acetabular coverage by use of the anterior acetabular sector angle (AASA), and the posterior acetabular coverage by use of the posterior acetabular sector angle (PASA). These measurements are particularly useful in the evaluation of acetabular dysplasia and for the preoperative assessment of the dysplastic hip⁽¹⁹⁾.

The unavoidable radiation load and the economic aspect of CT examination should be estimated beforehand. Therefore, CT examination in such hips can be performed when it is absolutely necessary. Studies have looked at the predictive value of CT for outcome. Measurements of acetabular angles and anteversion have not been found to be predictive of outcome of DDH. The acetabular rim consists of a large amount of cartilage, and similar to plain films, CT is limited in assessing the cartilage structures. However, the bony acetabular rim accurately reflects the shape of the unossified cartilage and CT is very helpful in the surgical planning⁽⁵⁾.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is a non-invasive tool that can be used to assess the bony and cartilaginous components of the acetabulum, soft tissue obstacles to reduction as well as the efficacy of reduction post-operatively⁽²⁰⁾.

Arthrography

Arthrography is useful during infancy and early childhood for outlining relationship of the non-ossified portion of the acetabulum. At one time, arthrography was the only method for assessing the cartilaginous components of the hip joint. It was an excellent method for detecting the presence of soft tissue interposition between a displaced femoral head and the acetabulum in dislocated, irreducible hips. The arthrogram can demonstrate deformity of the labrum, hypertrophy of ligamentum teres, and obstruction by the transverse acetabular ligament. When performed under fluoroscopy, it becomes a dynamic study and it is useful to assess the quality of reduction, the extent of coverage of femoral head, and the optimal position for immobilization in children between six months and four years of age, arthrography is particularly useful during closed reduction to evaluate the adequacy and stability of reduction and to help determine an appropriate position for immobilization⁽²¹⁾.

Arthrography is a useful resource, especially for pediatric orthopedic surgery. Periarticular structures in pediatric patients can be difficult to identify and assess secondary to the cartilaginous nature. Improved visualization of a given structure is integral to patient care, as this may impact surgical management for a given condition. Arthrography is useful for the evaluation of the pediatric hip joint, specifically as it pertains to developmental dysplasia of the hip⁽²²⁾.

Originally, arthrography was primarily used as an adjunct to radiography for diagnostic joint evaluation. More recently, CT and MRI have replaced arthrography for diagnostic purposes. Arthrography remains a helpful resource in the operating room. While the patient is under general anesthesia, arthrography provides diagnostic information that directly impacts decision-making⁽²³⁾.

The hip radiograph in a pediatric patient cannot yield all the information desired to diagnose or treat developmental dysplasia of the hip. Pediatric hip structures that are cartilaginous are not easily identified on plain radiographs. Hip arthrography can be used to visualize these cartilaginous structures. Hip arthrography aids the pediatric orthopedic surgeon in establishing a diagnosis and treatment for developmental hip dysplasia.⁽²²⁾

Hip arthrography is safe, minimally invasive, quick, and inexpensive when performed correctly⁽²³⁾. Arthrography is paramount for evaluating and managing pathology in the pediatric hip because it allows for visualization of the femoral head, acetabulum, and any soft tissue blocks to adequate hip reduction⁽²⁴⁾.

Evaluation of the pediatric hip with arthrography demonstrates the cartilaginous anatomy of the acetabulum and femoral head. Arthrography is a dynamic test to assess the stability and quality of hip reduction. Hip arthrography plays an integral role in the decision between closed and open reduction in patients with developmental dysplasia of the hip⁽²⁴⁾.

Acetabular Index

The term acetabular index was introduced by Kleinberg and Lieberman⁽²⁵⁾. The acetabular index is the angle formed between the roof of the acetabulum and the Hilgenreiner line, which connects the triradiate cartilages of both hips and is placed at the inferior bony margin of the ilia. The standard index is $<35^\circ$ at birth and $<25^\circ$ at the age of 1 year⁽²⁶⁾.

In pediatric orthopedics, particularly when evaluating Developmental Dysplasia of the Hip (DDH), the acetabular index (AI) is a critical measurement. While clinicians often refer to the "bony" index seen on standard X-rays, the "cartilaginous" index provides a more complete picture of the hip's true shape in infants.

Bony Acetabular Index

The bony acetabular index is the most common measurement used in clinical practice once the secondary ossification centers begin to appear.

Definition: The angle formed between Hilgenreiner's line (a horizontal line through the triradiate cartilage) and a line drawn along the ossified roof of the acetabulum.

Significance: It measures the slope of the visible bone.

At birth: Approximately 25° to 30° .

By 2 years: Usually decreases to less than 20° .

Limitation: It only accounts for the mineralized portion of the socket. In young infants, a significant portion of the acetabular roof is still cartilage, which is "invisible" on a standard radiograph⁽²⁷⁾.

From AP radiographs of the hip taken between 2 and 4 years old, it was selected radiographs showing acceptable pelvic inclination and rotation. The quotient of pelvic rotation, indicating the pelvis's position in the horizontal plane, was 1.02 ± 0.17 (range 0.58-1.5); The angle of the symphysis os-ischium, indicating the pelvis's position in the sagittal plane, was $107^\circ \pm 8^\circ$ (range 92° - 124°). The acetabular index and center-edge angle were measured using the lateral osseous margin of the acetabular roof (AIB and CEAB, respectively) and the lateral end of the acetabular sourcil (AIS and CEAS, respectively) (Figure 1). In hips that underwent osteotomy, the acetabular index and center-edge angle before osteotomy were used.

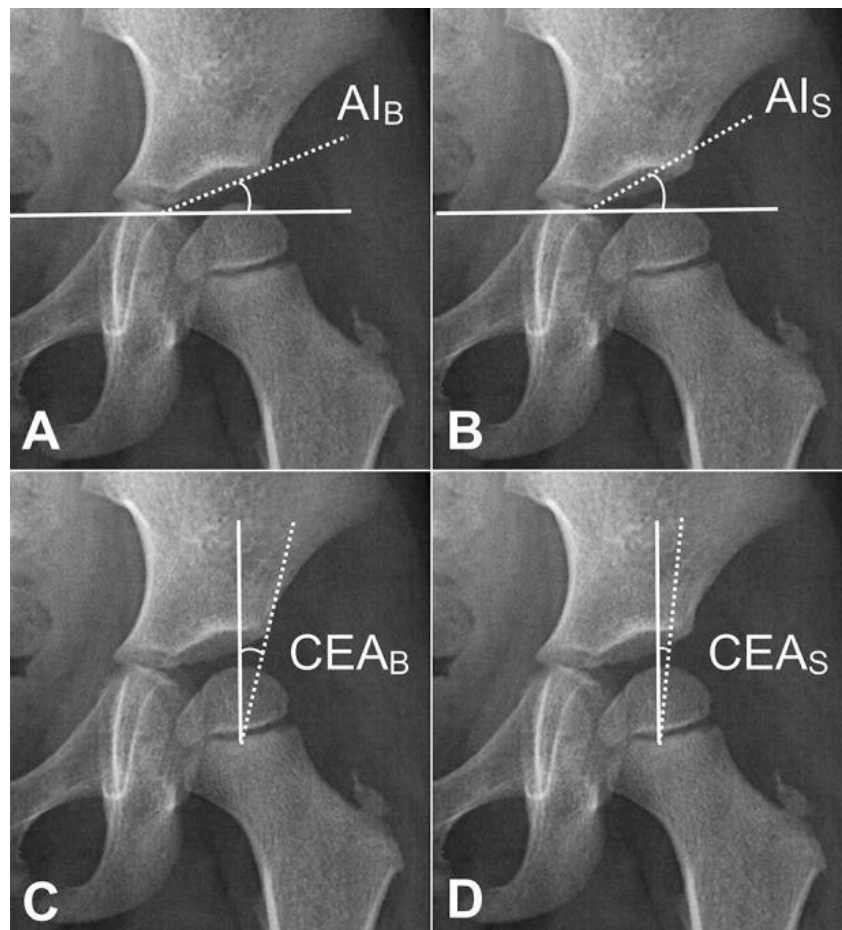


Figure (1): Two different measurement methods for the acetabular index and center-edge angle are shown in these radiographs. (A) The AIB was measured with the lateral osseous margin of the acetabular roof and (B) the AIS was measured with the lateral end of the acetabular sourcil. (C) The CEAB was measured with the lateral osseous margin of the acetabular roof and (D) the CEAS was measured with the lateral end of the acetabular sourcil⁽²⁸⁾

Cartilaginous Acetabular Index

Because a baby's hip is largely composed of cartilage, the bony slope seen on an X-ray can be misleadingly steep (suggesting dysplasia) even if the underlying cartilaginous structure is stable.

Definition: Measured primarily via ultrasound (Graf Method) or MRI. It reflects the angle of the actual cartilaginous surface that contacts the femoral head.

The "Alpha Angle": In ultrasound, the alpha angle is the functional equivalent. It measures the bony roof's slope, but because ultrasound sees soft tissue, it allows for the visualization of the labrum and the cartilaginous rim.

Comparison: The cartilaginous index is almost always lower (flatter/better coverage) than the bony index. This is because the cartilage extends further laterally and distally than the bone, providing extra "mold" for the femoral head⁽²⁹⁾.

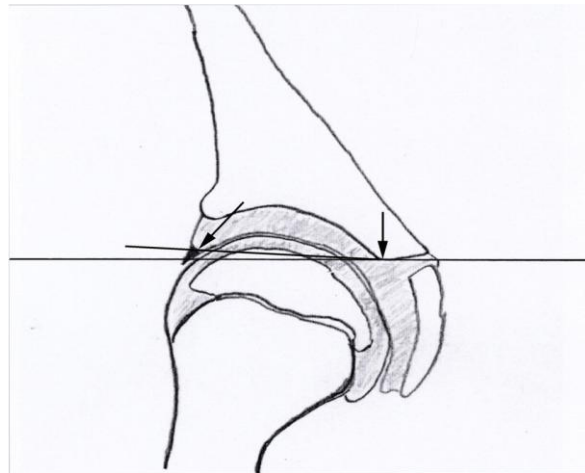


Figure (2): Measurement of the cartilaginous acetabular index measured from the MRI scan as 4.6 degrees.

Arrows show the lower margin of the ilium and the bony margin of the acetabulum⁽³⁰⁾.

Measurement of X-ray and MRI Images

The OAI was determined by measuring the angle between the line connecting the inferior edge of the ilium and the lateral edge of the bony acetabulum, and Hilgenreiner's line, as illustrated in Figure 1. The CAI was measured as the maximum diameter of the femoral head in the coronal plane of the T1-weighted image, the inferior edge of the ilium and the lateral edge of the cartilaginous acetabulum, and the Hilgenreiner's line, as shown in Figure 2. The AAR was calculated as the value of the square of the CAI to OAI. The cartilaginous acetabulum head index (CAHI) was used to evaluate the lateral cartilaginous acetabular coverage of the femoral head. The measurement of CAHI has been mentioned by Nakamura et al.⁽³¹⁾. The results of Sales de Gauzy et al. showed that the range of the CAHI for a normal hip is 77%–93%, and if the CAHI is <77%, it represents inadequate coverage of the femoral head by the acetabulum. They conducted measurements in T2 images for the purpose of better identification of cartilage borders. The coronal images of the maximum diameter of the femoral head were obtained on a T2-weighted image, and the distance from the innermost edge of the femoral head cartilage to the outermost edge of the acetabular cartilage (A) and the maximum transverse diameter of the femoral head (A + B) were measured, and the CAHI = $A/(A + B) \times 100\%$ as shown in Figure 3. The normal value of the OAI at birth is below 30°, reducing rapidly in the first 4 years toward $15 \pm 5.5^\circ$ and remaining stable until full hip ossification at maturity. They defined patients with RHD as having an OAI > 20° on the x-ray, as described by Merckaert et al.⁽³²⁾, and they were categorized as group 1, the residual hip dysplasia group, while healthy patients were categorized as group 2, the control group.

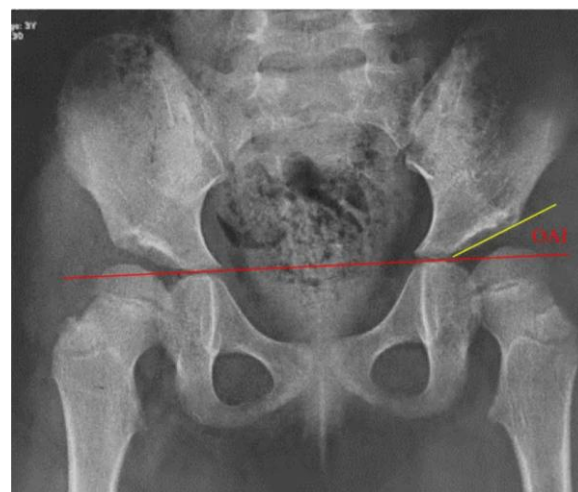


Figure (3): Measurement of the OAI in children with hip dysplasia⁽³³⁾

Acetabular Dysplasia and Clinical Significance

Developmental dysplasia of the hip (DDH) is a common musculoskeletal disorder in pediatric orthopedics, its prevalence in the population ranges from 0.1% to 3.4%. The pathological process includes hip dysplasia, subluxation, and complete dislocation⁽³⁴⁾. Osteoarthritis will develop more rapid and have to be treated by arthroplasty eventually if DDH is not identified timely and not treated in early childhood⁽³⁵⁾. However, there is a substantial likelihood of residual acetabular dysplasia (RAD) even after systematic therapy in infancy and early childhood, and acetabuloplasty is needed to protect the hip in the later stage⁽³⁶⁾.

There is still no uniform standard for the surgical timing and indications of RAD, so if some predictors can be identified to accurately assess and forecast the developmental prognosis after treatment, it can help to guide the timing of correction or avoid unnecessary surgery.

Previous researchers have proposed the use of acetabular index (AI), center edge angle (CEA), Reimer's index (RI), and center-head distance discrepancy (CHDD) as predictors of surgical indications⁽³⁵⁾. However, all of these indices are measured in radiographs and only reflect bony acetabular development, not cartilaginous acetabular development, which represents the true potential of acetabular development⁽³⁷⁾. Therefore, some cartilaginous indicators based on MRI or hip arthrography have been proposed to be used as early warning indicators of RAD, such as cartilaginous acetabular index (CAI), cartilaginous centre-edge angle (CCE), labral acetabular index (L-AI) [It is also called Acetabular Cartilaginous Angle (ACA)⁽³⁸⁾, labral centre-edge angle (L-CEA) [It is also called the center-edge of the acetabular limbus angle (CEALA). This meta-analysis summarized common cartilaginous predictors for assessing developmental prognosis after early treatment of DDH.

And the most commonly used indicators by clinicians and researchers—CAI and L-AI (We define them as CAI group), CCE and L-CEA (We define them as CCE group), were combined separately to compare their diagnostic and prognostic performance⁽³⁹⁾.

Some cartilaginous indicators measured on the coronal plane of MRI (A, C) and the anteroposterior film of hip arthrography (B, D). AI, acetabular index; CEA, centre-edge angle; CAI, cartilaginous acetabular index; CCE, cartilaginous center-edge angle; L, labral.

The acetabular index is an important measurement in the evaluation of hip dysplasia in children 4 months to 8 years old. In many cases, the acetabular index is used to determine the need for treatment and monitor the response to brace and/or surgical treatment. As such, a reliable method of measuring the acetabular index is essential to ensure standardization of care⁽⁴⁰⁾.

AI is a parameter showing the slope of the acetabular roof and borders of the acetabulum via the X-ray of the pelvis⁽⁴¹⁾. Tönnis⁽⁴²⁾ stratified the typical values of AI according to age, gender, and the side of the measurement in 1968 and 1976. In addition to being the standard imaging modality for hip dysplasia in infants older than 6 months, AI can also be used to assess hip morphology even in infants older than 4 months, given the initiation of femoral head ossification⁽⁴³⁾ (Figure 4).

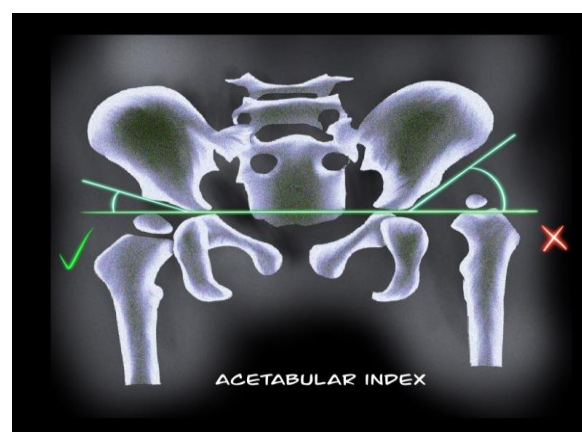


Figure (4): Acetabular Index. The normal index is less than 35° at birth and less than 25° at 1 year of age⁽⁴⁴⁾.

Pelvic Malposition When Assessing Acetabular Index

A plain radiograph cannot always be of reliable standard because of pelvic malposition during the acquisition of radiograph as well as inaccurate centralization of the X-ray beam. In addition, the imprecise location of the superolateral part of the acetabulum may contribute to the measurement error⁽⁴⁵⁾.

Acetabular Development Following Open Reduction

The treatment goal in developmental dysplasia of hip is to obtain stable congruous reduction either by closed or open methods to promote normal hip development. Many authors have reported that concentric reduction is the main factor affecting the acetabular development, and all acetabulae with DDH may develop satisfactorily if concentric reduction is obtained.

Failure to sufficiently remodel results in residual acetabular dysplasia which may need additional surgeries⁽⁴⁶⁾ (Figure 5).

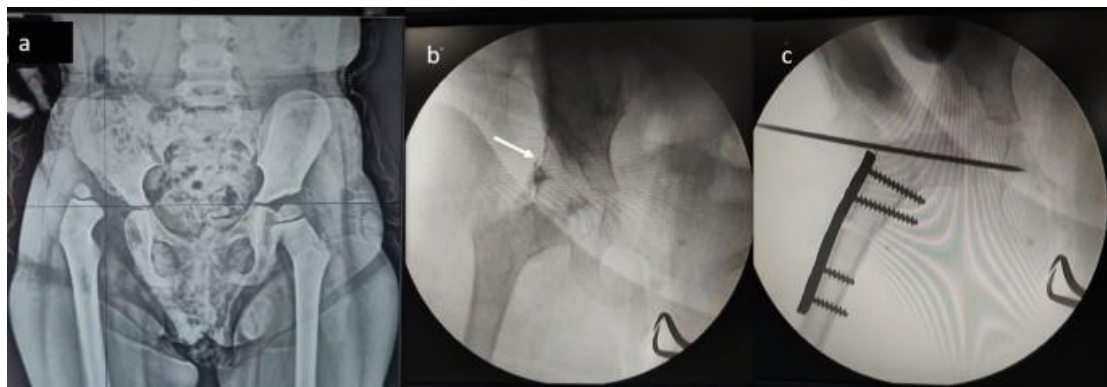


Figure (5): a- Anteroposterior radiograph of a 30 months old girl showing right DDH. b- Intraoperative C-arm image following dye injection into the joint showing well developed cartilaginous acetabulum (white arrow). c- arm image confirming well reduced joint with k wire transfixation and varus derotation femur osteotomy⁽⁴⁷⁾.

Acetabular Index as a Predictor of Residual Dysplasia

Developmental dysplasia of the hip (DDH) is a congenital defect of the skeleton, including acetabular dysplasia, subluxation and complete dislocation of the femoral head.

The aim of treatment for DDH is to obtain a stable and concentric reduction of the hip as early as possible. At present, closed reduction (CR) and spica cast immobilisation under general anesthesia is the gold standard of treatment for patients <18 months of age⁽¹⁸⁾.

The acetabular index (AI) is the simplest and reliable parameter to predict final outcome. AI was measured according to Kleinberg and Lieberman⁽²⁵⁾. The migration percentage (MP) was measured according to Reimers⁽⁴⁸⁾. When migration is 33% to 89% the hip is subluxated and 90% or more means complete dislocation. The centre-edge (CE) angle of Wiberg⁽¹⁰⁾ was included from three years after reduction.

Sonography and Radiography in the Evaluation of DDH

Universal physical examination for hip stability followed by selective ultrasound screening for newborns with risk factors for DDH (ie, infants delivered in breech presentation, family history, and history of clinical instability) is generally used as the screening strategy in infants under 4 months old⁽⁴⁹⁾.

The Graf method and femoral head coverage (FHC) ratio are the two most widely used techniques for ultrasound interpretation; both methods provide simple and quantitative results for accurate diagnosis. After the age of 4 months, as the ossification of the femoral head begins, the acetabular index (AI) in the anteroposterior view of a pelvic radiograph becomes effective in assessing hip morphology⁽⁵⁰⁾.

Pelvic radiography is the most preferred diagnostic modality for DDH in children over six months. On the other hand, several authors⁽⁵¹⁾ have recommended using radiographic screening instead of US to assess DDH in

infants at four months of age. In addition, most orthopedic surgeons favor using radiography in diagnosing DDH in infants over three months of age⁽⁵²⁾.

Digital X-ray imaging, a fast technique with low radiation, may potentially become the preferred auxiliary technique for diagnosing and monitoring DDH in infants aged 3-6 months⁽⁵³⁾ (Figure 6). Given the absence of ossific hip joints, pelvic radiography is not recommended for infants aged 3-4 months⁽⁵⁴⁾.

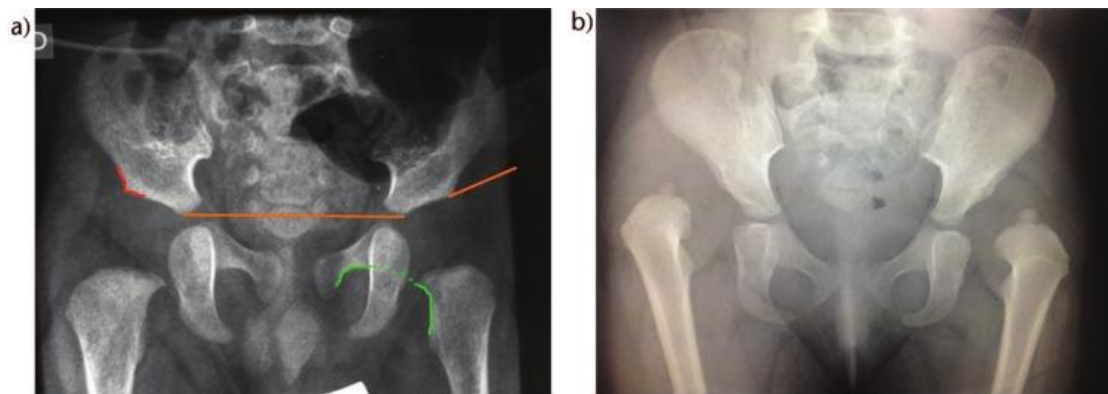


Figure (6): (a) Radiograph studies are the reference in children older than 4 to 6 months of age. In the image, although the ossification nucleus of the head is absent, indirect signs of concentric reduction as the formed talus (red line) and Shenton line (green lines) are present. The acetabular index (orange line) is the main parameter to control acetabular development during the first years of age. (b) Bilateral dislocation of a two-year-old child⁽⁵⁵⁾.

Conclusion

The treatment goal in developmental dysplasia of hip is to obtain stable congruous reduction either by closed or open methods to promote normal hip development. Many authors have reported that concentric reduction is the main factor affecting the acetabular development, and all acetabulae with DDH may develop satisfactorily if concentric reduction is obtained.

Failure to sufficiently remodel results in residual acetabular dysplasia which may need additional surgeries⁽⁴⁶⁾.

References

1. Barrera C, Cohen S, Sankar W *et al.* (2019): Imaging of developmental dysplasia of the hip: ultrasound, radiography and magnetic resonance imaging. *Pediatric Radiology.*, 49: 1652–1668.
2. Herring JA (2008): Tachdjian's pediatric orthopaedics. In Tachdjian's pediatric orthopaedics (pp. 3–v).
3. Keller MS, Nijs ELF (2009): The role of radiographs and US in developmental dysplasia of the hip: how good are they? *Pediatric Radiology*, 39(Suppl 2), 211–215.
4. Czerny C, Hofmann S, Neuhold A *et al.* (1996): Lesions of the acetabular labrum: accuracy of MR imaging and MR arthrography in detection and staging. *Radiology.*, 200 (1): 225–230.
5. Salter RB, Dubos JP (1974): The first fifteen years' personal experience with innominate osteotomy in the treatment of congenital dislocation and subluxation of the hip. *Clinical Orthopaedics and Related Research®.*, 98: 72–103.
6. Harris NH (1976): Acetabular growth potential in congenital dislocation of the hip and some factors upon which it may depend. *Clinical Orthopaedics & Related Research.*, 119: 99–106.
7. Walker K (2009): Pelvis radiographs. *The Identification and Treatment of Gait Problems in Cerebral Palsy*, 244.
8. Ryan MG, Johnson LO, Quanbeck DS *et al.* (1998): One-stage treatment of congenital dislocation of the hip in children three to ten years old. Functional and radiographic results. *JBJS.*, 80 (3): 336–344.

9. Grudziak JS, Ward WT (2001): Dega osteotomy for the treatment of congenital dysplasia of the hip. *JBJS.*, 83 (6): 845–854.
10. Wiberg G (1939): Studies on dysplastic acetabula and congenital subluxation of the hip joint. *Acta Chir Scand.*, 58: 5–135.
11. Murray KA, Crim JR (2001): Radiographic imaging for treatment and follow-up of developmental dysplasia of the hip. *Seminars in Ultrasound, CT and MRI.*, 22 (4): 306–340.
12. Czubak J, Kotwicki T, Piontek T *et al.* (1998): Ultrasound measurements of the newborn hip comparison of two methods in 657 newborns. *Acta Orthopaedica Scandinavica.*, 69 (1): 21–24.
13. Clarke NM, Clegg J, Al-Chalabi AN (1989): Ultrasound screening of hips at risk for CDH. Failure to reduce the incidence of late cases. *The Journal of Bone & Joint Surgery British Volume.*, 71 (1): 9–12.
14. Graf R (1980): The diagnosis of congenital hip-joint dislocation by the ultrasonic Combound treatment. *Archives of Orthopaedic and Traumatic Surgery.*, 97 (2): 117–133.
15. Wells J, Nepple JJ, Crook K *et al.* (2017): Femoral morphology in the dysplastic hip: three-dimensional characterizations with CT. *Clinical Orthopaedics and Related Research®.*, 475 (4): 1045–1054.
16. Sarban S, Ozturk A, Tabur H *et al.* (2005): Anteversion of the acetabulum and femoral neck in early walking age patients with developmental dysplasia of the hip. *Journal of Pediatric Orthopaedics B.*, 14 (6): 410–414.
17. Vaquero-Picado A, González-Morán G, Garay EG *et al.* (2019): Developmental dysplasia of the hip: update of management. *EFORT Open Reviews.*, 4 (9): 548–556.
18. Tomlinson J, O'Dowd D, Fernandes JA (2016): Managing developmental dysplasia of the hip. *The Indian Journal of Pediatrics.*, 83 (11): 1275–1279.
19. Elsharkawi KM, Barakat MS, Farahat AAK *et al.* (2021): Role of Magnetic Resonance Imaging in assessment of osseous and cartilaginous coverage in developmental dysplasia of the hip. *Senses and Sciences*, 8(2).
20. Rosenbaum DG, Servaes S, Bogner EA *et al.* (2016): MR imaging in postreduction assessment of developmental dysplasia of the hip: goals and obstacles. *Radiographics.*, 36 (3): 840–854.
21. Vitale MG, Skaggs DL (2001): Developmental dysplasia of the hip from six months to four years of age. *Journal of the American Academy of Orthopaedic Surgeons.*, 9 (6): 401–411.
22. Weishuhn LJ, Seidman A (2022): Hip arthrogram.
23. Haddad FS, Harper GD, Hill RA (1997): Intraoperative arthrography and the Ilizarov technique: Role in the correction of paediatric deformity and leg lengthening. *The Journal of Bone & Joint Surgery British Volume.*, 79 (5): 731–733.
24. Alshehri F, Almalki Y (2023): Developmental dysplasia of the hip in infants younger than six months: Ultrasonographic assessment in relation with risk factors. *International Journal of Health Sciences.*, 17 (2): 37.
25. Kleinberg S, LIEBERMAN HS (1936): The acetabular index in infants in relation to congenital dislocation of the hip. *Archives of Surgery.*, 32 (6): 1049–1054.
26. Tönnis D (2012): Congenital dysplasia and dislocation of the hip in children and adults. Springer Science & Business Media.
27. Bakarman K, Alsiddiky AM, Zamzam M *et al.* (2023): Developmental dysplasia of the hip (DDH): etiology, diagnosis, and management. *Cureus*, 15(8).

28. Shin CH, Yang E, Lim C *et al.* (2020): Which acetabular landmarks are the most useful for measuring the acetabular index and center-edge angle in developmental dysplasia of the hip? A comparison of two methods. *Clinical Orthopaedics and Related Research*®, 478 (9): 2120–2131.
29. Agus H, Filibeli M, Turgut A *et al.* (2022): Does the Cartilaginous Index Affect Acetabular Development in Developmental Dysplasia of the Hip? A Radiographic Study on Patients with Long-term Follow-up. *Journal of Behcet Uz Children's Hospital*.
30. Sherman B, Lalonde FD, Schlechter JA (2021): Measuring the acetabular index: an accurate and reliable alternative method of measurement. *American Journal of Roentgenology*., 217 (1): 172–176.
31. Nakamura T, Yamaguchi R, Wada A *et al.* (2021): A longitudinal study for the prediction of the mature acetabular morphology using childhood magnetic resonance imaging. *Journal of Orthopaedic Science*., 26 (4): 644–649.
32. Merckaert SR, Pierzchala K, Bregou A *et al.* (2019): Residual hip dysplasia in children: osseous and cartilaginous acetabular angles to guide further treatment—a pilot study. *Journal of Orthopaedic Surgery and Research*., 14 (1): 379.
33. Wang J, Li T, Yao Y *et al.* (2024b): The role of the cartilaginous to osseous acetabular angle ratio in children with developmental dysplasia of the hip. *Frontiers in Pediatrics*., 12: 1347556.
34. Moraleda L, Albiñana J, Salcedo M *et al.* (2013): Displasia del desarrollo de la cadera. *Revista Española de Cirugía Ortopédica y Traumatología*., 57 (1): 67–77.
35. El-Sayed MMH, Hegazy M, Abdelatif NM *et al.* (2015): Dega osteotomy for the management of developmental dysplasia of the hip in children aged 2–8 years: results of 58 consecutive osteotomies after 13–25 years of follow-up. *Journal of Children's Orthopaedics*., 9 (3): 191–198.
36. Onaç O, Alpay Y, Yapıcı F *et al.* (2021): Correlation of postoperative magnetic resonance image measurements with persisting acetabular dysplasia in open reduction of developmental hip dysplasia. *Joint Diseases and Related Surgery*., 32 (2): 461.
37. Mansour E, Eid R, Romanos E *et al.* (2017): The management of residual acetabular dysplasia: updates and controversies. *Journal of Pediatric Orthopaedics B*., 26 (4): 344–349.
38. Zamzam MM, Kremlı MK, Khoshhal KI *et al.* (2008): Acetabular cartilaginous angle: a new method for predicting acetabular development in developmental dysplasia of the hip in children between 2 and 18 months of age. *Journal of Pediatric Orthopaedics*., 28 (5): 518–523.
39. Yang S, Su F, Jia HR *et al.* (2023): Cartilaginous predictors of residual acetabular dysplasia (RAD) in developmental dysplasia of the hip following closed or open reduction: A systematic review and meta-analysis. *Frontiers in Pediatrics*., 11: 1124123.
40. Upasani VV, Bomar JD, Parikh G *et al.* (2012): Reliability of plain radiographic parameters for developmental dysplasia of the hip in children. *Journal of Children's Orthopaedics*., 6 (3): 173–176.
41. Akel, Songur M, Karahan S *et al.* (2013): Acetabular index values in healthy Turkish children between 6 months and 8 years of age: a cross-sectional radiological study. *Acta Orthopaedica et Traumatologica Turcica*., 47 (1): 38–42.
42. Tönnis D (1976): Normal values of the hip joint for the evaluation of X-rays in children and adults. *Clinical Orthopaedics and Related Research (1976-2007)*., 119: 39–47.
43. Chang WC, Hsu KH, Su YP (2022): Association between early sonographic findings and acetabular index at the age of 6 months: a prospective observational study. *BMC Pediatrics*., 22 (1): 228.
44. Nandhagopal T, Tiwari V, De Cicco FL (2024): Developmental dysplasia of the hip. In *StatPearls* [Internet]. StatPearls Publishing.

45. Janusz P, Tyrakowski M, Monsef JB *et al.* (2016): Influence of lower limbs discrepancy and pelvic coronal rotation on pelvic incidence, pelvic tilt and sacral slope. *European Spine Journal.*, 25 (11): 3622–3629.
46. Murphy RF, Kim YJ (2016): Surgical management of pediatric developmental dysplasia of the hip. *JAAOS-Journal of the American Academy of Orthopaedic Surgeons.*, 24 (9): 615–624.
47. Patwardhan S, Madegowda A, Sancheti P (2021): Evaluation of acetabular development following open reduction of developmental dysplasia of hip in children after walking age. *Indian Journal of Orthopaedics.*, 55 (6): 1583–1590.
48. Reimers J (1980): The stability of the hip in children: a radiological study of the results of muscle surgery in cerebral palsy. *Acta Orthopaedica Scandinavica.*, 51 (sup184): 1–100.
49. Kotlarsky P, Haber R, Bialik V *et al.* (2015): Developmental dysplasia of the hip: What has changed in the last 20 years? *World Journal of Orthopedics*, 6(11), 886.
50. Rosenberg HK, Benator RM, Bulas DI *et al.* (2013): Ultrasound examination for detection and assessment of developmental dysplasia of the hip. *Journal of Ultrasound in Medicine.*, 32 (7): 1307–1317.
51. Zhang SC, Sun J, Liu CB *et al.* (2020): Clinical application of artificial intelligence-assisted diagnosis using anteroposterior pelvic radiographs in children with developmental dysplasia of the hip. *The Bone & Joint Journal.*, 102 (11): 1574–1581.
52. Doski J, Mosa L, Hassawi Q (2022): An upgrade of the international hip dysplasia institute classification for developmental dysplasia of the hip. *Clinics in Orthopedic Surgery.*, 14 (1): 141.
53. Atalar H, Arikan M, Tolunay T *et al.* (2021): The infants who have mature hip on ultrasonography but have risk factors of developmental dysplasia of the hip are required radiographic examination. *Joint Diseases and Related Surgery.*, 32 (3): 598.
54. Li J, Zhao B, Ji H *et al.* (2022): Application Value of Combined Diagnosis of Ultrasound, MRI, and X-Ray in Developmental Dysplasia of the Hip in Children. *Contrast Media & Molecular Imaging.*, 2022 (1): 1632590.