Pelvis/Hip Paediatric

11

Prudencia N. M. Tyrrell, Apostolos H. Karantanas, and Victor N. Cassar-Pullicino

Contents

P. N. M. Tyrrell, F.R.C.R. (✉)
The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry, Shropshire, UK
e-mail: prudencia.tyrrell@rjah.nhs.uk

A. H. Karantanas, M.D., Ph.D.
University Hospital,
Stavrakia, Heraklion 711 10, Crete, Greece

V. N. Cassar-Pullicino, F.R.C.R.
Department of Radiology, Robert Jones and Agnes Hunt Orthopaedic Hospital NHS Foundation Trust, Oswestry, UK
e-mail: Victor.Pullicino@rjah.nhs.uk

V. N. Cassar-Pullicino, A. M. Davies (eds.), *Measurements in Musculoskeletal Radiology*, Medical Radiology, Diagnostic Imaging, https://doi.org/10.1007/978-3-540-68897-6_11

11.1 Introduction

At birth the acetabulum is partly cartilaginous with the epiphyseal plate composed of the triradiate cartilage with contributions from the unossified portions of the ilium, ischium and pubis. The hip joint at this stage consists of an entirely cartilaginous femoral capital epiphysis lying within the acetabulum formed by the triradiate cartilage. Continued growth, development and ossification result in eventual fusion of the bones of the acetabulum. The ossific nucleus of the femoral head appears in the early weeks after birth. It is visible earlier on ultrasound than on the radiograph. Its position within the cartilaginous femoral head may be more posterior than usual if there is developmental dysplasia present.

In early infancy much of the hip joint is cartilaginous, and the bone which is present is still developing, growing and maturing. As a result difficulty can be experienced in identifying the correct bony landmarks from which to make measurements on the radiograph. This can lead to great variability in attempted reproducibility of some measurements. Interobserver measurements are more likely to differ significantly than intraobserver measurements, and this is particularly important in the paediatric population. When performing measurements in the paediatric age group, particularly because of continued expected interval growth, it is not the value of a single measurement that should be interpreted as being important and whether it is normal or abnormal, but rather the evolving trend that is seen when measurements are repeated at regular intervals. The ideal situation would be that measurements are also repeated by the same observer as far as is possible and even if not, ensuring that exactly the same landmarks are used to make the measurement. Variability in reproducibility of some measurements may be because of difficulty in determining, for example, what represents the lateral margin of the acetabulum. This in itself may be indistinct due to the underlying pathological process for which the measurement is required, for example, developmental dysplasia of the hip (DDH). Kim specifically addressed this point in a study to evaluate the most accurate marking point on a plain radiograph when measuring the acetabular index and the centre-edge angle (Kim et al. 2000). The position of the hips for a particular measurement is important, and there must be clarity as to whether the measurement is being made with the hips in the neutral position or in a frog lateral position.

Measurements about the pelvis in the paediatric population require close attention to positioning of the pelvis ensuring that it is neither rotated nor inclined. Even a minor degree of obliquity can result in great variability of a measurement. Pelvic symmetry needs to be assessed before declaring that the radiograph is suitable to embark on obtaining the required measurements. As will be discussed later in this chapter, the transverse diameter of the obturator foramina bilaterally is used to confirm a true anteroposterior position. The ratio obtained by dividing the right obturator measurement by the left one should be 1 with the patient in the neutral position. It is still acceptable if it is in the range of **1.8–0.56** as the measurements will only differ by a maximum of 2° (Fig. 11.1). The degree of pelvic inclination can also introduce errors in the measured angles. The ratio between the vertical distance between the symphysis pubis and Hilgenreiner's line divided by the vertical obturator diameter should be in the range of **1.2 and 0.75** to ensure reliable accuracy of the measurements (Ball and Kommenda

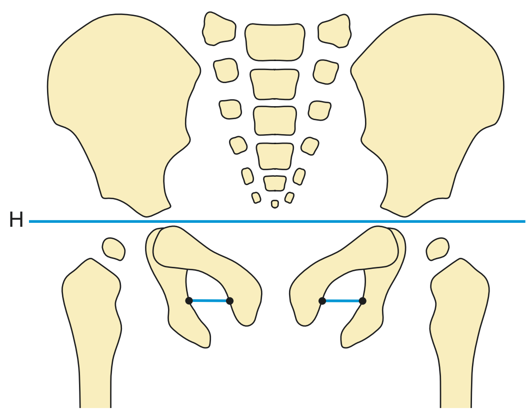

Fig. 11.1 **Hilgenreiner's line**. This is a horizontal line which passes through the centre of the triradiate cartilages. The obturator index is the ratio between the right and left obturator foraminal distance which is one in a neutrally positioned AP pelvis

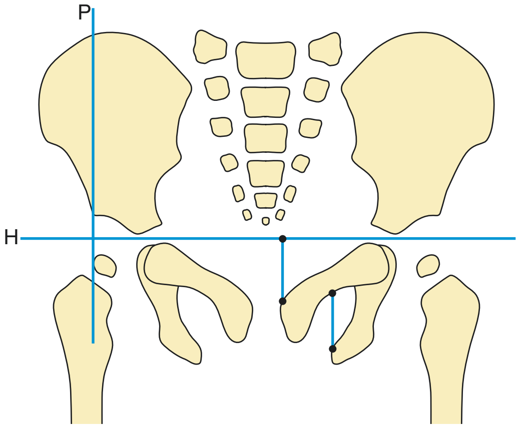

Fig. 11.2 **Perkins' line**. This is a vertical line drawn perpendicular to Hilgenreiner's line which passes through the lateral margin of the bony acetabulum. The ratio between the vertical obturator diameter and the vertical distance between the pubic bone and Hilgenreiner's line should be between 1.2 and 0.75 indicating an acceptable pelvic inclination range for reliable measurements

1968) (Fig. 11.2). Others have drawn lines from bony landmarks and then allowed for a conversion factor to ensure adequacy of position (Tönnis 1976). This is dealt with further in the pelvic inclination formula/pelvic symmetry sections.

Certain measurements are best made at a particular stage or age of development, for example, the acetabular index is best measured, while the triradiate cartilage is still open. This is because the measurement depends on Hilgenreiner's line which passes through the triradiate cartilage. The acetabular angle however is best measured when the triradiate cartilage is closed although it is often used in the older child when the cartilage is still open. For this measurement the teardrop needs to be visible, and this in itself only appears at 6–24 months of age and older in cases where the hip is dislocated. The centre-edge angle of Wiberg is best used after the age of 5 years. This is because it can be difficult to ascertain the centre of the femoral head when much of the head is cartilage and still relatively immature.

Most of the commonly used measurements will be made from a well-positioned anteroposterior (AP) radiograph. Radiographs are readily available and cheap. The time taken for the examination is brief, and usually an adequate and diagnostic radiograph can be obtained. Computed tomography (CT) and magnetic resonance imaging (MRI) have been used for some measurements, and there are anecdotal reports in the literature concerning these. Such modalities however are expensive and are not always readily available. Radiation dose is relatively high with CT, and keeping the child still for the duration of an MRI scan can be difficult without resort to use of some form of sedation. CT and MRI certainly have a role in the diagnosis and management of some conditions but would not be advocated for routine measurement of parameters which can be achieved otherwise by radiographs or by ultrasound.

The introduction of ultrasound (US) in the late 1970s and the work by Graf revolutionised how we assess and monitor the paediatric hip particularly in developmental dysplasia. The particular advantages of ultrasound in the paediatric population include no irradiation and assessment of cartilaginous structures not visible on radiographs, and it is dynamic and allows multiplanar evaluation. There is no sedation required (as compared with arthrography, CT, etc.), but it is operator dependent (Wientroub and Grill 2000). Measurement of Graf's alpha and beta US angles and assessment of femoral head coverage are routinely performed. Dynamic ultrasound is considered even more important than static evaluation and allows for assessment of the stability of the hip (Harcke and Grissom 1990). The literature reports variability in the degree of reproducibility of measurements but again emphasises the importance of serial measurements and evaluation of trend. Measurements alone are not everything, and any finding needs to be assessed in a clinical context.

There are a wide number of measurements referred to in the literature which have not been referred to here. Some of these are new measurements, and others are suggested variations of already established parameters. Reference here has only been made to the more common and generally accepted measurements, notwithstanding acknowledgement of other measurements used in other practices. The important aspect about any measurement and particularly so in the paediatric age group where normal growth (or lack of) can be a confounding variable is that the significance of a single measurement can be difficult to interpret and therefore it is valuable to obtain serial measurements using standardised methods, that the measurer is or has been trained how to do it and finally that consistent measurers are employed as far as possible. In the child, the importance of measuring the contralateral side cannot be overemphasised (Song et al. 2008). There is a need to be wary however in that bilateral pathology can occur and to be mindful of this in evaluating the measurements together.

Certain lines drawn on the radiograph, between fixed points, act as reference lines relative to anatomical structures. Displacement of such structures can therefore be ascertained, and a radiographic diagnosis made. Interpretation of the radiograph is potentially more difficult prior to appearance of the femoral ossification centre. The ossification centres are not fixed in the time of their appearance. A very early ossification centre may be visible on ultrasound (prior to its visualisation on the radiograph) as early as 3–4 weeks after birth. However, it may not be radiographically apparent for several months. The position of the ossification centre within the femoral capital epiphysis is also variable. Although in the entirely normal child, it usually occurs centrally within the epiphysis, it often appears in the more posterior aspect of the epiphysis particularly in those with a history of developmental dysplasia. Shenton's line, Hilgenreiner's line, Perkins' line and Z line are all common references on the radiograph and are detailed below.

The sourcil is a curved area of dense bone on the superior weight-bearing surface of the acetabulum. In a normal hip, the sourcil is uniformly thick and semilunar in shape with a horizontal or downward orientation. In the dysplastic hip, the sourcil is directed upwards (Kim et al. 2000). In childhood the sourcil may be difficult to appreciate due to much of the acetabulum being cartilaginous. If the pelvis is in any way rotated and in any event in hip dysplasia, the lateral bony margin and the sourcil may be difficult to define due to overlapping shadows and poor definition of the lateral bony margin of the acetabulum.

Not all measurements of the paediatric hip are related to developmental dysplasia. Most measurements however are related in some way to bony development. The acetabular angle and the alpha and beta angles are clearly related to developmental dysplasia. The iliac angle and iliac index are related to the shape of the ilium, alteration of which may be associated with some conditions such as Down's syndrome. Certain anatomical features are clearly associated with certain conditions, such as teardrop distance and Perthes disease. Although such measurements are not made routinely, when an abnormality has been identified, measurement of such a feature is a useful way of following the condition and evaluating development following appropriate treatment.

11.2 Lines in Paediatric Hip Measurement

The acetabulum is composed of the ilium, the ischium and the pubis. The junction of the three bones in the floor of the acetabulum is cartilaginous and known as the triradiate cartilage. The ossification centre of the femoral head becomes visible on radiographs between the second and eighth months of life. A number of lines have been identified about the pelvis and hips to assist with evaluation of the location of the unossified femoral head and also to assess the degree of acetabular coverage. These lines are drawn on the AP view of the pelvis and include the following.

Hilgenreiner's Line

Is a horizontal line which passes through the centre of the triradiate cartilages (Hilgenreiner 1925) (Fig. 11.1).

Perkins' Line

Is a vertical line drawn perpendicular to Hilgenreiner's line and is drawn at the lateral margin of the bony acetabulum (Perkins 1928) (Fig. 11.2). The intersection of Hilgenreiner's and Perkins' lines divides the hip into four quadrants. The femoral ossific nucleus, if present, or if not, the medial margin of the metaphysis, should lie within the inner lower quadrant if the hip is normal. The typical dislocated hip will lie in the upper outer quadrant.

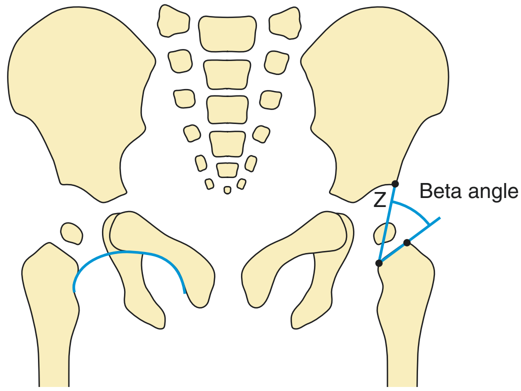

Fig. 11.3 **Shenton's line**. An arc drawn between the medial border of the right femoral neck and the superior margin of the obturator foramen should normally be smooth and continuous. The **Z line** should normally pass through the ossification centre of the femoral epiphysis (Z) and forms the **beta angle** with a line running along the femoral metaphysis

Shenton's Line

Is an arc drawn between the medial border of the femoral neck and the superior margin of the obturator foramen (Shenton 1911) (Fig. 11.3). In the normal hip, this is a smooth continuous uninterrupted line. In the dislocated hip with superior migration of the femoral head, the line is interrupted.

Z Line

Is an oblique line drawn across the hip joint connecting the lateral edge of the acetabular rim to the metaphyseal beak of the proximal femoral metaphysis medially. The line should pass through the centre of the ossified portion of the femoral epiphysis (Fig. 11.3).

Beta Angle of Zsernaviczky and Turk

Is formed between the femoral metaphysis and the edge of the acetabulum. A line is drawn along the proximal metaphysis of the femur and allowed to intersect the Z line (connecting the lateral edge of the acetabulum and the medial edge of the femoral metaphysis) (Figs. 11.3 and 11.4) (Zsernaviczky and Turk 1975).
Normal angle is 50–56° and abnormal is >56°.

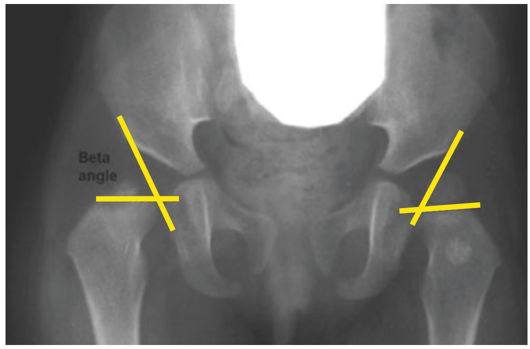

Fig. 11.4 Beta angle measured on AP radiograph

11.3 Pelvic Tilt, Inclination Formula and Pelvic Symmetry

Definition

Pelvic tilt (δ) is defined as the angle between a horizontal line and a line connecting the upper border of the symphysis with the sacral promontory (PS-SP line) (Fig. 11.5). A simple formula which is also used in adults is able to assess the pelvic tilt from AP radiographs.

Pelvic symmetry is the measurement to assess symmetry of the pelvis after proper radiographic positioning.

Indications

With increasing age the pelvis inclines posteriorly, whereas variations exist in the same subjects depending on the body position. When quantifying follow-up radiographs for any hip disorders, it is important to assess the pelvic inclination which is measured on the lateral radiograph. Obtaining the measurement of inclination from AP radiographs reduces significantly the radiation burden.

The symmetry of the pelvis should be confirmed before performing follow-up evaluations.

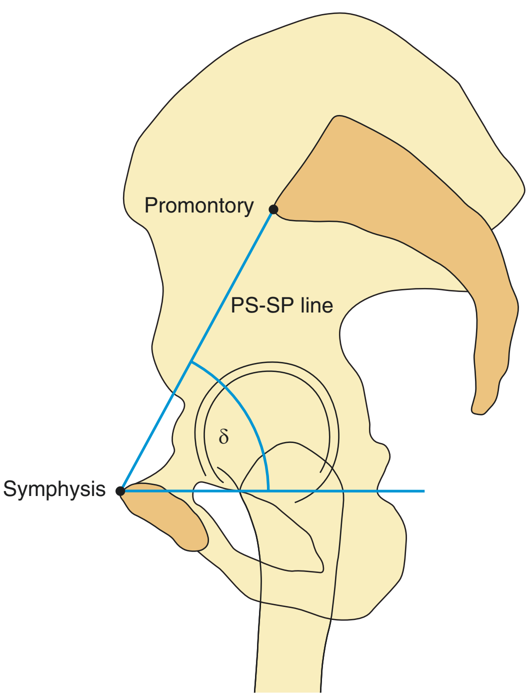

Fig. 11.5 The **PS-SP line** and pelvic tilt angle

Technique

Radiography: AP radiograph.

Full Description of Technique

Formula for Pelvic Inclination

A formula has been described to assess the pelvic tilt from AP radiographs.

The pelvic foramen distance (D) is defined as the distance between the midpoint of the inferior margins of the bilateral sacroiliac joints and the superior margin of the pubic symphysis on a lateral radiograph. The pelvic inclination angle (θ) is defined as the angle between a horizontal line and line D on a lateral radiograph. This allows conversion of the pelvic foramen height on AP radiographs to the pelvic inclination angle, using a mathematic formula (Kitajima et al. 2006).

The formula is $\theta = \arcsin$ ($H/165$ or $H/157$ for women and men, respectively) where θ is the inclination angle and H the distance between the midpoint of the line that connects the inferior margins of the bilateral sacroiliac joints and the superior margin of the pubic symphysis on an AP radiograph (Fig. 11.6).

Indicators of Pelvic Symmetry

Quotient of pelvic rotation (Tönnis' obturator foramen index). This measurement evaluates the pelvic position in the horizontal plane. It is the ratio of the maximum horizontal width of the obturator foramen of the right side and that of the left ('QR' and 'QL'). In neutral rotation the ratio is 1 but is considered to be acceptable when it is between **0.56** (pelvis turned to the right) and **1.8** (pelvis turned to the left). Within the range above, the measured angles do not differ by more than 2° (Fig. 11.7).

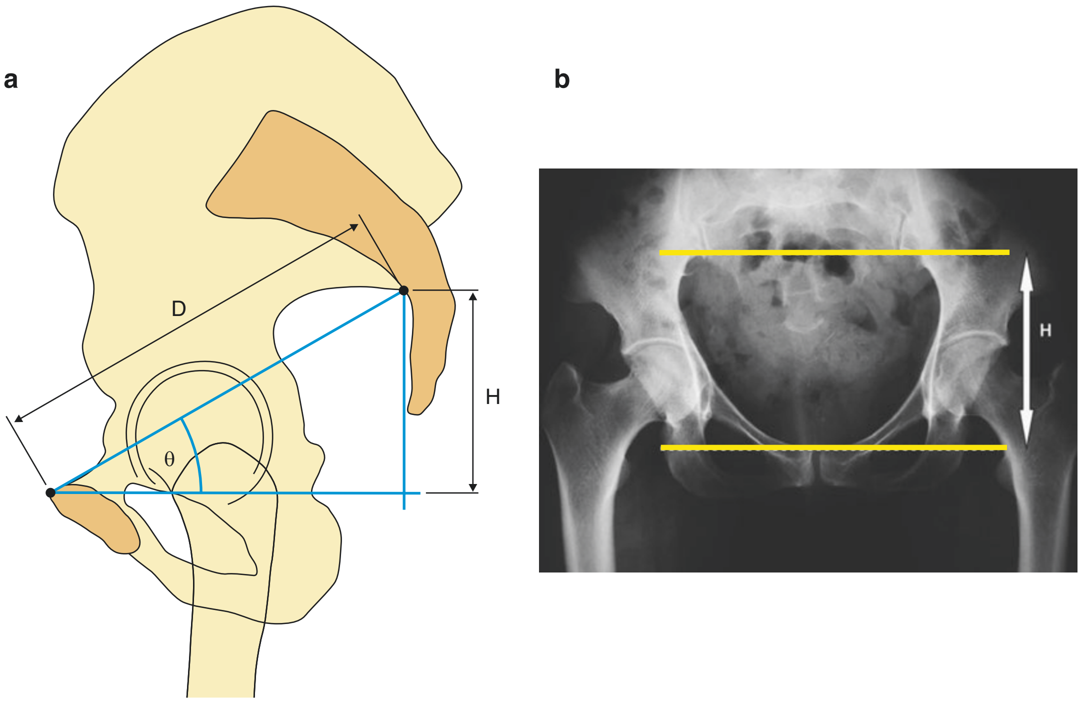

Fig. 11.6 Pelvic inclination formula to assess pelvic tilt from AP radiograph

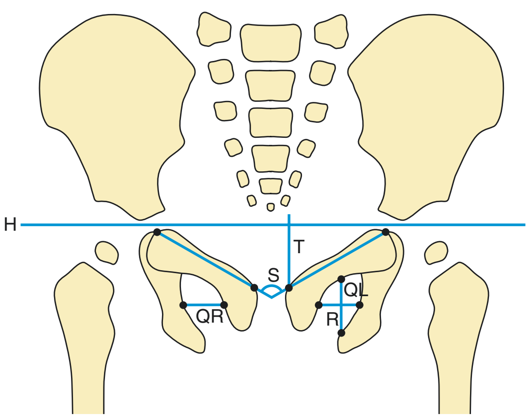

Fig. 11.7 Pelvic symmetry/tilt assessment utilising the **obturator index** (QR/QL), **symphysis-ischium angle** (S) and **pelvic tilt index** (R/T)

Symphysis-ischium angle. This evaluates the pelvic position in the sagittal plane and is formed by two lines which are tangential to the highest point on each ischium and which meet at the point of the symphysis that projects farthest into the pelvic aperture ('S') (Fig. 11.7). The range of normal values is from 90° to 135° and is related to the infant's age.

Pelvic tilt index. This also assesses the pelvic position in the sagittal plane and is the ratio between the vertical diameter of the obturator foramen and the distance between the upper brim of the symphysis pubis and Hilgenreiner's Y-line ('R' and 'T'). With the pelvis normally positioned, the ratio is between 0.75 and 1.2 (Fig. 11.7).

Reproducibility/Variation

The reliability of the obturator index increases with age. Quotient for pelvic rotation and pelvic tilt index is less accurate before the ossification appearance of the ischiopubic synchondrosis. High inter- and intraobserver variability exists for the pelvic inclination formula. The quotient of pelvic rotation becomes accurate after 7 months of age. The symphysis-ischium angle is useful up to the second year of life, but after this the pelvic tilt index becomes more reliable.

Clinical Relevance/Implications

The pelvic position influences the anteroposterior ratio of acetabular coverage in both the paediatric and adult age groups (Katada and Ando 1984, Siebenrock et al. 2003). In the adult it is relevant in the development of coxarthrosis and the orientation of the acetabular component in total hip arthroplasty.

The pelvis tends to incline posteriorly with ageing, whereas significant changes occur in the orientation of the pelvis during daily activities. Therefore, the assessment of the pelvic inclination is important for comparing follow-up radiographs.

On the AP radiograph of the hip, the pelvis does not show excessive inclination in the sagittal plane, if the tip of the coccyx is centred over the pubic symphysis within a distance of 2 cm or less from the latter. If the distance is longer, then a correction for the pelvic inclination has to be done when evaluating various measurements in follow-up radiographs.

11.4 Acetabular Index (AI) Angle

Definition

This is the angle between an oblique line drawn from the most lateral edge of the bony acetabular roof to the centre point of the triradiate cartilage and Hilgenreiner's line (Fig. 11.8). The AI is used to evaluate the orientation of the acetabular roof in the coronal plane and the superior lateral coverage of the femoral head.

Normal values (male measurements 2° larger than female):

Newborn	27.5° (±4.9)
< 6 months	22.8° (±3.6)
1 year	20.8° (±3.9)
2 years	19.8° (±4.3)
2–3 years	18°
3–7 years	14.5°
7–15 years	10°

Abnormal > 35° suggests acetabular dysplasia.

Indication

It is used to follow the radiographic development of the acetabulum in children with developmental dysplasia of the hip (DDH) and to determine the need for subsequent surgery. Along with the beta angle measurement, the AI evaluates the need for pelvic osteotomies in those children with primary acetabular dysplasia or acetabular dysplasia resulting from a dislocated hip.

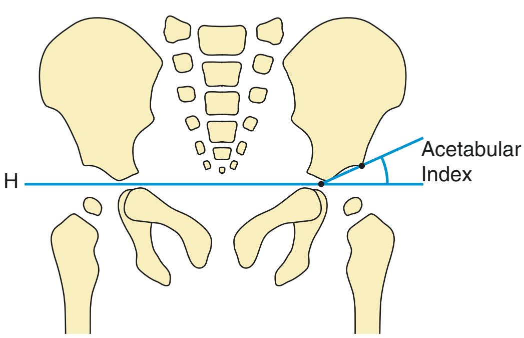

Fig. 11.8 **Acetabular index**. The angle between a line drawn from the most lateral edge of the bony acetabular roof to the centre point of the triradiate cartilage, intersecting Hilgenreiner's line

Technique

Radiography: AP radiograph of the pelvis centred 1 cm superior to the symphysis pubis.

Full Description of Technique

On an anteroposterior (AP) radiograph of the pelvis, a horizontal line is drawn between the centre of the two triradiate cartilages (Hilgenreiner's line). A line is drawn from the most lateral edge of the bony acetabular roof to the centre point of the triradiate cartilage. The acetabular index is formed at the intersection of these two lines.

Reproducibility/Variation

The AI is reproducible in all age groups. In children under 2 years of age, using a 95% confidence interval definition, a 4% change in AI is required before the observer can be certain that a true change has occurred in acetabular development. Other observers reported that a difference of less than 12° on successive radiographs should be interpreted with caution. Several studies have indicated that the AI is one of the most reliable and readily reproducible measurements related to assessment of developmental dysplasia in the child (Broughton et al. 1989; Kay et al. 1997; Spatz et al. 1997; Skaggs et al. 1998; Tan et al. 2001). Tan's study showed no significant interobserver or intraobserver difference between observers working in the same clinic.

Clinical Relevance/Implications

In the normal newborn, the AI averages 27.5° and decreases to approximately 20° by age 2 years (see normal values above). In the newborn with clinical evidence of DDH, a normal radiograph does not exclude the presence of instability. The age at which the radiological diagnosis can be established is near the upper limit of the age for successful treatment of hip dysplasia using the Pavlik harness. In addition, the radiation exposure (about 20 **uGy**) is not negligible, particularly when radiographs have to be repeated. For all the above reasons, ultrasonography has replaced in general the AP radiograph for screening DDH.

Analysis/Validation of Reference Data

All of the above studies were performed in children as opposed to a mixed adult-child population as is often found in studies on developmental dysplasia. This in itself lends more weight to the validity of the reproducibility of data as difficulties can be encountered with some other measurements due to lack of ossification. Tan (2001) emphasises the importance of positioning of the child for the radiograph avoiding rotation, and this point is also addressed by Boniforti et al. (1997).

Conclusion

The AI is a readily reproducible and reliable measurement in assessment of the dysplastic hip and its response to treatment.

11.5 Acetabular Angle

Definition

The acetabular angle was first described by Sharp in 1961. Sharp's angle is defined between the teardrop line and a line to the lateral acetabulum. It measures the slope of the acetabulum and has classically been used when the triradiate cartilage is closed.

Normal		Abnormal	
<10 years	<45°	<10 years	>45°
>10 years	<40	>10 years	>40°

At puberty the normal acetabular angle is within 33–38° range.

The greater the abnormal angle, the more severe the dysplasia.

Indication

The acetabular angle is used in the follow-up of developmental dysplasia of the hip to assess treatment when the triradiate cartilage is closed (see "Adult Hip" section). It can also be used when the triradiate cartilage is open although difficulty may be experienced with the measurement (see below).

Techniques

Radiography: AP radiograph of pelvis centred approximately 1 cm above the symphysis pubis.

Full Description of Technique

On an AP radiograph, a horizontal line is drawn connecting the inferior most aspect of the teardrops on each side. A second line is then drawn on each side connecting the most lateral edge of the bony roof of the acetabulum to the inferior aspect of the teardrop figure. The acetabular angle is formed at the intersection of these two lines (Fig. 11.9).

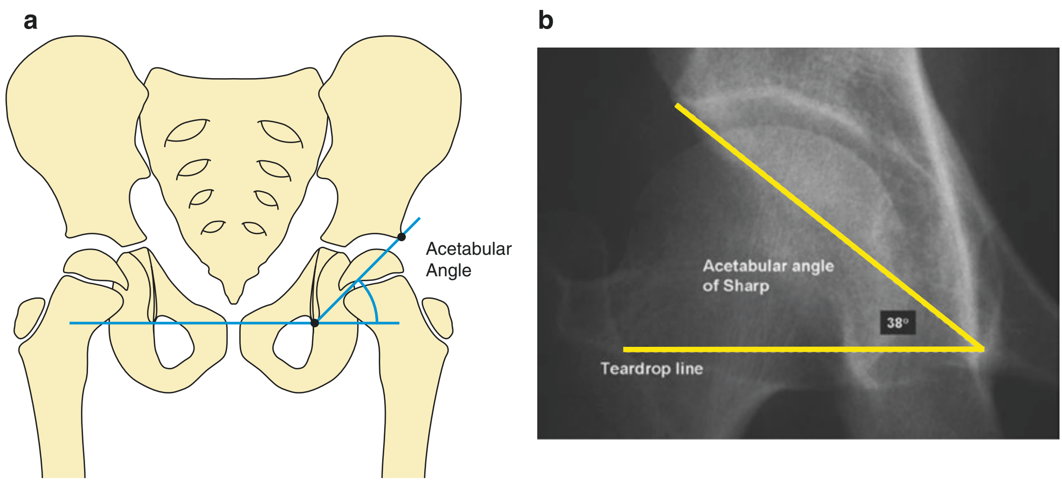

Fig. 11.9 **Acetabular angle**. This measures the slope of the acetabulum—diagram (**a**) and on radiograph (**b**). It is an uncommonly used measurement in the paediatric population

Reproducibility/Variation

Carney et al. (2005) indicates that few studies in the literature have addressed the reliability of the acetabular angle (in the child). Agus et al. (2002) analysed two methods. In the classic method, which was also used by Carney et al. (2005) the angle was measured from the inferior tip of the teardrop to the lateral edge of the bony acetabular roof. In the modified method, the angle was measured from the inferior tip of the teardrop to the most lateral portion of the subchondral bone condensation (the lateral aspect of the sourcil). In Carney's study the mean acetabular angle was in the abnormal range. They concluded that this was probably because normal acetabular angle values have been reported for patients with closed triradiate cartilages only, whereas their study was in children and hence with open triradiate cartilages. It is highly reproducible if applied after the age of 8. Carney et al. found that both the interobserver and intraobserver reliability of the measurement was good but would not recommend using it in preference to the acetabular index. Tan et al. (2001) found this angle reliable in intraobserver comparisons but not in interobserver comparisons.

Clinical Relevance/Implications

It has been put forward as another measurement in the assessment of developmental dysplasia and monitoring response to treatment but has not found universal acceptance in those with open triradiate cartilage often because of difficulty in readily identifying the inferior most tip of the teardrop on which an accurate measurement is dependent (Tan et al. 2001). It is also noteworthy that the teardrop does not appear on the radiograph until between 6 and 24 months and hence this measurement is difficult to perform in the very young.

Analysis/Validation of Reference Data

Little reference data on this measurement in the growing hip.

Conclusion

Uncommonly used measurement in the paediatric population.

11.6 The Iliac Angle and the Iliac Index

Definition

The iliac angle is a measure of the slope of the lateral margin of the iliac bone. The iliac index is the sum of both the AI and Iliac angles divided by two.

Normal iliac angle	55° (44–66)	Abnormal iliac angle	44° (30–56)
Normal index	> 78° (65–97)	Abnormal index	< 60° (49–78)

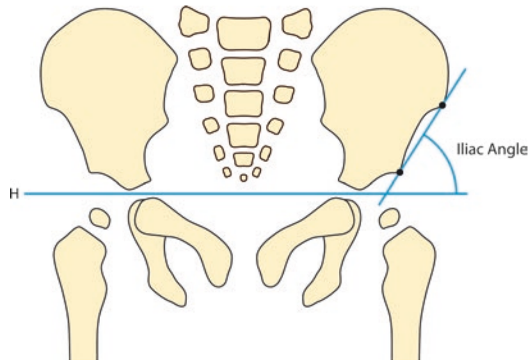

Fig. 11.10 **Iliac angle**. This a measure of the slope of the lateral margin of the iliac bone

Indication

It may be an indicator of underlying chromosomal abnormality (Caffey and Ross 1958; Astley 1963).

Techniques

Radiography: AP radiograph of pelvis.

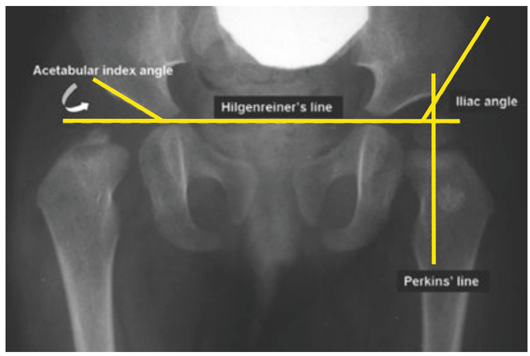

Fig. 11.11 AP pelvic radiograph. The **iliac index** is the sum of both the AI and iliac angles bilaterally divided by 2

Full Description of Technique

On the AP radiograph, the iliac angle is formed between Hilgenreiner's line and an oblique line joining two points of the ilium, that is, the most lateral point of the iliac wing above and the supero-lateral margin of the ossified acetabulum (Fig. 11.10).

The iliac index is a combination of the iliac angle and the acetabular angle of the growing hip (the acetabular angle of the growing hip being equivalent to the acetabular index). The iliac index is the sum of both the iliac angles and acetabular values bilaterally divided by 2 (Fig. 11.11).

Reproducibility/Variation

Few studies are available on reproducibility of this measurement.

Clinical Relevance/Implications

Astley studied 106 normal children from 0 to 8 years and 34 children in whom there was a clinical question of Down's syndrome. If the iliac index was less than 60, Down's syndrome was considered very possible. If the index measured more than 78, the child was probably normal.

With the advent of ultrasound and more sophisticated imaging methods, for assessment of Down's syndrome and other chromosomal disorders, and of course the advances in chromosomal analysis, the significance of this index has reduced.

Analysis/Validation of Reference Data

The iliac index, depending on its value, is potentially a contributory finding in chromosomal disorders, but no value is diagnostic.

Conclusion

Prenatal diagnosis of many chromosomal disorders can now be made, and postnatal chromosomal analysis obviates the need to use this index for assistance with diagnosis. However, it may be an additional observational finding in such conditions.

11.7 Alpha Angle (Graf US Angle)

The Graf angles are drawn relative to the iliac line, acetabular roof and labrum, in the true coronal plane.

Definition

The alpha angle is indicative of the slope of the bony acetabulum. This angle is a measure of the depth of the acetabulum and is an indicator of acetabular coverage as determined on ultrasound using the method of Graf (1980, 1984, 1987).

Normal	Abnormal
>60°	<50°

Indication

Evaluation of developmental hip dysplasia in newborns with clinical suspicion of instability. Most agree that in the presence of risk factors, US examination is best performed when an infant is 4–6 weeks old. Risk factors include mainly breech presentation, positive family history and oligohydramnios, talipes, arthrogryposis, spinal dysraphism, generalised ligamentous laxity, twins and postnatal saddling. The clinically unstable hip must be examined at 1–2 weeks of age. Infants with clinically stable hips presenting with a click should be examined at 2–4 weeks of age.

Techniques

Ultrasound: Coronal image of the hip.

Full Description of Technique

The high-frequency linear transducer should be placed on the lateral aspect of the hip joint while the infant is placed in the lateral decubitus position with the thigh flexed by 20° and slightly internally rotated. A coronal image of the hip is obtained by scanning longitudinally from this lateral approach so that the line of the ilium is parallel to the transducer. The true coronal plane shows both the femoral head and the deepest portion of the acetabulum. The basic line is drawn parallel to the straight lateral margin of the ilium.

The alpha angle is the angle between a line extended from the lateral line of the ilium (the iliac line) and a line tangent to the bony acetabular roof (Fig. 11.12).

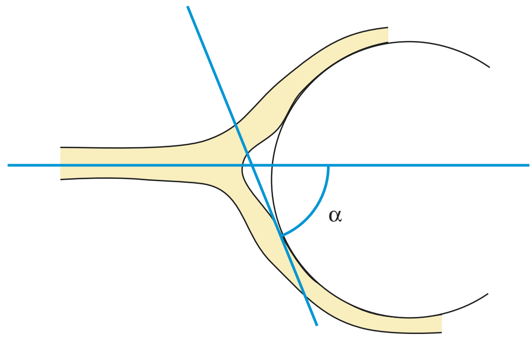

Fig. 11.12 The **alpha angle**, measured on ultrasound, is indicative of the slope of the bony acetabulum and is a measure of the depth of the acetabulum

Reproducibility/Variation

Dias et al. (1993) evaluated interobserver and intraobserver agreement with respect to interpretation of static images and found that the alpha angle had only a fair degree of reproducibility in both inter- and intraobserver comparisons. The range of interobserver measurements of the beta angle was much wider than the intraobserver range. Cheng et al. (1994) found the alpha angle to be the most reliable of the static measurements. Bar-On et al. (1998) found intraobserver reproducibility to be good but interobserver agreement only moderate. Rosendahl et al. (1995) found high intraobserver agreement in morphology on a static scan, whereas interobserver agreement was moderate. However, there was moderate interobserver agreement in determining hip stability. It was found that interobserver and intraobserver agreement in reproducing the scans was poorer than for interpreting them. They emphasise the need for substantial training and close attention to detail in order to obtain high interobserver agreement. Simon et al. (2004) found a high variability of the alpha and beta angles between observers for the same sonogram.

Clinical Relevance/Implications

US is the most widely used method for confirming a clinically suspected DDH and is the primary imaging technique for diagnosis and its follow-up. US alone cannot be considered a more reliable tool compared with physical examination. The surgical treatment rate did not decrease significantly in newborns screened with US compared to those who had clinical examination alone, but the non-surgical treatment rate was almost double in the US-screened group suggesting variable reliability.

The Graf classification is related to both the alpha and the beta angle. The alpha angle should be 60° or more. An angle <50° implies deficient development of the acetabulum at any age. A shallow acetabulum (between 50°and 60°) in a baby less than 3 months may simply reflect physiological immaturity (Graf type IIa) (Graf 1984; Millis and Share 1992; Gerscovich 1997a, b) but needs to be followed up to ensure normal development. A persistently shallow acetabulum after 3 months of age is abnormal. Quantitative measurements at one point in time are clearly important, but equally or even more important are the serial changes over time. Calculation of the alpha (or beta) angle cannot be made if the femoral head is dislocated anteriorly or posteriorly as the femoral head and the standard plane of the acetabulum are not visualised together (Fig. 11.13).

Analysis/Validation of Reference Data

There is wide variability in the degree of interobserver and to a degree of intraobserver reproducibility. Of the studies reviewed, no major misdiagnoses were made, and the important thing is that trends were identified correctly even if there was variability in actual figures measured. The diagnostic accuracy of US imaging for DDH in the screening population has not been investigated thoroughly (Roposch et al 2006). There is not sufficient evidence to support or reject a general US screening of newborns for DDH.

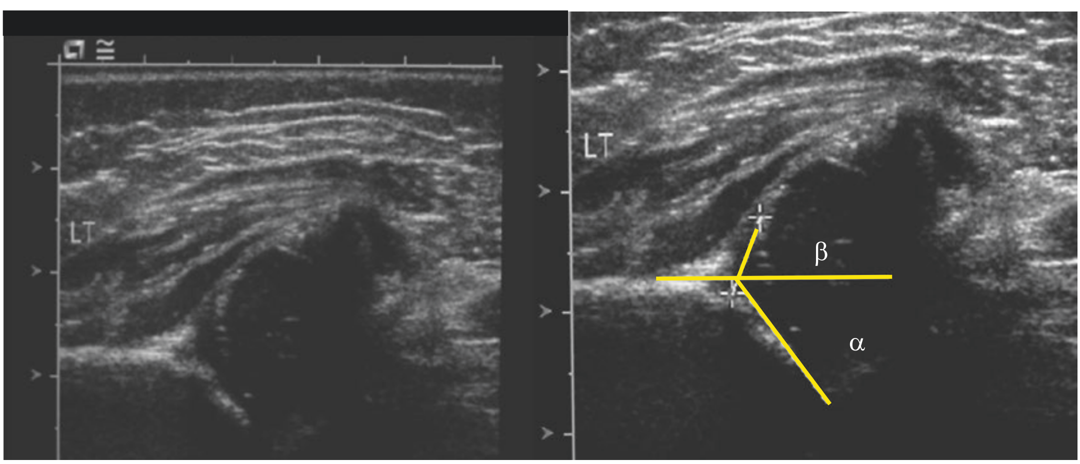

Fig. 11.13 US images done in the true coronal plane for calculating Graf's alpha and beta angles

Conclusion

Ultrasound is a satisfactory method for the diagnostic evaluation of hip dysplasia and is especially valuable if done on a serial basis to monitor improvement and response to treatment. Close attention to detail is necessary together with a good basic training in the application and frequent use to maintain skills. It is not yet clear if DDH detected by screening US is clinically relevant. Further studies on the best strategy for US screening are needed.

11.8 Beta Angle (Graf US)

Definition

The beta angle is the angle formed between a line drawn tangent to the lateral aspect of the femoral head and the iliac line (Fig. 11.14). It is indicative of the degree of fibrocartilaginous roof coverage through the labrum.

Normal	Immature	Abnormal
<55°	55°–77°	>77°

An increased beta angle indicates superior femoral head displacement and is used in subclassifying the dysplasia.

Indication

Used in the assessment of developmental dysplasia of the hip.

Techniques

Ultrasound: Coronal image of the hip.

Full Description of Technique

A coronal image of the hip is obtained by scanning longitudinally from a lateral approach so that the line of the ilium is parallel to the transducer. The true coronal plane shows the femoral head and the deepest portion of the acetabulum.

The beta angle is the angle between the iliac line and a line tangent to the lateral aspect of the femoral head. In practice, the beta angle is not as frequently used as the alpha angle and the percent coverage of the femoral head (Millis and Share 1992).

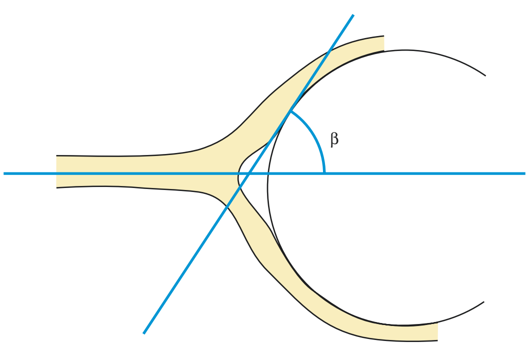

Fig. 11.14 The **beta angle**, as measured on ultrasound, is indicative of the degree of cartilaginous roof coverage

Reproducibility/Variation

See under Sect. 11.7.

Clinical Relevance/Implications

It is normal when <55°. An angle >77° is usually associated with subluxation and labral displacement. A value between 55°and 77° is associated with an immature hip. The beta angle together with the alpha angle contributes to the Graf classification of hip morphology and acetabular development (Graf 1984; Gerscovich 1997a, b).

Analysis/Validation of Reference Data

The beta angle is not as reproducible as the alpha angle. In the different studies, it is not used as much as the alpha angle.

Conclusion

The beta angle is not used to the same degree in analytical studies and during ultrasound assessment. It is probably more usual that the alpha angle or femoral head coverage will be measured. A full assessment will of course include this measurement.

11.9 Acetabular Coverage of the Femoral Head (US)

Definition

The relative percentage of coverage of the femoral head by the bony acetabulum (Morin et al. 1985).

Normal	Abnormal
50–58% coverage	<33% coverage

Indication

Assessment of developmental dysplasia of the hip.

Technique

Ultrasound: Coronal view—longitudinal scan from lateral approach.

Full Description of Technique

The US transducer is positioned on the lateral aspect of the flexed hip with the plane parallel to the long axis of the body and parallel to the line of the ilium. A coronal image of the hip is obtained by scanning longitudinally from a lateral approach so that the line of the ilium is parallel to the transducer. The true coronal plane shows the femoral head and the deepest portion of the acetabulum. The sonographic acetabular coverage of the femoral head is expressed as the percentage of femoral head coverage which is the depth between the iliac line and the medial aspect of the femoral head divided by the maximum diameter of the femoral head × 100 (Morin et al. 1985) (Fig. 11.15). The technique was introduced by Morin and further developed by Terjeson et al. (1989). It is based on the same principle as the radiographic migration percentage (MP) (Gerscovich 1997a, b). Values are not related to the patient's age.

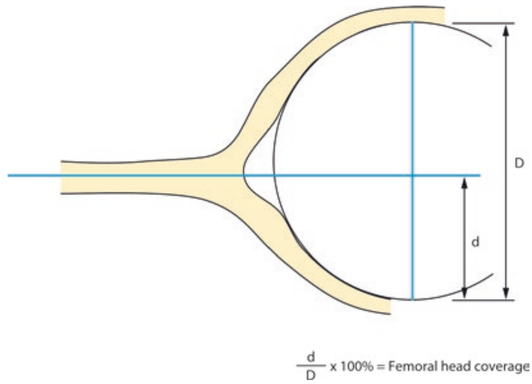

Fig. 11.15 The **acetabular coverage** of the femoral head as measured on ultrasound is the relative percentage of coverage of the femoral head by the bony acetabulum

Reproducibility/Variation

A study in 1994 (Holen et al. 1994) demonstrated moderate interobserver variation in evaluation of the femoral head coverage. The 95% confidence limit (±2 SDs) was ±8%. A study by Falliner in 2006 to determine the reproducibility of ultrasound measurements using the methods of Graf and Terjesen was done. This showed a mean alpha angle of 62.4° and mean femoral head coverage (FHC) of 55.4%. Statistical analysis showed almost equal reproducibility for alpha angle and FHC in the interobserver test but better repeatability for Graf's method (alpha angle) in the intraobserver test.

Clinical Relevance/Implications

There is varied opinion about what is normal. Holen et al. (1994) suggested that femoral head coverage of more than 50% should be considered normal. This is in agreement with Millis and Share (1992). However, Morin et al. (1985) suggested 58% or more femoral head coverage to be normal, while 33% is an absolute indicator of dysplasia. Terjesen (1996) also found this to be a rapid and reliable technique for the evaluation of hips in children under 2 years.

Analysis/Validation of Reference Data

Morin devised this method of assessment as an alternative method to the Graf technique as some people may find it easier.

Conclusion

Reproducible and considered by some easier to use than alpha and beta measurements in the assessment of developmental dysplasia of the hip.

11.10 Femoral Head Displacement in DDH (Yamamuro's Distances and Smith's Ratios)

Definition

Measurements of the lateral and superior displacement of the femoral head.

Indications

Developmental dysplasia of the hip.

Technique

Radiography: AP radiograph.

Full Description of Technique

A series of measurements produce the **Yamamuro's distances and Smith's ratios** to assess displacement (Yamamuro and Chene 1975, Smith et al 1968)**.**

Linear Measurements of Superior Femoral Displacement

Normal Values

Yamamuro-A distance. This is the distance in mm between the middle point of the proximal femoral metaphysis and the Hilgenreiner's or Y-Y line. The range of normal values for infants of **1 month to 4 years of age is 7–14 mm.**

Hilgenreiner-H distance. This is the distance between the highest point of the proximal femoral metaphysis and the Y-Y line. The normal value is **8–10 mm**.

h/b ratio. This is the ratio of the distance between the highest point of the femoral metaphysis and the Y-line and the distance between Perkins' line and a parallel line passing through the centre of the sacrum. The normal value for infants of **2–5 years of age is 0.10–0.20.**

Abnormal Values

h/b ratio: 0 to − 7.

Linear Measurements of Lateral Femoral Displacement

Normal Values

Yamamuro-B distance. This is the distance in mm between the middle point of the proximal femoral metaphysis and a line, perpendicular to the Y-line, which passes through the lateral edge of the ischium. The normal value for children of **1 month to 4 years of age is 5–12 mm.**

Hilgenreiner-D distance. This is the distance in mm between the inferior bony margin of the ilium and the projection on the Y-line of the high-

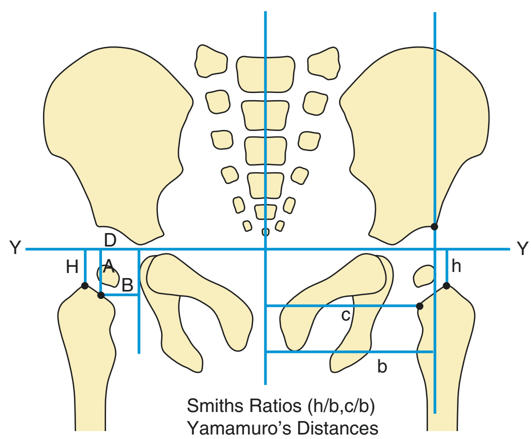

Fig. 11.16 **Yamamuro's** distances and **Smith's** ratio for linear (superior/lateral) displacement of the femoral head

est point of the proximal femoral metaphysis. Normal value is **14–16 mm**.

c/b ratio. This is the ratio of the distance between the medial beak of the proximal femoral metaphysis and the centre line and the distance between Perkins' line and the centre line. The normal value for infants of **2–5 years of age is 0.60–0.85.**

Abnormal Values

c/b ratio > 0.9.

Reproducibility/Variation

Yamamuro's measurements for linear displacement of the femoral head are accurate and less influenced by femoral rotation.

Smith's ratios are reliable. The use of a ratio reduces the effects of magnification.

Clinical Relevance/Implications

The measurements are useful to follow patients with DDH during treatment for normal development of the acetabulum (Fig. 11.16).

Conclusion

The measurements are a reliable indicator with an accurate performance rating between different observers.

11.11 Migration Percentage (MP) (Reimer's Index)

Definition

This was introduced by Mercer Rang in 1975 (Reimers 1980, Gerscovich 1997a, b). This indicates the percentage of the femoral head that is located lateral to the lateral edge of the acetabulum, i.e. lateral to Perkins' line. It is based on the same principle as the acetabular coverage of the femoral head as measured with ultrasound but essentially is measured as the percentage 'uncovered' femoral head. The remaining percentage represents the percentage femoral head coverage.

Normal	< 3 years	0%
	3–14 years	12% (0–20%)
Subluxation		33–100%

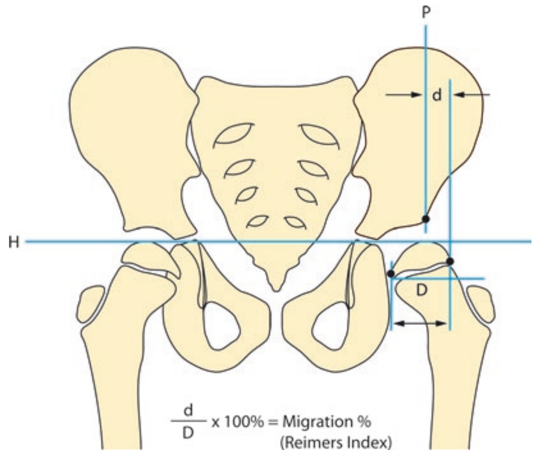

Fig. 11.17 The **migration percentage** (Reimer's index) indicates the percentage of the femoral head that is located lateral to the lateral edge of the acetabulum

Indication

Reimer's index is used to determine the extent of subluxation of the hip in children with spasticity. It measures the degree of lateral acetabular deficiency. The migration percentage is also used in the assessment of subluxation/lateralisation in developmental dysplasia.

Techniques

Radiography: AP radiograph.

Full Description of Technique

On an AP radiograph, the migration percentage is defined by $d/D \times 100\%$, where d is the distance from the lateral aspect of the femoral head to Perkins' line divided by D, the diameter of the femoral head parallel to Hilgenreiner's line (Gerscovich 1997a, b) (Fig. 11.17).

Reproducibility

Faraj et al. (2004) reporting on inter- and intra-measurer error in the assessment of Reimer's (1980) hip migration percentage found no statistical difference between the intra-sessional median absolute differences but found inter-measurer errors which may be clinically unacceptable. The two measurers however only had 6 months paediatric orthopaedic experience which may have contributed to the relatively sub-optimal results.

Clinical Relevance

A migration index of more than 20% is considered to be abnormal (Moberg et al. 1999). Gerscovich states that normal values for children less than 3 years old should be zero and for older children 12% (range 0–22%) (1997a, b).

Analysis/Validity of References

Parrott et al. (2002) believed that the results are acceptable in clinical practice provided treatment decisions are based on a series of radiographs taken at 6 month intervals, methods and training are standardised and consistent raters are used.

Conclusion

A valuable and useful measurement in follow-up of patients both pre- and postsurgical intervention.

11.12 Femoral Head Coverage

Definition

This is determined by calculating the percentage of the femoral head medial to Perkins' line in relation to the width of the femoral head parallel to Hilgenreiner's line (Wiig 2002) (Fig. 11.18). It was described by Heyman and Herndon in 1950 as the acetabulum-head quotient. It is based on the same principle as the acetabular coverage of the femoral head as measured with ultrasound.

Normal	Abnormal
70–80%	<70%

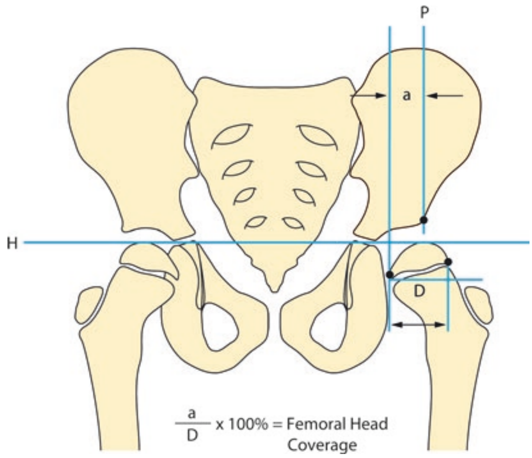

Fig. 11.18 The femoral head coverage as measured on a radiograph

Indication

It is useful in the assessment of the hip in Perthes disease and also in the assessment of femoral head coverage in hip dysplasia.

Technique

Radiography: AP radiograph.

Full Description of Technique

On an AP radiograph, the femoral head coverage is the width of the femoral head medial to Perkins' line divided by the width of the femoral head × 100 (Fig. 11.18).

Reproducibility

Femoral head coverage radiographically shows small interobserver variability, and there is even less variability when examiners are experienced. It is probably more reliable than the centre-edge angle for inexperienced examiners (Wiig 2002).

Clinical Relevance

The lower normal limit of femoral head coverage is 80% as shown by Wiig (2002), but Heyman and Herndon (1950) reported 70% in normal hips.

Validity of References

A relatively reliable and reproducible measurement for assessing femoral head coverage and containment.

Conclusion

Some assessors find this to be an easier measurement to perform than the centre-edge angle.

11.13 The Centre-Edge Angle (Wiberg's Angle)

Definition

The centre-edge angle of Wiberg (1939) is the angle between a line drawn from the centre of the femoral head to the supero-lateral ossified margin of the acetabulum and a line drawn from the centre of the femoral head perpendicular to Hilgenreiner's line joining the triradiate cartilages of the acetabula (Fig. 11.19).

Normal	< 5 years	Unreliable
	5–8 years	> 20°
	9–12 years	> 25°
	13–16 years	26°–30°

Indication

Assessment of developmental dysplasia of the hip and other situations where knowledge of acetabular depth is required.

Technique

Radiography: AP radiograph of pelvis.

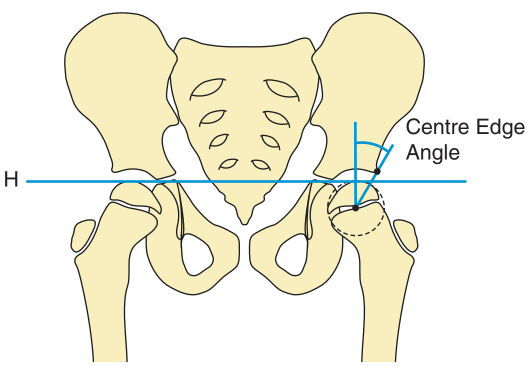

Fig. 11.19 The **centre-edge angle** of Wiberg

Full Description of Technique

On a well-positioned pelvic radiograph, Hilgenreiner's line (a horizontal line joining the triradiate cartilages of both acetabula) is drawn. The centre of the femoral head is determined, and from this two lines are drawn—one to the lateral bony edge of the acetabulum and one perpendicular to Hilgenreiner's line. The angle formed between these two lines is the centre-edge angle.

Reproducibility/Variation

In Tan's study (2001) which looked at 30 pelvic x-rays of 15 patients with an age range of 3–36 months (mean 26 months), there was no significant difference according to intraobserver reliability analysis. However, analysis of interobserver reliability showed significant differences. Differences in interobserver reliability in the very young may be due to difficulty in identifying the centre point of the unossified femoral head. Finding the centre point even in the stage of early ossification of the femoral head can be difficult (Tan et al. 2001) due to an eccentrically located ossific nucleus. Scoles et al. (1987) recommended that this angle should only be used after the age of 4 years, and Broughton suggested after 5 years (1989). Wiig et al. (2002) showed a low interobserver agreement for both normal hips and those affected by Perthes disease. They found better agreement between more experienced examiners when measuring the CE angle in patients over the age of 5 years than under it.

Clinical Relevance/Implications

Useful in older children in evaluating cases of minor dysplasia. At 5–8 years, the lowest normal limit is 19°; from 9 to 12 years the lowest limit is 25°, at 13–16 years 26–30° and

17–20 years 26–30° (Tönnis 1976). If the C-E angle is low, this may indicate dysplasia. If it is abnormally high, this may indicate protrusio acetabuli.

Analysis/Validation of Reference Data

It has been suggested that the centre-edge angle should be measured from the lateral most point of sclerosis in the roof of the acetabulum in this young age group rather than following the original method of Wiberg (Ogata et al. 1990). Kim et al. evaluated the lateral edge of the acetabulum to locate the most accurate marking point on a plain radiograph when measuring both the centre-edge angle and the acetabular index (Kim et al. 2000). They found that the most lateral bony margin of the acetabular roof on plain radiographs represents the anterolateral portion of the acetabulum, whereas the lateral end of the sourcil indicates the lateral margin of the superior portion of the acetabulum. In order to reduce the margin of intraobserver and interobserver error, it is important to indicate clearly which of the measuring points has been used and to remain constant in this when making and comparing measurements in individual patients, as there is quite a marked difference between the two depending on which point has been taken as the lateral marker.

Milani et al. (2000) described a technique for measuring Wiberg's angle in infants under the age of 3 months using sonographic images of their hips. Sonographic images were transferred to a computer where the images were analysed, and software provided the acetabular cartilaginous roof coverage angle (CRCA) which corresponds to the CEA angle in adults.

Conclusion

An appropriate measure for assessing femoral head coverage but only when measured by experienced examiners (Wiig 2002) due to difficulty in identifying the centre of the femoral head when it is incompletely ossified.

11.14 The Teardrop Distance

Definition

This is the distance from the lateral margin of the teardrop to the medial border of the proximal femoral metaphysis (Fig. 11.20).

Normal	Abnormal
<11 mm	>11 mm
Or >2 mm than contralateral side	

Indication

An indicator of hip joint disease and useful particularly in the early detection of Perthes disease. One of the earliest signs of Perthes disease is a widening of the teardrop distance (TDD).

Technique

Radiography: AP pelvis.

Full Description of Technique

AP radiograph. It is important that the femora/hips are not rotated internally or externally >30°, flexed more than 30° or abducted >15°. This is the distance from the lateral margin of the teardrop to the medial border of the proximal femoral metaphysis.

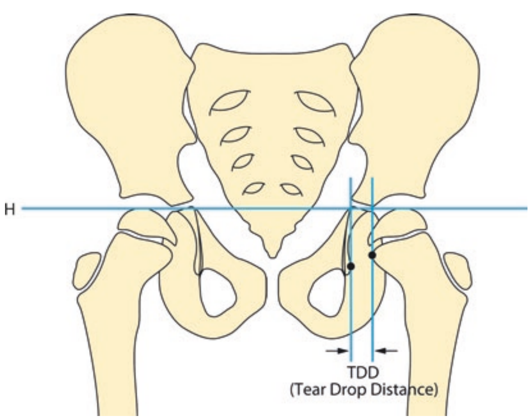

Fig. 11.20 The **teardrop** distance

Reproducibility/Variation

Eyring measured the teardrop distance on radiographs of 1070 normal hips of persons from 1 to 11 years old. He found the measurements were reproducible within 1 mm and were independent of the age of the patient (Eyring et al. 1965).

The teardrop distance is effectively measuring the medial joint space. Kaniklides and Dimopoulos (1996) suggested that the medial margin of the metaphysis and the medial boundary of the acetabulum as landmarks were not reliable measuring points for estimating subluxation in Perthes disease as they may be affected and deformed due to the disease and they may alter due to femoral or pelvic rotation. Katz (1969) however found that neither flexion nor extension of the pelvis significantly altered the teardrop figure, although pelvic rotation caused it to broaden.

Clinical Relevance/Implications

If the teardrop distance is >11 mm or more than 2 mm greater than that of the opposite hip, this is a sensitive indicator of hip joint disease, e.g. Perthes in the growing hip. It can also be indicative of the presence of a joint effusion.

Analysis/Validation of Reference Data

The teardrop does not appear until between 6 and 24 months of age in a normal hip and later in a dislocated hip. It is variable as regards its configuration in normals and can be dependent on a neutral position without rotation or inclination.

Conclusion

Based on Eyring's findings in 1070 children, it can be a sensitive indicator of early Perthes disease.

11.15 Medial Hip Joint Space

Definition

This is the distance from the medial aspect of the ossification centre of the femoral head at its widest portion, or from the medial aspect of the metaphysis when the femoral head is not ossified, to the adjacent acetabular wall (Gerscovic 1997) (Fig. 11.21).

Normal	Abnormal
5–12 mm	>12 mm
<1.5 mm between Rt and Lt	>1.5 mm between Rt and Lt

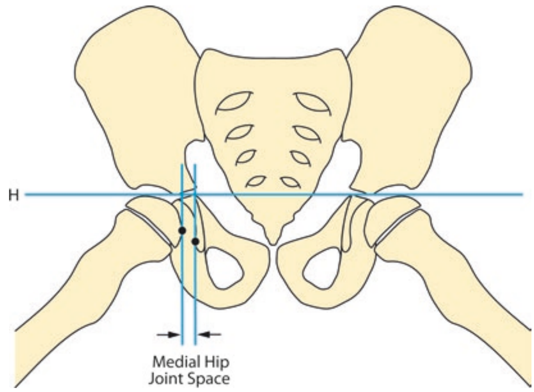

Fig. 11.21 The medial hip joint space

Indication

It evaluates for lateral displacement of the femoral head. Abnormality may indicate underlying hip pathology: if narrow, arthropathy, and if widened, possible effusion in children or early sign of Perthes disease.

Technique

Radiography: Measured on the frog lateral view (hips abducted and internally rotated).

Full Description of Technique

Radiography. Well-positioned frog lateral projection of the hips. Utilising Hilgenreiner's line, drop a perpendicular through the medial aspect/margin of the femoral head and through the lateral border of the teardrop. The distance between is the medial hip joint space measurement (equivalent to the teardrop distance of Eyring et al. 1965).

Reproducibility/Variation

Normal values are age independent and range from 5 to 12 mm. The difference between the right and left sides should not be more than 1.5 mm (Eyring et al. 1965). Kaniklides and Dimopoulos (1996) looked at AP radiographs and arthrograms of both hips on the same film with the legs in neutral position. The migration percentage (MP) was expressed as the fraction of the width of the femoral head extending beyond the acetabular edge. Kaniklides measured the medial joint space (MJS) from the medial border of the bony femoral head or femoral head cartilage on the arthrogram to the lateral border of the acetabular teardrop. This contrasted with Eyring. Kaniklides stated that the medial aspect of the metaphysis could become distorted due to underlying pathological processes and distort the metaphyseal beak leading to inaccurate measurement.

Kaniklides found a high interobserver agreement for both the medial joint Space (MJS) and the migration percentage (MP). He looked at 166 normals and 37 affected hips of patients with unilateral Perthes and 37 contralateral hips and therefore 240 in total. The lateral margin of the teardrop can be poorly defined in the dysplastic hip (Broughton et al. 1989) which may lead to difficulties in measurement.

Clinical Relevance/Implications

An abnormal medial hip joint space may indicate underlying joint disease or insult to the femoral head.

Analysis/Validation of Reference Data

This can be a difficult measurement to reproduce in some disease processes. In some situations, such as Perthes disease, to assess containment, the migration percentage may be more valuable.

Conclusion

May be valuable. If the joint space is widened and no obvious evidence of Perthes may indicate an effusion and suggest further assessment with ultrasound to confirm or further imaging, for example, with magnetic resonance imaging.

11.16 Symphysis Pubis Width

Definition

The width of the symphysis pubis.

Normal	Abnormal
<10 mm	>10 mm

Indication

To identify if abnormally widened. A number of conditions are associated with widening of or defective ossification of the symphysis pubis.

Due to bone growth and ossification of cartilage, the interpubic distance varies with age.

Technique

Radiography: An abdominal or pelvic radiograph can be used. Patel and Chapman (1993) found that there was no difference in the measurement whether one used a centring point at the level of the iliac crests or one 5 cm above the symphysis pubis as used in a pelvic radiograph.

The transverse width of the symphysis is measured to the nearest millimetre at its narrowest point (Fig. 11.22).

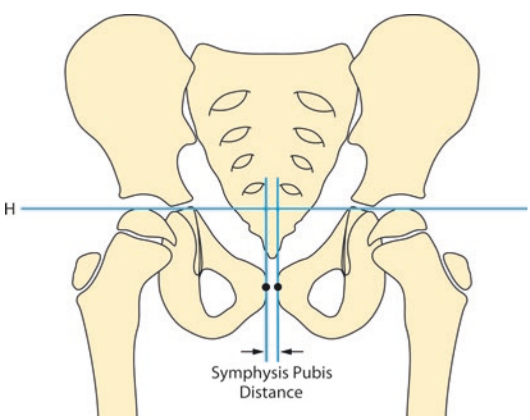

Fig. 11.22 The **symphysis pubis** distance. This is the transverse width of the symphysis measured to the nearest millimetre at its narrowest point

Reproducibility

Patel and Chapman (1993) examined 888 radiographs over an age range of birth to 16 years. Their findings were in broad agreement with the findings of Muecke and Currarino (1968). Ten mm as the upper limit of normal agreed with data from Heyman and Lundquist (1931). The mean width at 16 years is similar to that of Vix and Ryu (1971) in their study of 400 adults.

Clinical Relevance

Separation of the symphysis may be an important clue to an underlying condition in the paediatric age group. This may be divided into congenital and acquired conditions. Congenital disorders may be due to defective ossification or with normal ossification.

Analysis of Reference data

No significant areas of conflict.

Conclusion

A simple to perform measurement which, if widened, is a useful finding in relation to making an underlying diagnosis.

11.17 Klein's Line

Definition

This is a line drawn along the superior surface of the femoral neck. The epiphysis should normally project superior to it (Fig. 11.23), and the line laterally cuts off about 15% of the femoral epiphysis (Klein et al. 1951).

Indication

It is used in assessment of early slipped upper femoral epiphysis. In early slipped upper femoral epiphysis (SUFE), the epiphysis lies flush or level with the line. As slip continues, the epiphysis moves posterior and inferior to it.

Techniques

Radiography: AP radiograph of the pelvis centred approximately 1 cm above the symphysis pubis. The projection must be produced accurately, and the patella should face forward exactly parallel to the x-ray table. If this is not possible clinically on the affected side, the pelvis should be elevated on the affected side.

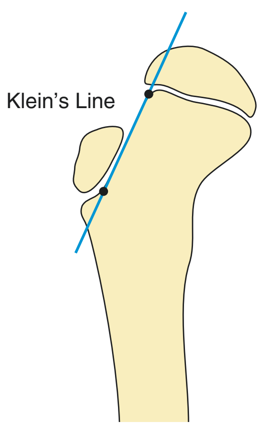

Fig. 11.23 **Klein's line** should pass through the femoral epiphysis laterally. A difference of 2 mm with the contralateral side indicates a slip

Full Description of Technique

On an AP radiograph, a line is drawn along the superior surface of the femoral neck. In the normal situation, this will extend through the superior aspect of the epiphysis (the epiphysis should normally project superior to it).

Reproducibility/Variation

Green et al. (2009) measured the head-shaft angle of Southwick and the Wilson percent epiphyseal displacement and evaluated the interobserver and intraobserver reliability and efficacy of these methods and also compared with Klein's line. They found that on the basis of the classical definition of Klein's line, only 40.3% of slips were identified. However, by modifying Klein's line such that they measured the width of epiphysis lateral to Klein's line, they improved sensitivity to 79% if a difference of 2 mm between hips indicated a slip.

Clinical Relevance/Implications

If the epiphysis lies level or inferior to Klein's line, there has been epiphyseal slip.

Analysis/Validation of Reference Data

Early or mild degrees of slip may be difficult and can be overlooked. Clinically if a slipped upper femoral epiphysis (SUFE) is suspected and Klein's line appears normal, the head-shaft angle of both hips should be measured to better evaluate for possible SUFE.

Conclusion

Application of Klein's line can be difficult in mild cases of slipped upper femoral epiphysis.

11.18 Femoral Neck-Shaft Angle

Definition

The angle formed between a line drawn parallel to the femoral neck and one drawn parallel to the long axis of the femoral shaft (Fig. 11.24).

Normal	3 years 145°	Coxa vara	< 125°
Adult	128° (125–135)	Coxa valga	> 135°

Indication

The amount of a varus deformity can be measured.

Technique

Radiography: AP radiograph.

Full Description of Technique

On an AP radiograph of the pelvis with the hips in neutral position, a line is drawn along and parallel with the femoral neck passing through the centre of the femoral head. A second line is drawn along and parallel to the femoral shaft. The femoral neck-shaft angle is the angle subtended between these two lines (Fig. 11.24).

Reproducibility/Variation

There is broad individual variation with a wide standard deviation in this angle (Tönnis 1976; Broughton et al. 1989).

Clinical Relevance/Implications

This normally measures 145° at 3 years of age, decreasing to between 125°and 135°in the adult with an average value of 128°.

Analysis/Validation of Reference Data

There is an intrinsic variability of the measurement between individuals.

Conclusion

Useful and straightforward measurement in the evaluation of varus deformity.

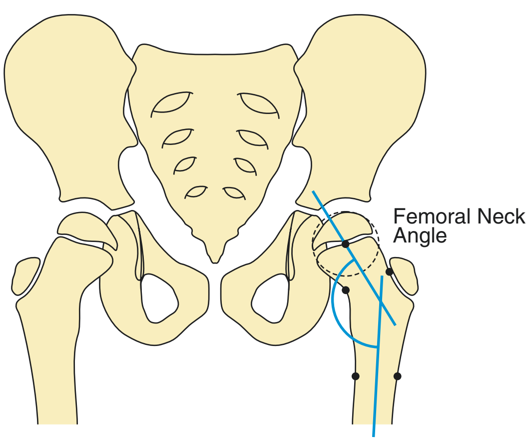

Fig. 11.24 The **femoral neck-shaft** angle

11.19 Epiphyseal-Shaft Angle of Southwick

Definition

This is the angle subtended between a perpendicular line to the epiphyseal line drawn along the femoral neck and one drawn along the femoral shaft. It is measured for both sides, and the difference between the two is the magnitude of slip severity.

Indication

This is used to describe the radiographic magnitude of epiphyseal slip severity in cases of slipped upper femoral epiphysis (SUFE).

Technique

Radiography: The angle is measured on the frog lateral radiograph of the pelvis.

Full Description of Technique

The angle is measured on the frog lateral radiograph of the pelvis. A line is drawn between the anterior and posterior tips of the epiphysis at the physeal plate level. A perpendicular line is drawn to this epiphyseal line through the femoral neck.

A line is then drawn along the mid femoral shaft.

The epiphyseal-shaft angle is the angle formed by the intersection of the perpendicular line and the femoral shaft line (Fig. 11.25). It is measured for both hips, and the magnitude of slip displacement is the angle of the involved hip minus the angle of a contralateral normal hip (Southwick 1967).

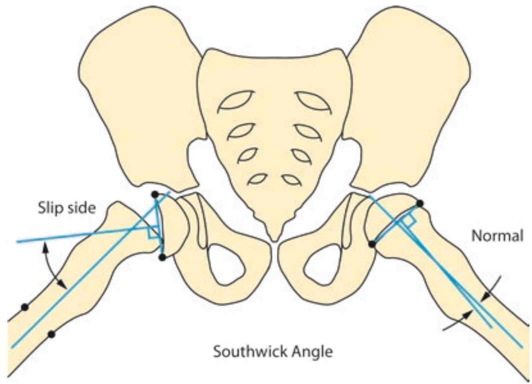

Fig. 11.25 The **epiphyseal-shaft angle** of Southwick

Reproducibility/Variation

In a study by Green et al. (2009), five separate observers on two separate occasions evaluated 30 AP and 30 frog lateral radiographs of patients with unilateral slipped capital femoral epiphysis (SCFE) for head-shaft angle, percent epiphyseal displacement and width of epiphysis lateral to Klein's line. Head-shaft angle and percent epiphyseal displacement were found to provide a reliable means of SCFE diagnosis.

Clinical Relevance/Implications

Normally the femoral neck axis is at 90° angle to the base of the epiphysis dividing into two equal halves. In the frog lateral projection, the base of the epiphysis is also normally perpendicular to the longitudinal femoral neck axis. The femoral head-shaft angle is used to identify the severity of slip in cases of slipped upper femoral epiphysis (SUFE). Using the measurement of this angle, a slipped upper femoral epiphysis is classified as mild if it less than 30°, moderate if it is between 30 and 50° and severe if it is more than 50°. If there is bilateral slipped upper femoral epiphysis, then 12° can be used as the control angle (Loder et al. 1999).

Analysis/Validation of Reference Data

Early or mild degrees of slip may be difficult and can be overlooked. Clinically if a slipped upper femoral epiphysis (SUFE) is suspected and Klein's line appears normal, the epiphyseal-shaft angle of both hips should be measured to better evaluate for possible SUFE.

Conclusion

The head-shaft angle of Southwick is valuable in evaluating the degree/severity of epiphyseal slip. Although it takes a bit longer to perform than the lateral slip angle of Wilson, its results are more reliable and reproducible.

11.20 Articulo-Trochanteric Distance (ATD)

Definition

The distance between the proximal femoral head and the greater trochanters.

Indications

Monitoring patients with Perthes disease.

Technique

Radiography: AP Radiograph

Full Description of Technique

The articulo-trochanteric distance (ATD) is measured between two lines perpendicular to Perkins' line: the line through the proximal tip of the greater trochanter and that through the most proximal point of the femoral head (Fig. 11.26).

Reproducibility/Variation

The level of interobserver agreement is high.

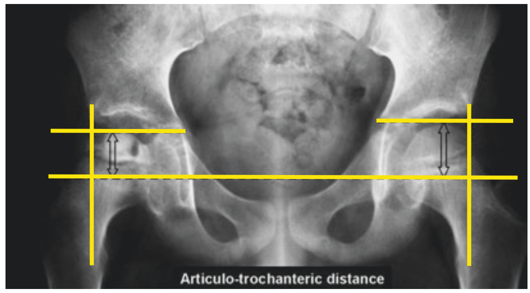

Fig. 11.26 **Articulo-trochanteric** distance is reduced on the right due to ischaemic necrosis

Clinical Relevance/Implications

The measurement is also applied for assessing the proper position of implants in various surgical procedures.

Analysis/Validation of Reference Data

Although the data is limited, the ATD showed good interobserver agreement with few interobserver differences.

Conclusion

The ATD is probably best utilised as a radiological measurement criterion in combination with other measurements in the follow-up assessment of Perthes disease such as CE angle and femoral head coverage.

References

Agus H, Bicimoglu A, Omeroglu H et al (2002) How should the acetabular angle of Sharp be measured on a pelvic radiograph? J Pediatr Orthop 22:228–231

Astley B (1963) Chromosomal abnormalities in childhood, with particular reference to Turner's syndrome and mongolism. Br J Radiol 36:2

Ball F, Kommenda K (1968) Sources of error in the roentgen evaluation of the hip in infancy. Ann Radiol (French) 11:299–301

Bar-On E, Meyer S, Harari G, Porat S (1998) Ultrasonography of the hip in developmental hip dysplasia. J Bone Joint Surg 80B(2):321–324

Boniforti FG, Fujii G, Anfliss RD, Benson MKD (1997) The reliability of measurements of pelvic radiographs in infants. J Bone Joint Surg (Br) 79-B:570–575

Broughton NS, Brougham DI, Cole WG, Menelaus MB (1989) Reliability of radiologic measurement in the assessment of the child's hip. J Bone Joint Surg 71-B:6–8

Caffey J, Ross S (1958) Pelvic bones in infantile mongolism. AJR Am J Roentgenol 80:458

Carney BT, Rogers M, Minter CL (2005) Reliability of acetabular measures in developmental dysplasia of the hip. J Surg Orthop Adv 14:73–76

Cheng JCY, Chan YL, Hui PW, Shen WY, Metreweli C (1994) Ultrasonographic hips morphometry in infants. J Pediatr Orthop 14:24–28

Dias JJ, Thomas IH, Lamont AC, Mody BS, Thompson JR (1993) The reliability of ultrasonographic assessment of neonatal hips. J Bone Joint Surg (Br) 75B(3):479–482

Edgren W (1965) Coxa plana. A clinical and radiological investigation with particular reference to the importance of the metaphyseal changes for the final shape of the proximal part of the femur. Acta Orthop Scand Suppl 84:1–129

Eyring EJ, Bjornson DR, Peterson CA (1965) Early diagnostic and prognostic signs in Legg-Calvé-Perthes disease. Am J Roentgenol Radium Ther Nucl Med 93:382–387

Falliner A, Schwinzer D, Hahne HJ, Hedderich J, Hassenpflug J (2006) Comparing ultrasound measurements of neonatal hips using the methods of Graf and Terjesen. J Bone Joint Surg (Br) 88B:104–106

Faraj S, Atherton WG, Stott NS (2004) Inter- and intra-measurer error in the measurement of Reimers hip migration percentage. J Bone Joint Surg (Br) 86:434–437

Gerscovich EO (1997a) A radiologist's guide to the imaging in the diagnosis and treatment of developmental dysplasia of the hip. I. Skelet Radiol 26:386–397

Gerscovich EO (1997b) A radiologist's guide to the imaging in the diagnosis and treatment of developmental dysplasia of the hip. II. Ultrasonography. Skelet Radiol 26:447–456

Graf R (1980) The diagnosis of congenital hip joint dislocation by the ultrasonic compound treatment. Arch Orthop Traum Surg 97:117–133

Graf R (1984) Classification of hip joint dysplasia by means of sonography. Arch Orthop Trauma Surg 102:248–255

Graf R (1987) Guide to sonography of the infant hip. Thieme, New York

Green DW, Mogekwu N, Scher DM (2009) A modification of Klein's line to improve sensitivity in slipped capital femoral epiphysis. J Pediatr Orthop 29:449–453

Harcke HT, Grissom LE (1990) Performing dynamic sonography of the infant hip. AJR Am J Roentgenol 155:837–844

Heyman CH, Herndon CH (1950) Legg-Perthes disease. J Bone Joint Surg Am 32:767–778

Heyman J, Lundquist A (1931) Symphysis pubis in pregnancy and parturition. Acta Obstetr Gynecol Scand 12:191–226

Hilgenreiner H (1925) Zur fruhdiagnose und fruhbehandlung der angeborenen Huftgelenkverrenkung. Med Klin 21:1385

Holen KJ, Terjesen T, Tegnander A et al (1994) Ultrasound screening for hip dysplasia in newborns. J Pediatr Orthop 14:667–673

Kaniklides C, Dimopoulos P (1996) Radiological measurement of femoral head position in Legg-Calvé-Perthes disease. Acta Radiol 37:863–869

Katada S, Ando K (1984) A roentgenographic evaluation of the indices for hip dysplasia in children influenced by pelvic tilt. In: Ueno R, Akamatsu N, Itami Y, Tagawa H, Yoshino S (eds) The hip: clinical studies and basic research. Elsevier Science, Amsterdam, pp 137–140

Katz JF (1969) Identification of the teardrop figure and acetabular margins on the roentgenogram. Clin Orthop 62:232

Kay RM, Watts HG, Dorey F (1997) Variability in the assessment of acetabular index. J Pediatr Orthop 17:170–173

Kim HT, Kim J II, Yoo C II (2000) Diagnosing childhood acetabular dysplasia using the lateral margin of the Sourcil. J Pediatr Orthop 20(6):709–717

Kitajima M, Mawatari M, Aita K et al (2006) A simple method to determine the pelvic inclination angle based on anteroposterior radiographs. J Orthop Sci 11:342–346

Klein A, Joplin RJ, Reidy JA et al (1951) Roentgenographic features of slipped capital femoral epiphysis. AJR Am J Roentgenol 66:361–374

Loder RT, Blakemore LC, Farley FA, Laidlaw AT (1999) Measurement variability of slipped upper femoral epiphysis. J Orthop Surg 7:33–42

Milani C, Ishida A, Filho JL, Dobashi ET (2000) A new methodology for the measurement of the Wiberg angle in infants under 3 months. J Pediatr Orthop 9: 108–113

Millis MB, Share JC (1992) Use of ultrasonography in dysplasia of the immature hip. Clin Orthop Relat Res 274:160–171

Moberg A, Hansson G, Kaniklides C (1999) Acetabulum-head index in children with normal hips.: a radiographic study of 154 hips. J Pediatr Orthop 8:268–270

Morin C, Harcke HT, MacEwen GD (1985) The infant hip: real time US assessment of acetabular development. Radiology 157:673–677

Muecke EC, Currarino G (1968) Congenital widening of the symphysis pubis. Associated clinical disorders and roentgen anatomy of affected bony pelves. AJR Am J Roentgenol 103:179–185

Ogata S, Moriya H, Tsuchia T, Kamegaya M, Someya M (1990) Acetabular cover in congenital dislocation of the hip. J Bone Joint Surg 72-B:190–196

Parrott J, Boyd RN, Dobson F et al (2002) Hip displacement in spastic cerebral palsy: repeatability of radiologic measurement. J Pediatr Orthop 22:660–667

Patel K, Chapman S (1993) Normal Symphysis pubis width in children. Clin Radiol 27:56–57

Perkins G (1928) Signs by which to diagnose congenital dislocation of the hip. Lancet 1:648

Reimers J (1980) The stability of the hip in children. A radiological study of the results of muscle surgery in cerebral palsy. Acta Orthop Scand Suppl 184: 1–100

Roposch A, Moreau NM, Uleryk E, Doria AS (2006) Developmental dysplasia of the hip: quality of reporting of diagnostic accuracy for US. Radiology 241:854–860

Rosendahl K, Aslaksen A, Lie RT, Markestad T (1995) Reliability of ultrasound in the early diagnosis of developmental dysplasia of the hip. Pediatr Radiol 25:219–224

Scoles PV, Boyd A, Jones PK (1987) Roentgenographic parameters of the normal infant hip. J Pediatr Orthop 7:656–663

Sharp I (1961) Acetabular dysplasia. The acetabular angle. J Bone Joint Surg 43B:268–272

Shenton EWH (1911) Disease in bone and its detection by the X-rays. Macmillan, London, pp 40–43

Siebenrock KA, Kalbermatten DF, Ganz R (2003) Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. Clin Orthop Relat Res 407:241–248

Simon EA, Saur F, Buerge M et al (2004) Inter-observer agreement of ultrasonographic measurements of alpha and beta angles and the final type classification based on the Graf method. Swiss Med Wkly 134:671–677

Skaggs DL, Karminsky C, Tolo VT, Kay RM, Reynolds RAK (1998) Variability in measurement of acetabular index in normal and dysplastic hips, before and after reduction. J Pediatr Orthop 18:799–801

Smith WS, Badgley CE, Orwig JB, Harper JM (1968) Correlation of postreduction roentgenograms and thirty-one-year follow-up in congenital dislocation of the hip. J Bone Joint Surg Am 50-A:1081–1098

Song FS, McCarthy JJ, MacEwen GD, Fuchs KE, Dulka SE (2008) The incidence of occult dysplasia of the contralateral hip in children with unilateral hip dysplasia. J Pediatr Orthop 28:173–176

Southwick WO (1967) Osteotomy through the lesser trochanter for slipped capital femoral epiphysis. J Bone Joint Surg Am 49:807–835

Spatz DK, Reiger M, Klaumann FM, Stanton RP, Lipton GE (1997) Measurement of acetabular index intraobserver and inter-observer variation. J Pediatr Orthop 17:174–175

Tan L, Aktas S, Copuroglu C, Ozcan M, Ture M (2001) Reliability of radiological parameters measured on anteroposterior pelvis radiographs of patients with developmental dysplasia of the hip. Acta Orthop Belg 67:374–379

Terjesen T (1996) Ultrasound as the primary imaging method in the diagnosis of hip dysplasia in children aged < 2 years. J Pediatr Orthop B 5:123–128

Terjeson T, Bredland T, Berg V (1989) Ultrasound for hip assessment in the newborn. J Bone Joint Surg (Br) 71-B:767–773

Tönnis D (1976) Normal values of the hip joint for the evaluation of X-rays in children and adults. Clin Orthop Relat Res 119:39–47

Vix VA, Ryu CY (1971) The adult symphysis pubis: normal and abnormal. AJR Am J Roentgenol 112:517–525

Wiberg G (1939) Studies on dysplastic acetabula and congenital subluxation of the hip joint. With special reference to the complication of osteoarthritis. Acta Chirurgica Scandinavica, Suppl. 58

Wientroub S, Grill F (2000) Ultrasonography in developmental dysplasia of the hip. Curr Conc Rev J Bone Joint Surg 82(B):1004

Wiig O, Terjesen T, Svenningsen S (2002) Inter-observer reliability of radiographic classifications and measurements in the assessment of Perthes disease. Acta Orthop Scand 73:523–530

Yamamuro T, Chene SH (1975) A radiological study on the development of the hip joint in normal infants. J Jap Orthop Assoc 49:421–439

Zsernaviczky J, Turk G (1975) The beta-angle. A diagnostic sign for the early diagnosis of congenital hip dysplasia. Rofo 123:131–133