EVALUATION of the HIP JOINT by COMPUTED TOMOGRAPHY and ULTRASONOGRAPHY

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_Evaluation of the Hip Joint by Computed Tomography and Ultrasonography_
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This thesis is based on the following papers I to VII. In the general introduction, results, discussion and summary, these papers are referred to by their Roman numerals.


IV Anda S, Terjesen T, Kvistad KA.: Computed tomography measurements of the acetabulum in adult dysplastic hips: which level is appropriate? Skeletal Radiol 1991;20:267-71


TERMINOLOGY and ABBREVIATIONS

In this thesis the following terminology and abbreviations have been used:

CDH: Congenital dysplasia of the hip.

CE angle: The centre edge angle of Wiberg (1939) measured on a frontal pelvic radiogram as the angulation of the line through the centre of femoral head and the upper lateral acetabular margin with the vertical line (Fig 3).

HTE-angle: The angulation of the line through the medial and lateral points of the subchondral bony condensation of the acetabulum with the transverse line (Fig 3).

CCD angle: The angle between the femoral neck and shaft (Fig 14).

CCD' angle: The projection of the CCD angle on to the posterior condylar plane (Fig 14).

FeAV angle (ANTEV 1): The anteversion angle of the central femoral neck is the angulation of the line through the centres of the femoral head and neck with the posterior condylar plane projected on to a plane perpendicular to the long axis of the femur (Figs 5,12-15).

Rippstein FeAV: Femoral anteversion measured according to the biplanar radiographic method of Dunlap et al. (1953) as modified by Rippstein(1955). This parameter coincides with the FeAV as defined above.

ANTEV 2 -angle: As FeAV, but the lateral point of the head-neck line is the mass centre of the trochanter region (Fig 13).

The rAT-angle of König: The angulation between the central head-neck line and its projection on to the posterior condylar plane. Measures the absolute spatial angulation of the femoral neck (Fig 14).
The inlet or opening plane of the acetabulum: Plane through the acetabular margins. May be decomposed into acetabular anteversion and inclination.

AcAV angle: The acetabular anteversion defined as the angulation of the horizontal line through the anterior and posterior acetabular margins of the hip with the sagittal plane (Fig 5).

Acetabular inclination: The slope of the acetabulum with the horizontal plane.

The intercapital centreline: Line connecting the centres of the femoral heads (Figs 5, 6, 11).

AASA: The anterior acetabular sector angle defined as the angulation of the horizontal line from the centre of the femoral head to the anterior acetabular margin and the intercapital centreline (Figs 6, 11).

PASA: The posterior acetabular sector angle. As AASA, except that the posterior acetabular margin is used for measurement (Figs 6, 11).

HASA: The horizontal acetabular sector angle = AASA + PASA (Fig 6).

Pelvic inclination - reclination (pelvic tilt - Tönnis 1987): Rotation of the pelvis around a transverse axis, for instance the centres of the femoral heads. Increase of pelvic inclination is a rotation forward of the anterior superior iliac spines. Increase of reclination is a backward rotation of the anterior iliac spines.

Pelvic obliquity: Rotation of the pelvis around an antero-posterior axis.

Pelvic rotation: Rotation of the pelvis around the long axis of the body.

CT: X-ray computed tomography.

ScoutView: Digital radiograph obtained by GE CT 9800.

3D CT: Three dimensional computed tomography.

MRI: Magnetic resonance imaging.
US: Ultrasonography.

Static US: Ultrasound method where a composite image is made by moving the probe.

Real-time US: Ultrasound method where multiple piezoelectric crystals make an immediate image of the scanned area.

Linear US probe: Ultrasound probe with multiple piezoelectric crystals in line and with a square surface.

Inclinometer: Device for measuring angles in clinical practice.

US FeAV: Femoral anteversion measured by ultrasound.

Femoral neck tangent: A tangent to the image of the central part of the anterior femoral neck, usually measured from an ultrasound image.

Head - trochanter (HT) tangent: Anterior tangent of the central part of the femoral head to the proximal area of the greater trochanter, usually obtained from an ultrasound image (Fig 15).

HT FeAV: Ultrasound measurement of the angulation of this tangent with the horizontal plane in the supine patient with the posterior femoral condyles oriented horizontally.

Posterior femoral condylar tangent: Line connecting the femoral condyles posteriorly (Figs 8,9,12,13).

The tilted transducer US technique: A specific ultrasound modification where the real-time linear ultrasound probe is tilted until the measurement line appears horizontal on the monitor screen. The angulation is read directly from a clinometer attached to the ultrasound probe.

The horizontal transducer US technique: Ultrasound modification where the real-time transducer is kept horizontal, and the angulation of the measurement line is measured against the base line of the ultrasound image.
NORMAL ANATOMY

The hip joint is a true diarthrosis of the ball and socket type (Walmsley 1928). The joint surfaces are covered by hyaline cartilage, and synovial fluid is produced by the synovial membrane covering the noncartilaginous part of the joint cavity. A strong capsule stabilizes the joint in extension but not in other positions when the rotation is neutral (Johnston 1973). Powerful muscles ensure a tight fit between the femoral head and the acetabulum, even when the joint is in a relaxed position. The main abductor muscles of the hip, the gluteus medius and minimus, insert on the trochanter major and are essential for maintaining the erect stance and the bipedal gait of man.

The acetabulum is made from components of the three pelvic bones. In the neonate approximately 2/5 of the superior acetabulum comes from the iliac bone, the posterior 2/5 from the ischial bone, and the anterior 1/5 from the pubic bone (Weinberg & Pogrund 1980). These components ossify from separate centres and meet in the hyaline three-
radiate cartilage which is continuous with the joint cartilage proper of
the acetabulum. The triradiate cartilage, also denoted the Y-cartilage,
is the physeal plate of the acetabulum and is consequently important in
the growth and remodeling of the acetabulum (Ponseti 1978).

The anterior and posterior acetabular rims have a medial-caudal
slope. The acetabulum has an inverted U-shape due to the acetabular
notch, which is filled with fibro-fatty tissue, usually called the
pulvinar. Approximately one half of the spheroid femoral head is
covered by the acetabulum anteriorly, posteriorly and superiorly. A
lateral flange of the acetabular rim covers the outer portion of the
femoral head superiorly (Murray 1965). The acetabular rim is reinforced
by the fibrocartilaginous labrum glenoidale, while the ligamentum
transversum bridges the inferior part of the acetabular notch, and
offers support to the femoral head inferomedially. The ligamentum
teres arises in the acetabular notch and inserts on the fovea of the
femoral head. This ligament is comparatively large in the neonate, and
contains the femoral head artery.

The femoral head is not exactly spherical. At birth the meridian
radius is slightly greater than the equatorial. During the growth period
this reverses, finally ending with a slightly flattened femoral head
(Walmsley 1928). Moreover, the femoral head is not completely
congruous with the acetabulum in the extended, unloaded position, (Fig
1) as the acetabulum has a slightly arched form (Bullough & Goodfellow
1973). Under light load the areas of contact are at the front and back of
the acetabulum, and there is a gap above (Bullough & Goodfellow 1973)
(Fig 1). Due to the visco-elasticity of the articular cartilage
(Armstrong et al.1979), this gap closes as the load increases
(Greenwald & O’Connor 1971). This mechanism probably also helps in
the lubrication and nutrition of the cartilage, as the movements of the
hip and the loading and unloading with resultant variation of contact
surfaces will act as a pump for the synovial fluid (Afoke et al.1980).
Goodfellow & Mitsou (1977) postulated a pressure sensitive mechanism which maintains this slight incongruity, necessary for adequate function of the hip joint throughout the years (Mizrahi et al. 1981).

![Figure 1](image)

**Figure 1**
Drawing showing hip congruency with increasing load

- Contact area

and they suggested that break down of this regulatory mechanism is the main cause of the so called primary or idiopathic arthrosis of the hip.
DYSPLASIA OF THE HIP

Definitions

The normal relation between the femur and the pelvis through contact between the articular surfaces of the femoral head and the acetabulum is the all important stimulus for the normal development of the hip joint (le Damany 1908, McKibbin 1970, Ralis & McKibbin 1973, Watanabe 1974, Ponseti 1978). If for some reason normal development is disturbed pre- or post-natally, suboptimal or pathologic relations may develop between the femoral head and the acetabulum. This may be due to several factors (Wilkinson 1963), mechanical (le Damany 1908, Somerville 1962, McKibbin 1970) and hormonal (Andren 1962) being the most important. Congenital, familial joint laxity has been found in some cases (Carter & Wilkinson 1964, Wynne-Davies 1970), while congenital dislocation of the hip associated with other malformations as arthrogryphosis or neurological disorders such as meningomyelocele are commonly classified as teratological.

If the hip of the neonate or young child presents without contact between the femoral head and the acetabulum, the condition is commonly called congenital dislocation of the hip.

Congenital subluxation of the hip (Leveuf 1947, Wedge and Wasylenko 1978, 1979) indicates that there exists a contact between the two components, but less than in the normal hip. The femoral head is displaced laterally and cranially and articulates with the outer part of the acetabulum.

Congenital dysplasia of the hip denotes that there is maldevelopment of the joint but no definite displacement of the femur from the acetabulum, which is shallower than normal.

Dysplastic hips are often easily dislocated at birth (Ortolani 1937, 1976, Barlow 1962). Somerville (1962) graded the severity of the problem from a functional point of view and made the following
statement: "We can divide subluxation from dislocation by saying that so long as the head of the femur is the fulcrum of movement, any displacement will be no more than a subluxation, but when the head ceases to be the fulcrum a dislocation is present".

Radiography and some relevant clinical observations
A pelvic radiogram of the neonatal or young child with hip dysplasia, may show an increased acetabular angle (Hilgenreiner 1925), lateral dislocation of the femoral head (Perkins 1928) as well as cranial migration (Hilgenreiner 1925, Perkins 1928) (Figure 2). It is important

![Figure 2](image)

**Figure 2**

Drawing from a pelvic radiograph of an 8 months old child. The right hip is normal, while congenital dislocation is present in the left hip. The Ac-angle is the angulation between the horizontal line and the line through the medial and lateral parts of the inferior ossification of the iliac bone. Note the small femoral head nucleus on the left side with lateral and cranial displacement, as well as the large Ac-angle.
to realize however, that the acetabular angle of Hilgenreiner is determined from the infero-lateral border of the ossified part of the iliac bone, and consequently tells nothing of the cartilaginous development of the acetabulum (Laurenson 1965). An increased acetabular angle may therefore reflect a delay in the ossification of the iliac bone, rather than an incomplete development of the acetabulum, analogous to the delayed ossification of the femoral head nucleus commonly observed in hip dysplasia (Putti 1933).

The earlier effective treatment is instituted, the better is the chance of normalization of hip joint development (Hilgenreiner 1925, Putti 1933, Severin 1941, 1950, von Rosen 1962, Harris et al. 1975, 1976, Weintroub et al. 1979, Siffert 1981, Dahr et al. 1990). However, some dysplastic hips remain undetected and untreated for several years (Williamson et al. 1989), and some are not detected before adolescence or adulthood, despite extensive screening programs for congenital hip dysplasia (Paterson 1976, Tredwell & Bell 1981). Furthermore, some hips develop with signs of residual dysplasia, despite early diagnosis and treatment (Smith et al. 1968, Lindstrom et al. 1979, Renshaw 1981). In some hips treatment for hip dysplasia leads to avascular necrosis of the femoral head and neck (Kalamchi & MacEwen 1980), and extreme treatment positions should therefore be avoided as this may impair the blood circulation (Ogden 1975). The necrosis of the femoral head nucleus has a relatively good long term prognosis, while involvement of the femoral neck physis leads to growth disturbances of the femoral neck. The result is varus or valgus deformity in partial epiphysiodesis, and in complete damage to the physeal plate reduced length growth resulting in a short femoral neck (Kalamchi & MacEwen 1980).

The acetabulum of the dysplastic hip is shallow and surrounds the femoral head less than normal. This is reflected by a Centre-edge angle of Wiberg (1939) of less than 20 degrees (Figure 3) in adults (Wiberg 1939, Severin 1941, Tönnis 1976, Broughton et al. 1989). In older
Figure 3

The centre-edge (CE) angle of Wiberg (1939) is the angle between the vertical and the line from the centre of the femoral head (C) to the superior lateral acetabular edge (E). On this schematic drawing from a radiograph of an adult pelvis the CE angle is normal on the right side. The left hip is dysplastic with a shallow acetabulum and a CE angle of 10°.

The HTE-angle of Lequesne (1963) is the angulation of the subchondral bony condensation of the acetabulum with the horizontal line—

Condensation of the subchondral bone - the "weight bearing surface"

The weightbearing area of the acetabulum, observed as an approximately horizontal line of subchondral bony condensation (the "sourcil" or pelvic "eyebrow" of Pauwels 1965) on a frontal pelvic radiogram in older children and adults (Fig 3), is smaller in dysplastic than in normal hips (Bombelli et al.1983), as the acetabulum is
shallower. As a consequence the weight load is distributed over a smaller surface area than in normal hips, and the stress per square unit consequently increased (Pauwels 1965). The clinical significance is that dysplastic hips regularly develop secondary osteoarthritis (Wiberg 1939, Somerville 1962, de Sèze et al. 1962, Tönnis 1987) in early adult life.

It is usually possible to define a lateral (Müller 1971) as well as a medial end point (Lequesne 1963) of this “sourcil”. Lequesne (1963) defined the angulation of the line between these points and the horizontal line as the HTE angle (Fig 3). This angle with an upper normal limit of 10 degrees, gives information on the vector forces acting on the weightbearing surface of the acetabulum (Lequesne 1963, Lingg & Torklus 1981a,b).

Acetabular cover, coverage or support (Unterstützung) are words used to describe how the acetabulum partly surrounds the femoral head, while containment denotes the concentricity of the femoral head in the acetabular socket. Moseley (1980) discussed the difference between cover and containment (Rab 1981b). These words, however, have often been used more or less synonymously in the literature, without consideration as to their slightly different meanings. In this thesis acetabular coverage is defined as the part of the acetabulum primarily concerned with weight-bearing in the standing position (Rab 1981b), while acetabular support to the femoral head is defined as deriving from the non-weight-bearing parts of acetabulum which contribute to containing the femoral head in the acetabulum (Paper IV).

Hip dysplasia is often associated with an increase of the femoral neck anteversion (Badgeley 1943, Alvik 1962). Clinically this is expressed by increased internal rotation, restricted external rotation and often an in-toeing gait (Somerville 1957, Gelberman et al. 1987, Svenningsen et al. 1989).
Operative procedures
Discussion on closed (Pavlik 1957, von Rosen 1962) or open reduction (Dahr et al. 1990) of the neonatal hip with congenital dislocation is considered to be outside the scope of this thesis. Consequently will only operative procedures for late detected or residual hip dysplasia, aimed at normalizing the anatomy and function of the hip (Tönnis 1°.87), and thereby preventing or postponing early osteoarthrosis, be briefly reviewed. These operations are performed consequent to the results of the clinical evaluation and the measurements of the dysplastic hip performed by imaging methods.

The importance of postponing development of osteoarthrosis must be stressed, as the long term results of “total hip replacement” in young adults are unsatisfactory (Salter et al.1984, Werner et al.1990). In vigorous young adults total hip prostheses will have a tendency to loosen. An extra 10 or 15 years “survival” of the native, dysplastic hip due to a corrective operation is consequently of great benefit, and, furthermore, it does not negate a total hip replacement at a later date.

Two principally different modes of operative treatment are possible:

1) Operations on the femur
Previously derotational subtrochanteric osteotomy of the femur in children with increased femoral anteversion and in-toeing gait was commonly performed (Pauwels 1951, Alvik 1962, Müller 1971, Svenningsen et al.1990). During recent years osteotomies have been performed less frequently because of the tendency towards spontaneous regression of femoral anteversion with increasing age (Svenningsen et al.1989, Svenningsen 1991). However, in CDH derotation and varus osteotomy is still performed (Dahr et al.1990). Alternatively rotational osteotomies may be performed at other femur levels, for instance intertrochanteric (Chapchal 1976, Werner et al.1990).
The common goal of these operations, besides relieving incongruity, is to alter the muscular lever arm and force acting on the hip joint.

2) Operations on the pelvis.

The shelf plasty of Spitzy (1933) is aimed at increasing the acetabular coverage of the femoral head laterally and anteriorly by inserting a piece of autogenous bone just above the capsular insertion (Wiberg 1953), while Colonna (1937) describes how to ream out a new acetabulum.

Several pelvic osteotomies, aimed at redirecting the acetabulum, thereby increasing its weightbearing surface, are in use. Most widespread in children is probably the innominate osteotomy of the iliac bone of Salter (1961, 1966, 1974, Wedge & Salter 1974, Rab 1978, Wong-Chung et al.1990). Although this method also may be used in young adults (Salter 1966, Wedge & Salter 1974), many authors have found it difficult to obtain satisfactory results with the Salter procedure in this age group (Hansson et al.1990). More extensive and technically demanding double or triple osteotomies of the pelvis have therefore been worked out (Pemberton 1965, Steel 1973, Sutherland & Greenfield 1977). Epprignt (1975) performed mobilization of the periacetabular area and "dialed" the acetabulum into the desired position.

Current literature (Utterback & MacEwen 1974, Coleman 1974, Sutherland & Greenfield 1977, Salter et al.1984) seems to agree that there are several prerequisites in pelvic osteotomies with redirection of the acetabulum:

1) The femoral head must rest in the acetabulum, or be easily reduced - without force - in to the acetabulum.

2) The joint surfaces must be relatively congruent in the intended postoperative position.

3) The hip must have a satisfactory range of motion.

4) There must be no signs of osteoarthritis of the hip.
5) Muscle contractures must be released.

In Chiaris operation (Chiari 1956, 1974, Rejholec et al. 1990) a transverse osteotomy of the pelvis is performed at the level of the capsular insertion. The acetabulum is brought medially, thereby increasing the lateral cover to the femoral head. Furthermore, the lever of the muscles attached to the proximal femur is shortened, which is considered advantageous. Chiari operation is considered a salvage procedure and may be used even when there are moderate radiographic signs of osteoarthritis (Rejholec et al. 1990).

**IMAGING METHODS FOR HIP INVESTIGATIONS**

The bony components of the hip joint are depicted by techniques employing X-rays (Armbuster et al. 1978, Katz 1979, Bowerman et al. 1982, Saks 1986). Discrimination of soft tissues is impossible by radiography but feasible by computed tomography. The fibrocartilaginous labrum glenoidale, which surrounds and thereby reinforces the superior and posterior acetabular rim, is therefore not depicted by radiography and also inconsistently by computed tomography. The same applies to the hyaline cartilage of the hip joint proper. Cartilage, including the fibrocartilage of the labrum is, however, depicted by ultrasound. Ultrasound waves are totally reflected by bone surfaces, which consequently appear as white lines on the realtime ultrasound images.

The hip joint consists of two components, and consequently it is possible to evaluate:
1) the femur with the femoral neck and head
2) the pelvis with the acetabulum
3) the relationship between these two components
   a. In the anatomical, extended position
   b. In other positions, for instance in 90 degree flexion

Various imaging methods and techniques have been employed for these purposes.

**Plain Radiography**

It is important to stress that the frontal radiograph of the hip with the femurs in the anatomical position, should always include the entire pelvis with the femoral heads and necks. A radiograph of one hip only is insufficient, as it is impossible to evaluate the spatial orientation of the acetabulum as well as the relation between the acetabulum and femoral head.

The slope (inclination with a transverse line) of the acetabulum can be measured by the acetabular angle (the AC-angle, the acetabular index, German: der Pfannendachwinkel) of Hilgenreiner (1925) in the frontal pelvic radiogram in neonates and older children (Fig 2). With ossification of the triradiate cartilage of the acetabulum, it is no longer possible to measure the acetabular angle of Hilgenreiner. Sharp (1961) defined an acetabular angle of adults using the teardrop shadow of the pelvis (Bowerman et al. 1981) as an alternative medial measuring point, but his definition has found little use. This also is the case of the acetabular ACM angle of Idelberger and Frank (1952) measuring the depth of the acetabulum from a frontal pelvic radiogram.

As the nucleus of the femoral head epiphysis normally does not ossify until at four months of age (Visser 1984), and usually even later in dysplastic hips (Putti 1933), radiography is of limited value in the neonatal period for evaluation of the femoro-acetabular relationship.
With ossification of the femoral head nucleus, however, evaluation of the concentricity of the femoral head in the acetabulum, becomes feasible. The femoral head nucleus should lie inferior to the line of Hilgenreiner (1925), which is drawn from the innermost, caudal part of the ilium at the Y cartilage of the acetabulum (Fig 2). Furthermore most of the head nucleus should lie medial to the line of Perkins (1928), drawn vertically from the lateral bony rim of the acetabulum (Fig 2).

In the older child calculation of the Centre-Edge angle of Wiberg (1939) (Fig 3) is the most important single measurement in hip dysplasia (Severin 1941, Tönnis 1976). This also holds true in the adolescent and adult hip (Wiberg 1939, Jentschura 1951, Solomon 1976, Engelhardt 1988). It should be realized that the CE-angle gives no information on the size of the femoral head. In a femoral head of moderate size a small CE-angle will indicate a reduced weight bearing surface. This will not necessarily be so when the femoral head is large (coxa magna) (Tönnis 1987).

The HTE-angle (Lequesne 1963) is measured as the angulation of the pelvic "sourcil" (Pauwels 1965) with the transverse, horizontal line (Fig 3).

The lateral radiographic projection of the hip (Laage et al.1953) is somewhat cumbersome to obtain, and that may be the reason why the Lauenstein (1900) projection (the frog position) of the hips often is employed.

It should be clearly realized that this only is a survey of what the author considers the most important measurements by radiography of the hip. Several additional lines and angles have been defined and found useful, especially in German speaking countries. Interested readers are advised to consult the comprehensive book of Tönnis (1987) for further information.
Special radiographic projections

The Chassard-Lapiné view has been used in determination of the antero-posterior position of the femoral head relative to the acetabulum (Broderick 1955, Pinck et al. 1963). Martz & Tailor (1954) used a 45 degrees antero-posterior cephalad projection for the same purpose. Dunlap et al. (1956) studied the acetabulum by a lateral, oblique acetabular projection in the sitting patient. The tube was angled 30 degrees with the long axis of the body approximately in the plane through the acetabular rim. Dechambre and Teinturier (1966) made a slight modification to this method, and measured the acetabular anteversion, while Teinturier et al. (1967, 1970) used the same projection for evaluation of osteoarthritic hips. Frot and Duparc (1973), employing a sine curve, showed that the acetabular anteversion could be calculated from four radiographic projections with variation of pelvic rotation by measuring the distance between the anterior and posterior acetabular rims. Lequesne & de Sèze (1961) described a 25 degrees lateral slightly oblique projection of the pelvis termed "le faux profil du bassin" for evaluation and measurement of the anterior acetabular cover of the femoral head. The ACV angle thus defined is analogous to the CE-angle of Wiberg, and in fact shows corresponding normal values to the CE-angle. Wientroub et al. (1981) suggested stereophotogrammetry for measurement of acetabular and femoral anteversion. Schultz (1924) conceived the idea of an axial projection of the femur in the sitting patient for direct measurement of femoral neck anteversion, later on promoted by Budin & Chandler (1957). Rab (1981a) described special preoperative radiographic projections to simulate the postoperative result of osteotomies about the hip. The restricted use of the multitude of special radiographic projections and techniques suggested, indicates that they are of limited value for routine work.

Frontal or lateral conventional tomography of the hip joint give
comparatively high radiation doses to the patient, and have consequently largely been replaced by computed tomography.

Biplanar radiography
These are methods for determination of femoral torsion, or more commonly called femoral neck anteversion, as this is what is usually measured. Multiple methods employing two radiographic projections for measurements from which the femoral neck anteversion is constructed or calculated have been described (Dunn & Notley 1952, Ryder & Crane 1953, Magilligan 1956, Reynolds & Herzer 1959, Norman 1965, Edholm 1966, Chevrot 1976, Ogata & Goldsand 1979, Henrikson 1980, Herrlin & Ekelund 1983). In Norway the method of Dunlap et al. (1953) as modified by Rippstein (1955) has found wide application. Gross & Haike (1970), Ruby et al. (1979) and Henrikson (1980) have shown that the accuracy of this method when used correctly is within ±5 degrees. The method is consequently considered adequate for practical clinical work and is used widely as a standard method for preoperative evaluation of femoral torsion before derotational osteotomy.

Arthrography
This is an invasive technique performed with an anterior (Severin 1939, 1941), supero-lateral (Mitchell 1963) or infero-medial (Astley 1967) puncture of the hip joint. A positive, watersoluble radiopaque contrast medium is injected, monitored by fluoroscopy. The method has proven useful for the delineation of the surface of the joint cartilage, that is the acetabulum and the circumference of the femoral head, which consequently can be visualized prior to the start of ossification of the femoral head nucleus. Furthermore, interposed soft tissues, as for
instance an inverted labrum glenoidale (limbus), hyperplrophied ligamentum teres and transversum, excessive fibro-fatty tissue (pulvinar) from the acetabular notch, as well as hourglass contractures of the joint capsule, may be detected (Severin 1941, Mitchell 1963, Astley 1967, Staheli et al.1978, Tönis 1987).

Even taking into consideration the impact of recent imaging techniques as ultrasound, CT and MRI, Drummond et al. (1989), however, uphold hip arthrography as the golden standard for evaluation of the intra-articular soft tissues of the hip joint.

**Computed Tomography**

Due to the way computed tomographic images of the hips are generated, the slices have to be transpelvic, perpendicular to the long axis of the body and standard frontal radiograms. Computed tomography therefore offered a completely new way of evaluating the hip joint, facilitating assessment of the acetabular anteversion (Visser & Jonkers 1980, Visser et al.1982, Reikerås et al.1982, 1983). Gugenheim et al. (1982) measured the acetabular angles on the CT-image through the triradiate cartilage in children and thereby quantified the anterior and posterior acetabular margins.


Egund & Palmer (1984) pointed out that a CT investigation with multiple transaxial images of the femur represented a cartesian, three dimensional coordinate system. The X and Y values were found in each CT image, while the slice location gave the Z value. Femoral anatomy and torsion could consequently be described in cylindrical coordinates.
Three dimensional reconstructions from thin transaxial CT-images of
the hip had been introduced (Totty & Vannier 1984, Lafferty et al.1986,
Gillespie & Isherwood 1986), but had so far not found routine
application.

**Ultrasound**

Ultrasound depicts cartilage and has therefore proven very useful for
the investigation of the neonatal hip prior to the commencement of
femoral head nucleus ossification (Graf 1983, 1985, Clarke et al.1985,
Langer 1987). This is the time of golden opportunity in the diagnosis of
hip dysplasia, as good results depend on early treatment (Putti 1933,
Smith et al.1968).

As bone surfaces give total reflection of the ultrasound waves, soft
tissue/bone interfaces are depicted as white lines. Ultrasound was
therefore tested for measurements of femoral neck anteversion using
images of anterior surface contours of the proximal femur. The first
investigators used static, compound ultrasound scanners (Moulton &
Upadhyay 1982, Upadhyay et al.1987). This ultrasound mode is very
operator dependent (Berman et al.1987). Moreover, compound scanners
are rapidly being replaced by real-time ultrasound scanners. The first
reports of femoral neck anteversion measurements by real-time
scanners, showed diverging conclusions regarding the applicability of
ultrasound for this purpose (Zarate et al.1983, Clarac et. al.1985,

**Magnetic resonance imaging - MRI**

MRI employs magnetic fields and radiosignals for the generation of
images and holds great promise regarding hip dysplasia (Bos et al.
1988, Johnson et al.1988), and probably also for angle measurements as
the anatomy is adequately reproduced (Totty et al. 1984, Littrup et al. 1985), but further research is needed.

SUMMARY OF PREVIOUS IMAGING TECHNIQUES

The possibilities of standard and special radiographic projections have been extensively explored at the start of this investigation. Frontal radiography of the pelvis with the hips, have an established and undisputable position in the routine evaluation of the dysplastic hip both in children and adults. Measurements from biplanar radiography give reliable values of the femoral neck anteversion, which alternatively can be calculated by computed tomography. CT depicts the version of the acetabulum, and angles measuring the anterior and posterior acetabulum at the region of the triradiate cartilage in children have been defined. Three dimensional CT has been introduced. Ultrasound has established a position in the evaluation of the neonatal hip, and can together with computed tomography in many instances replace hip arthrography. Some reports of ultrasound measurement of femoral neck anteversion have appeared, with diverging conclusions regarding the reliability of this method. MRI holds great promises for hip investigations.

PELVIC INCLINATION - RECLINATION

It has been widely recognized that the spatial orientation of the acetabulum is dependent on the inclination of the pelvis (Getz 1955, McKibbin 1970, Reikerås et al. 1982, Visser 1984). In order to standardize this parameter, McKibbin (1970) suggested that the AcAV
should be measured in a horizontal plane through the central part of the hips, perpendicular to a reference plane through the anterior, superior iliac spines and the anterior pubic tubercles. McKibbin (1970) assumed that this reference plane was vertical in the standing subject, and horizontal in the prone position, while it was considered variable in the supine position. This postulate has become somewhat of an axiom, although no one has to our knowledge actually measured the inclination of this plane in living subjects. Moreover, in old anatomical drawings, for instance those of Vesalius (1543), the pelvis was often depicted in marked reclination.

**SHORTCOMINGS OF PREVIOUS METHODS**

Computed tomography has not previously been applied for quantification of the relationship between the femoral head and the acetabulum. In a 17 year old girl with voluntary subluxation of the hip, we managed to obtain CT images in the subluxed position (Anda et al. 1986). A poor support from the posterior acetabular rim was suspected, and a posterior shelf operation cured the patient. This led to a search for angles which quantified the relationship between the femoral head and the acetabulum in the horizontal plane. Angles corresponding to those of Gugenheim et al. (1982) were considered, but discarded as they only measured the acetabulum without taking into consideration the shape and concentricity of the femoral head. Moreover, in adults the triradiate cartilage is ossified, which negates the measurements of Gugenheim et al. (1982). The acetabular notch would furthermore interfere with such measurements at the level of the centreslice through the femoral head.

Previous reports have assumed that the CT measurements of the hips
in the supine patient were equal to corresponding standing angles (Reikerås et al. 1983), that is that the pelvic inclination was identical supine and standing relative to the horizontal and vertical frontal planes, respectively (Wiberg 1939). This assumption has so far not been proven, however.

Although ultrasound had been tested for the measurement of femoral neck anteversion, the results of these measurements were ambiguous. We suspected that this might be due to non-optimal techniques.

At the start of this investigation it was therefore clear that radiography was indispensable for hip investigations, but it was equally obvious that this imaging technique had limitations. In order to explore further the acetabulum and the relationship between the acetabulum and the femoral head, computed tomography offered great possibilities. Ultrasound obviously could not be used for evaluation of the acetabulum in adults, due to the total reflexion of ultrasound waves from bone surfaces, but this property could be used for measurement of line angulations. Femoral neck anteversion could therefore be investigated by ultrasound employing anterior bone contours. Ultrasound has the advantage that the patient is not exposed to radiation. The same applies to MRI, but we did not have this technique at our disposal at the start of this investigation, which consequently rests on computed tomography and ultrasound, and uses commonly accepted radiographic methods for control.
AIMS of the present study

1. To quantify the anterior and posterior support offered by the acetabulum to the femoral head in normal and dysplastic adult hips.

2. To determine the relation between anterior and posterior acetabular angles and pelvic inclination.

3. To determine the relation between the acetabular anteversion and the pelvic inclination and to try to draw some theoretical and possibly practical consequences from this.

4. To investigate whether acetabular angles measured at supine CT of the hips were equal to corresponding angles in the erect position, by comparing the pelvic inclination supine and standing.

5. To investigate which level of CT-slices of the hip was optimal to characterize the adult dysplastic hip, and to examine whether several levels or one level only was required.

6. To investigate whether real-time ultrasound could be used reliably for measurement of femoral torsion.

7. To determine the most appropriate modification of various real-time ultrasound techniques for clinical practice.

8. To decide the most appropriate technique for measurement of the femoral torsion in femurs with extreme valgus.

9. To evaluate whether standard radiography is sufficient to diagnose dysplasia of the adolescent and adult hip.

10. To evaluate what are the most relevant preoperative imaging investigations of the adolescent and adult dysplastic hip.
SUMMARY OF PAPERS

Paper I
A new set of angles measured on standard transaxial computed tomographic images of the hip joint was defined. The angles provide information on the support to the femoral head from the anterior and posterior part of the acetabulum. These angles, called the anterior and posterior acetabular sector angles (AASA and PASA), were measured on the central CT-slice through the femoral head in 82 normal adult hips with equal gender distribution, and correlated to a set of established parameters commonly measured in conventional roentgenography and on CT images of the hip joint. The corresponding angles were also measured on the four adjacent slices, and showed that both the anterior and posterior support increased cranially. The acetabular anteversion was equal in all cuts. The study comprised a normal material obtained for comparison with dysplastic hips.

Paper II
In a study of 40 normal young adults the pelvic inclination measured by a specially constructed inclinometer was found to be the same in the supine and standing positions when related to the horizontal and vertical frontal planes, respectively. Consequently supine CT measurements of the hip are also representative of corresponding standing angles. The variations of the acetabular anteversion (AcAV)
and the sector angles (AASA and PASA) on CT of normal hips in 5 adult corpses were measured by angulating the gantry in increments of 5 degrees to ±20 degrees. An approximate linear relationship was found for all parameters, the acetabular anteversion varied 0.5 degree and the sector angles 0.7 degree per degree pelvic inclination. A theoretic mathematical model for the variation of the acetabular anteversion outside the measured range employing a sine curve was introduced.

Paper III
Transpelvic CT was used to quantify the relationship between the acetabulum and proximal femur in 21 adult patients with 33 dysplastic hips (defined by a centre edge angle of less than 20 degrees). The anterior and posterior acetabular sector angles (AASA and PASA) were measured, as well as the degree of acetabular and femoral anteversion (AcAV and FeAV). The results demonstrated deficient anterior acetabular support (i.e. decreased AASA) in two-thirds of the dysplastic hips and reduced posterior support (i.e. decreased PASA) in one-third. The acetabular anteversion was normal. The femoral anteversion, however, was greater than normal in most hips. As important additional information was obtained by CT compared with conventional radiography, CT is recommended when operative procedures of the pelvis aimed at preventing or postponing osteoarthritis are considered.

Paper IV
This study was performed to evaluate whether one CT-level only or several levels were needed to provide sufficient information regarding anterior and posterior acetabular support to the femoral head and acetabular anteversion. 23 dysplastic hips in 14 adults with uni- or
bilateral congenital hip dysplasia (CE-angle less than 20 degrees) were included. Acetabular measurements were performed at four levels from 5mm contiguous CT slices, two cranial to and one caudal to the centre slice through the femoral head. Both the anterior and posterior acetabular support as quantified by the anterior and posterior acetabular sector angles (AASA and PASA) were significantly lower than normal at all measurement levels. The sector angles increased in the cranial cuts, whereas the acetabular anteversion increased caudally. Because no important additional information was obtained by measuring at different levels, we concluded that one level only is sufficient for acetabular measurements by CT in hips with spheroid femoral heads, and suggested that the slice through the centre of the femoral head is the most appropriate. In hips with non-spherical femoral heads, contiguous slices through the hip joint for a qualitative evaluation was suggested.

**Paper V**

The femoral anteversion was measured by ultrasound and biplanar radiography in 57 children, most of whom had clinical signs of increased anteversion. A modification of previously reported real-time ultrasound techniques was introduced, as the linear transducer was tilted instead of being kept horizontally. Four different modes of ultrasound examination were evaluated.

The most appropriate technique involved only one ultrasound scan at the hip level, with measurement of the anterior tangent to the femoral head and the greater trochanter (the head trochanter tangent). The dorsal condylar plane of the femur was horizontally oriented by flexing the knee 90 degrees and strapping the legs vertically.

The correlation between the results of ultrasound and radiography was good. A discrepancy of less than 10 degrees was found in the majority.
Ultrasound was consequently found suitable for screening of children with rotational disorders of the femur. One great advantage of ultrasound methods is that exposure to radiation is avoided, and this permits repeated measurements, if indicated.

Paper VI
Radiographic and real-time ultrasound measurements of femoral anteversion were compared in an anatomic study of 20 dried adult femurs. The real femoral neck anteversion (FeAV) angle was determined by biplanar radiography. In four ultrasound measurements, the linear transducer was kept either horizontal or tilted. The measuring lines were either the anterior tangent of the femoral head/greater trochanter or to the femoral neck. With the tilted transducer, the correlation between the head-trochanter AV angle measured by US and radiography was high \((r=0.97)\). Furthermore, with tilted transducer the correlation with the real radiographic measured FeAV angle was also high \((r=0.945)\), but slightly less when the anterior femoral neck AV angle was used \((r=0.914)\). The clinical relevance is that the tilted transducer technique with the head-trochanter tangent is recommended for AV screening in patients. US employing the head-trochanter tangent consistently measured higher AV values than radiography, and the mean discrepancy was 8.5 degrees.

Paper VII
Femoral anteversion was determined by ultrasound in 40 adolescent and adult patients with rotational disorders of the femur, and the results were compared with measurements of the FeAV by biplanar radiography. With the patients supine, their knees flexed 90 degrees, and their lower
legs strapped in the vertical position, one scan only of the proximal femur was needed to measure the anteversion by ultrasound. The transducer was tilted until the desired measuring line appeared horizontal on the monitor screen. The angle of tilt of the transducer, which represented the AV angle, was measured with an attached clinometer. The correlation between ultrasound and roentgenographic FeAV angles was high, indicating that reliable results were obtained by ultrasound. The preferred reference line was the anterior head-trochanter tangent, which is recommended for clinical use. Consistently greater AV values were measured by ultrasound than by roentgenography, on average 11.2 degrees. Because the study of dry bones (paper VI) indicated a similar trend with a mean discrepancy of 8.5 degrees, we concluded that 10 degrees should be subtracted from the ultrasound AV value in order to obtain an approximation of the real FeAV angle. This investigation confirmed that ultrasound may be used as a screening technique for patients with rotational disorders of the femur.
GENERAL DISCUSSION

MATERIALS

Paper I: The patient material comprised 41 adults, with equal sex distribution, hospitalized and CT-investigated for other diseases, predominantly malignancies. The patients had normal hip joints, however, with a CE-angle of more than 20 degrees (Wiberg 1939). Furthermore all hips except for one, had CE-angles above 25 degrees. We consider therefore our material to consist of normal hips, using this to establish normal adult values of the acetabular sector angles for each gender. Subsequently Høiseth et al. (1989c) published a normal material of the sector angles of 80 adult hips, and Murphy et al. (1990) one of 43 adult hips.

Paper II: The clinical material for this study of adult pelvic inclination comprised 40 volunteers, 27 women and 13 men. The radiographic study of a dried pelvic specimen illustrated a principle, and measurements were not attempted. Ten hips of five cadavers without known hip disease were considered normal as pathology was not observed from the radiograms and CT slices of the hips. Statistical evaluations were not attempted due to the small sample number, but the curves of each hip were presented separately. Each single observation was therefore subject to the errors of the method of measurements of acetabular angles.

Paper III: 21 adults or adolescents with 33 dysplastic hips judged
from a CE-angle of Wiberg (1939) to be less than 20 degrees were included. Most of these patients had CE-angles well below 20 degrees, and inclusion was easy in these cases. In hips with CE-angle of 18-19 degrees, careful consideration and repeated measurements were done, both from the ScoutView and from the frontal pelvic radiograph, or radiographs if more than one existed. We are therefore confident that all of the included hips are in fact dysplastic according to the criterium set by Wiberg (1939).

The femoral neck anteversion was measured in 17 dysplastic hips with non-operated femurs.

It proved difficult to find candidates for this study. The patients were referred to the Orthopaedic outpatient clinic of Trondheim University Hospital chiefly because of hip pain, from a population of approximately 0.3 million people over a four years period. Many of the referred patients had too advanced coxarthrosis at first examination to be included. Some of those included had incipient coxarthrosis with reduced joint space superiorly, cranial migration of the femoral head of up to one cm judged from Shenton's line, and subchondral sclerosis. None had osteophytes or gross deformity of the hips, however. It is in this context important to realize that this material was highly selective. It represented treated dysplastic hips as well as untreated where the long term results had been moderately good. The hips with most severe CDH had probably presented with a frank luxation in early childhood, or early advanced osteoarthritis in adult life. This material was similar in size to that of normal female hips (Paper I), to which it was compared.

**Paper IV:** The CT-investigations of 14 patients with 21 dysplastic hips were selected from the material of dysplastic hips (Paper III) for further studies. In two patients the CT-examinations could not be retrieved, and were lost for follow up. Five other patients had changes
of the femoral head in the slices adjacent to the central cut, obviating measurements of the sector angles. The remaining 21 dysplastic hips had sufficiently spheroid femoral heads to permit measurements at four levels.

Paper V: Fortyseven girls and 10 boys remitted to the outpatient Orthopaedic clinic, the majority with clinical signs of increased femoral neck anteversion, were investigated. This was our first attempt to evaluate whether ultrasound could be used for measurement of femoral neck anteversion, and different modes were tried. In light of this, the material seems adequate both regarding size and pathology of femoral neck anteversion.

Paper VI: An anatomic material of 20 dry adult femurs excavated from a medieval burial ground in Trondheim were borrowed from the Historical Museum of Trondheim. The femurs were selected from a total of 387 well preserved skeletons and were without gross pathology. We were especially critical in ensuring that the subchondral bone of the joint surface was intact. "Survival" and excavation of adult bones under soil conditions permitting preservation is probably a random event. Although environmental factors were different from those of present time, the genetics of medieval man in Norway was probably the same as those of contemporaries. Furthermore the mean FeAV was 14 degrees (-3 to 27 degrees), with an even distribution, and this compared favourably with the values of other normal materials (Kingsley & Olmsted 1948, Terjesen et al.1982, Reikerås et al.1983). We consequently consider this material to represent normal femurs.

Paper VII: This material comprised 40 adults and adolescents remitted to the outpatient Orthopaedic clinic with rotational disorders of the femur, and is considered adequate for its use.
METHODS

COMPUTED TOMOGRAPHY

Technical considerations
A GE-CT-T 9800 (General Electric, Milwaukee, USA) was employed for the CT-investigations using standard software programs. Initially we used soft-tissue algorithms (Paper I) as the investigation of normal adult hips was part of a CT-examination for other diseases, predominantly malignancies. In the other CT-investigations (Papers II-IV) we used bone algorithms. The measurements were made at bone settings with a window of 1000 Hounsfield Units (HU), and level of 350-500 HU.

Slice thickness
In a case report (Anda et al. 1986) we used 3mm thick contiguous CT-slices through the hip of a 17 year-old girl. This gave excellent images, but 20 cuts were necessary to cover the entire hip joint. After the sector angles had been conceived, 10 mm CT cuts were used in a pilot study. The joint space was poorly depicted in the slices somewhat remote from the central cut, however, even in hips with normal thickness of the joint cartilage as observed from plain radiography (Fredensborg 1977). The probable explanation was the partial volume effect.

Usually the acetabular inclination with the horizontal plane is 35-40 degrees (v Lanz 1951, Getz 1955, McKibbin 1970). This will consequently also be the inclination of the acetabular rims with the trans-pelvic plane of the CT images. This means that an acetabular rim in 10mm CT-slices will be depicted in pixels stretching over a length of: 10mm x tg 35 degrees = 6 mm. The femoral head is perpendicularly cut in the central region, at an increasing angle superiorly, and finally
becoming tangential to the top of the femoral head. The error due to the partial volume effect will therefore be negligible in the central cuts through the femoral head, but considerable in the cranial cuts. This will not influence measurements in a spheroid femoral head, as the error is the same all around the circumference, and the centrepoint of the femoral head in each slice is consequently relatively precisely defined.

Ten mm cuts were therefore considered too thick for accurate measurement of the acetabular sector angles. 3mm cuts were excellent for this purpose, but it was felt that too many slices were needed to cover the entire hip joint, with resulting increase of examination time and radiation. We intended to establish a normal material of adults (Paper I) and it was therefore important to choose an acceptable slice thickness. After due consideration, we decided that 5mm thick images would be most fitting.

**Angle measurement by GE CT 9800**

may be performed in different manners from transaxial images:

1. **The angulation of a line through two points.**
The crosshair cursor is brought to one of the points of measurement and deposited. Thereafter the other point is marked in the same way. The "measure distance" button is pressed. The distance between the two points is consequently calculated by the computer, and more important in this context, the angulation of the line between these points and the vertical as well as the horizontal is also calculated.

2. **The angulation between the centres of circles.**
A circle is fitted around the femoral head and the crosshair button pressed. This marks the centre of the circle. The procedure is repeated for the remaining circle. Then the measure distance button is pressed, and the angulation of the line is read as in 1.

3. **The angulation between two lines measured from points as well as centres of circles.**
A combination of method 1. and 2. can be used. However, the angle measure program can be employed. The centre of the circles must then be chosen on eye-sight, and may consequently vary between different
investigators. The angle measure program on GE CT 9800 does not permit the change between circles and centre of the circle marked by the crosshair cursor. It would be a minor adjustment for the manufacturer to include software programs permitting this manipulation, however.

Choosing the centreslice through the femoral head

A circle fitting the outline of the femoral head was made on the ScoutView by means of the standard CT software program, and the centrepoint marked by pressing the cursor button as described (Fig 4).

Figure 4

Schematic drawing made from a ScoutView of an adult pelvis. The transverse lines indicate the position of the finished transaxial CT slices. Circles have been fitted around the femoral heads. The centre of a circle marks the centre of the femoral head. The horizontal line closest to the centre, marked as a broad line on the drawing, represents the centreslice which is used for acetabular measurements.
In an intra- and inter-observer study the acetabular sector angles of two corpses with normal hips were measured repeatedly by the author and a junior staff member (KAK). From the monitor image of the ScoutView the centre of the femoral head was identified by the cursor as previously described. The program which indicated the position of the finished CT slices on the ScoutView was then activated. This was repeated five times for each investigator. Thus ten observations were made for each hip. In three hips the same slice was indicated in each trial. In the fourth hip one slice was indicated seven times, and the one below once. In the remaining two observations the cursor was equi-distant from these two cuts. This probably indicated that no slice was centred through the exact middle of the femoral head, but that two slices, one cranial and one caudal, were equally close.

In many dysplastic hips the femoral head appeared somewhat flattened and it was not feasible to fit a perfect circle around. In these cases the circle was made slightly oval to conform to the outline of the femoral head. The possible error created by this manipulation was taken into consideration, when the central slice was selected for measurements.

**Acetabular anteversion - AcAV**

The centreslice was identified. The crosshair cursor was deposited at the anterior and posterior acetabular margins, and the measure distance button pressed. This gave the angulation of the line between these points. The centres of both femoral heads were then identified, and the angulation of the line between the centres marked the obliquity (rotation) of the pelvis around the long axis of the body. The acetabular anteversion is the angulation of the AP-line with the perpendicular to the intercapital centreline (Fig 5). As the anterior and posterior acetabular rims have approximately the same slope in each hip (Paper I,II,IV), the error due to the partial volume effect will
Figure 5 Schematic drawing of the centre image through the femoral heads of an adult pelvis. The acetabular anteversion is the angulation of the line between the anterior (A) and posterior (P) acetabular margins with a perpendicular to the intercapital centreline (C1 - C2)

be equal. Consequently measurement of the acetabular anteversion will contain the same error anteriorly and posteriorly, and come out therefore correctly. In 5 mm images, this error will never be more than 3mm. Some inaccuracy of measurements may occur with the placement of the intercapital centreline. As the femoral heads are situated relatively far apart (19±3cm in adults - own unpublished data) when compared to the distance between the acetabular margins, this will, however, only cause a minor error of measurement in the angulation of this line. The accuracy of the AcAV measurements should therefore be high, and Visser (1984) stated that it is ±2 degrees.

Acetabular sector angles - AASA and PASA
These angles are measured as the angulation of the intercapital
centreline with a line from one femoral head centre to either the femoral head centre.

**Figure 6**

Schematic drawing from a centre slice through an adult pelvis. The intercapital centreline C1-C2 is marked and is the baseline for the measurement of the anterior (AASA) and posterior (PASA) acetabular sector angles. The angulation from the lines from the femoral head centre to the anterior (A) - respectively the posterior (P) acetabular rims are employed. The horizontal acetabular sector angle (HASA) is the sum of AASA and PASA.

Wrong identification of a femoral head centre will have a major impact on the angulation of the line from the centrepoint to either the anterior or posterior acetabular margins, however, as these points are relatively close together (the radius of the normal femoral head ≈ 2 cm). The identification of the
measuring points on the anterior and posterior acetabular rims was easy. However, because of the partial volume effect, the acetabular sector angles will be measured from points on the acetabular rim, which may be as much as 3mm (5mm x tg 35 degrees) off those intended on 5mm CT slices, and this will be a source of inaccuracy. This is a systematic error common to all measurements of the acetabular sector angles. As long as the slope of the anterior and posterior acetabular rims are the same, however, this will consequently impose a systemic error of little practical importance. The same reasoning applies to other measurements of the acetabular rim as for instance the angles of Gugenheim et al. (1982), who employed 10 mm CT cuts.

An intra- and inter-observer study of the sector angles
The acetabular sector angles were measured separately five times by two investigators (SA & KAK) from each of the four hip-images indicated as being central from the ScoutView in three different modes:

Method I:
From the CT-monitor employing the angle measure program of GE CT 9800.

Method II:
By use of the CT-program from the CT-monitor employing the measure distance button after having marked the centres of femoral heads by circles.

Method III:
Hard print copies were obtained by a laser camera (Agfa Gevaert, Belgium), and the measurements performed by means of the Müller Ischiometer (Paper I). One of the concentric circles of the transparent Müller Ischiometer was fitted around the outline of the femoral head, and the centrefpoint marked with a pencil through the hole in the middle. The results of these measurements are presented in the general tables:

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASA</td>
</tr>
</tbody>
</table>

42
The results in each group have been arranged with increasing values. The **median** figure is in **bold type**.

<table>
<thead>
<tr>
<th></th>
<th>method I</th>
<th>method II</th>
<th>method III</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hip 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>62.9 63.5 63.8 63.9 64.1</td>
<td>57.8 58.6 58.8 59.2 60.2</td>
<td>59 59 59 59 60</td>
</tr>
<tr>
<td>KAK</td>
<td>60.7 60.8 61.2 61.9 62.5</td>
<td>59 59.2 59.2 60 60</td>
<td>59 59 60 60 62</td>
</tr>
<tr>
<td>Diff. medians</td>
<td>2.6</td>
<td>-0.4</td>
<td>-1</td>
</tr>
<tr>
<td>Largest - smallest</td>
<td>3.4</td>
<td>2.4</td>
<td>3</td>
</tr>
</tbody>
</table>

| **Hip 2** |
| SA    | 58.8 58.9 59.2 59.4 60.2 | 59.2 59.6 59.6 59.8 59.8 | 59 59 60 60 61 |
| KAK   | 61.1 61.9 63.9 65.0 67.9 | 59.1 59.6 59.7 59.9 60.7 | 58 58 60 60 60 |
| Diff. medians | -4.2 | -0.1 | 0 |
| Largest - smallest | 9.1 | 1.5 | 3 |

| **Hip 3** |
| SA    | 68.6 68.7 69.2 69.7 70.5 | 64.6 65.1 65.1 65.1 65.3 | 64 65 65 66 66 |
| KAK   | 67.0 67.3 67.5 67.5 68.7 | 65.6 65.6 66.5 66.5 67.5 | 65 65 65 66 66 |
| Diff. medians | 1.7 | -1.4 | 0 |
| Largest - smallest | 3.5 | 2.9 | 2 |

| **Hip 4** |
| SA    | 67.3 67.6 67.8 68.1 68.1 | 66.5 68.1 68.3 68.7 69.5 | 68 68 68 68 70 |
| KAK   | 69.2 69.5 70.7 71.3 72.4 | 66.8 67.4 69 69 69 | 68 68 69 69 70 |
| Diff. medians | -2.9 | -0.7 | -1 |
| Largest - smallest | 5.1 | 3.0 | 2 |

Difference of absolute largest - smallest: Hip 1=6.3 Hip 2=10 Hip 3=6.5 Hip 4=6

---

**Table 2**

**PASA**

The results in each group have been arranged with increasing values. The **median** figure is in **bold type**.

<table>
<thead>
<tr>
<th></th>
<th>method I</th>
<th>method II</th>
<th>method III</th>
</tr>
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<tbody>
<tr>
<td><strong>Hip 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>103 103 103 104 105</td>
<td>97 99 99 99 101</td>
<td>100 100 100 101 101</td>
</tr>
<tr>
<td>KAK</td>
<td>100 101 102 104 105</td>
<td>99 100 101 101 101</td>
<td>100 100 101 102 103</td>
</tr>
<tr>
<td>Diff. medians</td>
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<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>Largest - smallest</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

| **Hip 2** |
| SA    | 99 99 99 99 100 | 99 99 99 100 101 | 97 98 99 100 101 |
| KAK   | 101 104 104 104 105 | 99 99 100 100 101 | 97 97 99 101 101 |
| Diff. medians | -5 | -1 | 0 |
| Largest - smallest | 6 | 2 | 4 |

| **Hip 3** |
| SA    | 100 101 101 101 103 | 96 97 97 97 98 | 96 96 97 97 98 |
Table 3

The results in each group have been arranged with increasing values. The median figure is in **bold type**.

<table>
<thead>
<tr>
<th>Hip</th>
<th>Method I</th>
<th>Method II</th>
<th>Method III</th>
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<tbody>
<tr>
<td></td>
<td>SA</td>
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<tr>
<td>Hip 1</td>
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</tr>
<tr>
<td>SA</td>
<td>166 166 167 168 168</td>
<td>155 157 158 158 161</td>
<td>159 159 159 160 161</td>
</tr>
<tr>
<td>KAK</td>
<td>162 163 163 166 166</td>
<td>158 159 160 161 161</td>
<td>159 160 161 161 165</td>
</tr>
<tr>
<td>Diff. medians</td>
<td>4</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>Largest - smallest</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td>Hip 2</td>
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<tr>
<td>SA</td>
<td>158 158 158 158 160</td>
<td>158 159 159 160 161</td>
<td>155 158 158 160 162</td>
</tr>
<tr>
<td>KAK</td>
<td>162 166 169 169 171</td>
<td>158 159 159 160 161</td>
<td>155 155 159 161 161</td>
</tr>
<tr>
<td>Diff. medians</td>
<td>-11</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>Largest - smallest</td>
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<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Hip 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>169 169 170 170 174</td>
<td>161 162 162 162 153</td>
<td>160 161 162 163 164</td>
</tr>
<tr>
<td>KAK</td>
<td>167 168 169 169 169</td>
<td>163 163 165 165 166</td>
<td>162 162 163 165 166</td>
</tr>
<tr>
<td>Diff. medians</td>
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<td>-3</td>
<td>-1</td>
</tr>
<tr>
<td>Largest - smallest</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Hip 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>169 170 171 171 171</td>
<td>170 173 173 173 173</td>
<td>170 171 171 172 173</td>
</tr>
<tr>
<td>KAK</td>
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<td>169 171 172 173 174</td>
<td>171 171 171 172 172</td>
</tr>
<tr>
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<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Largest - smallest</td>
<td>10</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Difference of absolute largest - smallest: Hip 1=13 Hip 2=16 Hip 3=14 Hip 4=10

Tables 1-3 show that the largest estimate of the sector angles occurred with method I, which involved eyesight. This was also the method which had the largest discrepancy of the results, as well as...
largest inter-observer variation.

Both method II and III showed good agreement of the results for both investigators. The largest absolute difference of any measurements by these methods was 4 degrees for PASA of hip 2 and 3 by method III, all the other observations were closer together. HASA is determined from adding AASA and PASA, and consequently showed larger variation of the results, also in this case largest by method I. However, method II and III gave consistent results also for HASA, with the largest difference calculated to 6 degrees for hip 1, 2 and 3. As a conclusion it seems that method II and III have a high accuracy for determination of the sector angles, if the correct measuring slice is chosen. Method I is unprecise with a tendency towards overestimation of the values of the sector angles, and can consequently not be recommended.

If it is assumed that we chose one level wrong for the centreimage, it can be seen (Papers I, IV) that the sector angles will be 5-6 degrees off the measurements from those of the correct slice both in normal and dysplastic adult hips.

The sector angles changed approximately 0.7 degrees per degree of pelvic inclination (Paper II). The pelvic inclination appeared rather fixed in each subject (Paper II), so changes of the sector angles due to change of pelvic inclination are probably not a great problem.

As a conclusion from this discussion of errors of measurement of the acetabular sector angles and from the study presented above, it would seem safe to assume an uncertainty of ±5 degrees in the measurements of these angles.

CT - measured femoral neck anteversion - FeAV

The identification and marking of the centrepoint of the femoral head (Paper III) was easy and precise. This point was kept on the TV-monitor, and images advanced until an image of the middle part of the femoral neck appeared. The line between the centre of the femoral head
and the midpoint between the anterior and posterior margins of the femoral neck then represented the apparent femoral neck anteversion (Paper III). The main objection to this method is that one out of several possible slices of the femoral neck has to be chosen for measurement. Several groups of investigators (Murphy et al. 1987, Mesgarzadeh et al. 1987, Høiseth et al. 1989 a) have shown that the results will vary considerably with the chosen CT slice.

The tangent to the posterior femoral condyles was used as a reference line. The femoral condyles have a relatively even and symmetrical curvature posteriorly, and this indicates that the measuring error by employing this line is relatively small (Murphy et al. 1987), as long as measurements are made at the most posterior part of the condyles. We deliberately used 10 mm thick slices in order to take advantage of the partial volume effect.

Høiseth et al. (1989 a) found that the CT measurement of FeAV has an accuracy of ±5 degrees, and that the method is slightly less accurate than the biplanar method of Dunlap/Rippstein. CT measurements of FeAV would therefore seem indicated as part of a total CT evaluation of the hip.

**RADIOGRAPHY**

"Direct" measurement of the femoral neck anteversion
During the in vitro study (Paper VI), radiographic projections were obtained with the femur oriented to get the line of measurement parallel with the film. In this way direct measurements of the projected line could be made from the radiographs with minimal projectional distortion. We consequently consider the error of these
measurements as small, probably less than ±2 degrees.

An almost axial projection of the femur as described by Budin & Chandler (1957) for measurement of the femoral neck anteversion was also included, but the femur was abducted 5 degrees to better project free the femoral neck, as did Reikerås et al. (1985), Mesgarzadeh et al. (1987) as well as Høiseth et al. (1989a). A frontal radiograph of each femur was also obtained and the projected collum-diaphyseal angle (the CCD angle) measured. The formula of the Dunlap/Rippstein method (see below) was used to correct the 5 degree abducted FeAV angle, as did Reikerås et al. (1985). The corrected values were 0 to 2.5 degrees larger than those measured. Mesgarzadeh et al. (1987) gave ±2 degrees as the accuracy of direct axial determination of the FeAV angle in dried bones - although they did not correct for the slight abduction. We cannot agree with this, as we in some instances found it difficult to determine the projected outline of the femoral neck, even when using 5 degrees abduction. In some cases with discrepancy of measured values of direct FeAV (Paper VI), the two investigators made a common decision as to where the measuring point on the femoral neck image should be made. This was done to the best of our ability, but this decision was not necessarily correct.

The biplanar radiographic method of Dunlap/Rippstein for determination of femoral neck anteversion - FeAV

The "real" femoral neck anteversion was calculated from two standardized, supine radiographic projections. The first was obtained in a specially designed apparatus called the Müller frame (1971) with the patient lying on the X-ray table with 90 degrees flexion and 20 degrees abduction of the hips. The knees were also flexed 90 degrees, and the legs rested in the horizontal arms of the Müller frame. A frontal radiograph was obtained with vertical x-ray beam, and 100cm film...
focus distance, centered 2 cm above the pubic symphysis. The second frontal radiograph was obtained with the same film focus distance, with the hips extended, the knees flexed 90 degrees over the table edge and the legs vertical. The apparent anteversion (FeAV") was measured from the first projection, and the apparent collum-diaphyseal angle (CCD") from the second. The real femoral neck anteversion was calculated by a standard conversion table (Skandfer & Sudman 1976) made from the formula:

1) \[ \text{tg Real FeAV} = \frac{\text{tg apparent FeAV} \times \cos (\text{projected CCD angle} - 90 - 20)}{\cos (\text{projected CCD angle} - 90)} \]

The errors and inaccuracies of this method have been extensively studied (Ruby et al. 1979, Henriksson 1980, Reikerås 1985, Høiseth et al. 1989a). If the patient is properly positioned the accuracy is reported to be ± 5 degrees. If the method is performed incorrectly, the error can of course be much larger (Brattstrøm 1962, Gross & Haike 1970, Ruby et al. 1979). We used this method as a standard (Papers V, VII) for comparison with ultrasound measurements, realizing that dedication to the method was all important in order to obtain reliable results. The author therefore personally positioned all the patients measured by this method, as well as making the calculations in order to minimize inaccuracies.

The centre-edge (CE) angle of Wiberg

The CE angle was measured from a standard frontal radiogram of the pelvis obtained with 100cm film focus distance as described by Wiberg (1939). The centres of the femoral heads were identified by use of a Müller (1971) ischiometer, and the intercapital centreline drawn. Thereafter the line from one femoral head centre to the upper lateral acetabular rim was drawn (Fig 3). The angle between these lines minus
90 degrees is the Centre Edge angle of Wiberg (1939). The CE-angle also changes with pelvic inclination (Wiberg 1939). If gross posture changes caused for instance by contractures of the hip, are not present, however, there is no reason to believe that the pelvic inclination will vary substantially (Paper II). In several of our patients with hip dysplasia we had multiple pelvic radiograms obtained at different times. There was never a discrepancy of more than 2 degrees between measurements of the CE-angle from different radiograms. Wiberg (1939) set a lower normal limit of 20 degrees (Paper I), while 20-25 degrees were considered borderline values. All hips measuring 20 degrees or more were consequently excluded from the material of dysplastic hips (Papers III, IV). Hips with CE-angles less than 18 degrees were included. Those measuring 18-19 degrees were given close consideration and measured several times, if possible from multiple pelvic radiograms before inclusion.

ULTRASONOGRAPHY

A real-time ultrasound apparatus with a 5 MHz rectangular, linear, transducer (Sonoline SL 2, Siemens AB, Erlangen, Germany) was employed in all the ultrasound investigations. The linear transducer contained 64 piezoelectric crystals arranged in groups. The emitted US beams were parallel and perpendicular to the surface of the transducer. A clinometer with square sides, originally made for a standard Siemens X-ray apparatus was used for direct measurements of angles.

US measurements of femoral neck anteversion -
the tilted transducer technique
The clinometer was fixed to one side of the linear probe (Paper V, VII). Ultrasound gel was applied to the skin, and the probe manipulated until
the measurement line was clearly seen on the monitor screen. The probe was then tilted until the measurement line appeared horizontal on the screen, i.e. parallel with the base line. The probe was kept vertical in other respects, and the angulation of the probe was read directly from the attached clinometer.

There are several methodological and theoretical objections to this method:

**First** Good eye-sight is a prerequisite, as a possibly irregular line shall be brought parallel with the screen base line. To minimize this error, horizontal auxiliary lines were mounted on the monitor screen. In practice this error is probably not great, as most people who are potential users of the method should have good training and dedication to imaging work.

**Second** There may exist inaccuracies in the ultrasound image itself. This is improbable, however, as the distance from each piezoelectric crystal to the measurement line is equal in all parts of the image.

**Third** The probe and the inclinometer may not be exactly square. However, we were not able to detect deviations from the right angle in any of the components by testing with a standard carpenter right angle measure.

**Fourth** It requires familiarity with the method and practice to identify the line of measurement.

However, despite these theoretical objections, clinical testing has shown a surprisingly low inter-observer variation, found to be only mean 1.3 degrees SD 1.9 (0 - 8 degrees), in a clinical investigation of 100 normal adult hips (Bråten et al.1990).

**US measured FeAV with the probe horizontal**

The same objections as above are relevant, but in this case the clinometer only ensures that the linear probe is kept horizontal. The measurement line is more or less oblique, and the angulation of this line with the image base line gives the femoral anteversion (Papers VI).

Possible inaccuracies in the ultrasound apparatus itself must be
considered. Distortion in the deep part of the image may occur, as the
distance from different piezoelectric crystals varies. This error may be
considerable if the measurement line has a steep angulation, as in hips
with large anteversion of the femoral neck. There is furthermore a
tendency for the linear ultrasound probe to lose contact with the skin
laterally over the lateral femoral neck and greater trochanter in
patients with particularly large AV angles (Papers V,VII). These may be
the reasons why Phillips et al.(1985) found the horizontal transducer
method unreliable when the anteversion was greater that 40 degrees.
These objections to ultrasound measurements with the probe horizontal
are important, as the patients with high values of femoral neck
anteversion are those who are considered for operative treatment.

**Orientation of the femoral condyles**
The posterior femoral condyles were oriented horizontally by flexing
the knees 90 degrees over the table edge and strapping the legs
vertically. Ligamentous laxity of the knee may cause missing contact
between the tibial and posterior femoral condyles (Brattstrøm 1962),
but this objection is probably of no great practical concern. Henriksson
(1980) has shown that the posterior condylar tangent is not exactly
horizontal when the leg is oriented vertically, which involves eyesight.
However, the Dunlap/Rippstein method also employs 90 degrees
flexion of the knees for orientation of the posterior femoral condyles.

Ultrasound measurements of the posterior condylar line were tested
(Paper V). The objections to this method are the same as those
regarding measurements of the FeAV, see above.

**THE PELVIC INCLINOMETER METHOD**
A new concept was developed by this method. Cyriac (1924) and later
McKibbin (1970) suggested a reference plane through the anterior superior iliac spines and the anterior pubic tubercles. A specially designed inclinometer for the measurement of the angulation of this plane both in supine and standing subjects was constructed. Three 10cm blocks of wood were attached to a sheet of plywood. The two

![Diagram of the pelvic inclinometer](image)

**Figure 7**

The pelvic inclinometer applied to a standing subject

- Mark the contact points of the wooden blocks;
- the anterior superior iliac spines (ASIS), and the anterior pubic tubercles (PT)
cranial blocks could be moved along oblique slits in the plywood to adjust for patient size. On the other side of the plywood square, two identical commercial angle measurers for maritime use (Silva, Sweden) were mounted, one for horizontal and one for vertical registration (Fig 7). These were accurate when tested against a spirit level both for the horizontal and vertical position.

The measurements by this method are probably accurate in thin and middle weight subjects as the measuring points of the anterior pelvis are covered by approximately the same amount of soft tissue. This may not be the case in the overweighty. The angulation of the reference plane may in these cases be inaccurate. For comparison between standing versus supine measurements in the same subject, however, this should not influence the results as the error is the same in both positions. An intra-observer study was not performed, and this is a weakness. The inter-observer variation was small, however (Paper II).

**STATISTICAL METHODS**

Generally accepted and simple statistical evaluations have been used. Students two tailed t-tests for evaluation of distribution of the measurements has been used extensively. The limit of normality has been set as mean ±2 standard deviations, at the 95% confidence level of probability. Students t-test was also used to test the significance of mean differences. Pearson's coefficient for linear correlation between different parameters was used (Papers I, III, VI). The values of the sector angles of the cadaver hips (Paper II), were deliberately not treated statistically due to the small number investigated (10 hips). The values were instead presented as curves for each hip separately. In the intra-/inter-observer study of the acetabular sector angles, the results were presented in general tables.
RESULTS

SPATIAL ORIENTATION OF THE ACETABULUM

The inlet (von Lanz 1951) or opening plane of the acetabulum (Murphy et al.1990), defined from all the points on the acetabular margin, faces infero-laterally and slightly forward (von Lanz 1951, Getz 1955, Tönnis 1987, Murphy et al.1990). This opening plane may be characterized by two lines. A horizontal line will represent the acetabular anteversion, while the line perpendicular to this will be the inclination of the opening plane with the horizontal plane. Murphy et al.(1990) in a 3D CT study of adult hips found the abduction of the perpendicular to the opening plane to be $53 \pm 6$ degrees in normal adults, and $62 \pm 3$ degrees in dysplastic hips. We have not measured this parameter.

THE ACETABULAR ANTEVERSION

The pelvic inclination

The pelvic inclination relative to the frontal plane was almost the same supine as standing in normal subjects (Paper II). This indicated that supine CT measurements of the hip with unangulated gantry, are equivalent to corresponding angles in the standing subject. Furthermore the reference plane through the anterior superior iliac spines and pubic tubercles (McKibbin 1970) showed only a slight reclination in living subjects in relaxed positions, both erect and supine, (Paper II) as well as in the corpses. The conclusion was that the suggestion by McKibbin (1970), that the reference plane was frontally oriented in normal subjects, was sufficiently accurate for practical work (Paper II). This indicated furthermore that the acetabular
anteversion measured by supine CT was relatively standardized in normal subjects (Paper II).

In order to orientate the scanning plane exactly perpendicular to the reference plane of McKibbin, the pelvic inclination is measured. Thereafter the gantry of the CT machine may be angulated to exactly counteract the pelvic inclination. This may be of practical importance in patients with unpredictable pelvic inclination as in flexion contractures of the hip.

The study of the hips of the corpses (Paper II) showed that the acetabular anteversion changed approximately 0.5 degree with each degree of pelvic inclination, decreasing with increase of pelvic inclination (rotation forward) and increasing with reclination.

Dechambre & Teinturier (1966) realized the dependency of the AcAV on pelvic inclination, and measured the acetabular anteversion by a lateral oblique radiographic projection of the hip (35 degrees angulation) in sitting subjects (Dunlap et al 1956). One radiograph was obtained with the plateau of S1 horizontal, and one in the "functional position", defined as 30 degrees forward inclination of the S1 plateau relative to its first position. Note that 90 degrees should be subtracted from the figures in order to obtain the values of AcAV as commonly defined.

<table>
<thead>
<tr>
<th></th>
<th>12 Men</th>
<th>6 Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>AcAV with horizontal S1</td>
<td>29</td>
<td>33.5</td>
</tr>
<tr>
<td>&quot;Functional&quot; AcAV</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Difference</td>
<td>14</td>
<td>16.5</td>
</tr>
</tbody>
</table>

In other words; they found on average a 15 degree change of AcAV with 30 degrees change of pelvic inclination, that is 0.5 degree change of
AcAV per degree pelvic inclination complying exactly with our results (Paper II). It must be realized, however, that their figures should be taken as an approximation only, as the two positions were obtained on eyesight, and the film holder was angulated 35 degrees with the X-rays causing projectional distortion of the radiographic image.

Furthermore this is in accordance with the biomechanical considerations of Rab (1978) regarding the change of AcAV in Salter osteotomy of the innominate bone, where the lower pelvic quarter of the acetabulum is bent laterally and rotated forward with the pubic symphysis as a fulcrum.

As a practical consequence it is possible to calculate the exact AcAV according to McKibbin when the pelvic inclination has been measured by the inclinometer, adjusting 0.5 degree for each degree of pelvic inclination.

Most recent reports of AcAV in the literature have been performed according to McKibbin (1970). McKibbin (1970) cited Fernández (1965) who found values of AcAV between 11 degrees and minus 27 degrees in neonates - i.e. that the acetabulum was in some instances actually facing backwards.

Older investigators as von Lanz (1951) and Getz (1955) give much higher values of AcAV. They measured in a plane parallel to the pelvic inlet. In our pelvic preparation we found as von Lanz (1951), Getz (1955), later on confirmed by others (McKibbin 1970, Visser 1984, Tönnis 1987) that this plane inclined 60 degrees with the measurement plane of McKibbin (1970). By extrapolating the formula of 0.5 degree change of AcAV per degree pelvic rotation outside the range of our measurements (Paper II), we found that the corrected values of von Lanz (1951) and Getz (1955) were far smaller than measurements made according to McKibbin (1970). This indicated that our formula was not valid far beyond the measurement range (Paper II), and led to the concept of a mathematical model employing a sine curve. This curve
probably describes more correctly the change of the acetabular anteversion outside the range of our measurements of 40 degrees pelvic tilt (Paper II):

2) \[ \text{AcAV} = \text{AcAV-max-angle} \times \text{Sine pelvic inclination angle} \]

The AcAV-max-angle is here defined as the largest possible value of AcAV obtained by reclining the pelvis. Using this formula (Paper II) it was possible to reconcile the values of von Lanz (1951) and Getz (1955) with those of others. Moreover, it was also possible to explain why Fernández (1965) in some cases actually measured a retroversion of the acetabulum. It was also seen that the curve had an even slope with a coefficient of 0.5 in the range of our measurements thereby complying with these, as well as those of Dechambre & Teinturier (1966).

As the AcAV-max-angle coincides with the angle of the acetabular inclination with the horizontal plane, it will be small in hips with large inclination. Furthermore, the sine curve will be flatter, and the change of acetabular anteversion will be less than 0.5 degree per degree of pelvic inclination.

It had previously been shown that the anteversion of the acetabular cup of the Müller total hip prosthesis could be calculated by measuring the projection of the equatorial ring marker in a standard frontal radiograph (McLaren 1973, Ghelman et al.1979, Petterson et al.1982, Visser & Konings 1982) according to the formula:

3) \[ \text{Sine AcAV angle} = \frac{\text{Small diameter of equatorial acetabular marker}}{\text{The large diameter}} \]

This is easy to explain theoretically as we are dealing with a perfect circle projected as an oval.

Frot & Duparc (1973) suggested measurement of the distance between
the anterior and posterior acetabular margins from four pelvic radiographs, with standardized rotation around the long axis of the body. These projected distances were shown to vary according to a sine curve. The real AcAV was found as the rotation of the pelvis where the sine curve passed zero. That this was the true AcAV was confirmed by a final pelvic radiograph taken with exactly this pelvic rotation. This method therefore required altogether five takes, with rather high radiation exposure. Furthermore, with the advent of CT, measurement of AcAV from proper transaxial images became easy, and this consequently replaced previous radiographic methods.

Practical implications

From figure 10 may be seen that increase of pelvic inclination will cause a considerable retroversion of the acetabulum. Weinberg & Pogrund (1980) maintain that the femur is entirely passive in the neonatal period and remains stationary. The active movement is an unfolding of the pelvis from a fetal position of strong reclination with flexion of the spine to increased inclination with extended spine. A further increase of pelvic inclination in older subjects is obviously impossible due to the restricted mobility of the lumbar spine. However, it is the relationship between the femur and acetabulum which is important, and instead of inclining the pelvis 90 degrees, which is not feasible, the femur may be flexed 90 degrees. This will cause a functional retroversion of the acetabulum, relative to the femur shaft. What is observed as the slope or inclination of the acetabulum with the transverse line on the frontal pelvic radiogram, now has become the acetabular anteversion. Or to be precise; the complimentary angle of the acetabular inclination has become the AcAV angle. This is also the theoretic maximal value of AcAV=AcAV-max-angle. In dysplastic hips is the inclination of the acetabulum often increased (Murphy et al. 1990), and as a consequence of this is the AcAV max-angle of these
hips lower than in normals.

Moreover, the Ortololani (1937, 1976) and Barlow (1962) maneuvers demonstrate posterior luxation, elicited by 90 degrees hip flexion, where according to the sine curve, there is a considerable functional retroversion of the acetabulum.

The normal neonatal value of the AcAV is approximately 5 degrees (McKibbin 1970). Tilting the pelvis forward, or rather by flexing the

![Figure 8](image)

**Figure 8**
View along the femoral shaft in the extended neonatal hip after de Daman (1908). C is the centre of the femoral head. FS is the femoral shaft. PFC are the posterior femoral condyles. Note marked obliquity between the axis through the femoral head-neck and the acetabular anteversion (broad lines).

![Figure 9](image)

**Figure 9**
The same hip as above, viewed along the femur shaft - but now in 90 degrees flexion. Note that the head-neck axis of the femur now is perpendicular to the acetabular anteversion or rather - acetabular retroversion.
femur 90 degrees, causes a relative retroversion of the acetabulum of approximately 30 degrees (Fig 9). The approximate normal value of the femoral anteversion in the neonate is 30 degrees (McKibbin 1970). In other words, the femoral anteversion matches the functional retroversion of the acetabulum in the 90 degree flexed normal neonatal hip (Fig 9) as also realized by le Damany (1908). The conclusion is that the neonatal human hip was built for flexion, just as the hip of other mammals (le Damany 1908). However, it should be clearly realized that this calculation presumed that there was a neutral rotation and abduction of the femur. It is well known that the neonate prefers a marked abduction and external rotation in the supine position. It may be speculated that this will counteract the functional retroversion of the 90 degrees flexed hip. Moreover, this is a stable position for the reduced hip in CDH (Pavlik 1957, von Rosen 1962).

**Hip rotation in extension and flexion**

Internal and external rotation of the femur may depend on restrictions from soft tissues (Somerville 1957) or impingement of bony structures (le Damany 1908, Fig 8). If the concept of retroversion of the acetabulum relative to the flexed hip is valid, this should reflect on the rotation of the femur in extension compared to that of flexion.

Gelberman et al. (1987) performed a CT study of femoral anteversion and a clinical assessment of idiopathic in-toeing gait in 23 children aged 3 to 10 years, 15 girls and 8 boys. The lateral (external) and medial (internal) rotations of the hip were investigated clinically both in extension in the prone position with the knees flexed to 90 degrees, as well as supine with both the hips and knees held in 90 degrees flexion. The femoral neck anteversion was determined by CT and the material divided in two. Furthermore was a normal control group included:

Group I: 15 children (30 hips) - increased FeAV=mean 49 degrees SD 10.
Group II: 8 children (16 hips) - normal FeAV = mean 32 degrees SD 6.

Group III: 20 children (40 hips) with the same age distribution and with normal hip rotation were used for control of rotation, but did not have CT.

Table 5
Femoral rotation and femoral neck anteversion in degrees (mean SD) according to Gelberman et al. (1987):

<table>
<thead>
<tr>
<th>n</th>
<th>extension Medial</th>
<th>extension Lateral</th>
<th>90 degrees flexion Medial</th>
<th>90 degrees flexion Lateral</th>
<th>Femoral anteversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>80</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>49</td>
</tr>
<tr>
<td>16</td>
<td>71</td>
<td>4</td>
<td>18</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>80</td>
<td>51</td>
<td>8</td>
<td>54</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

There are three important unknown factors in this study:
1) The AcAV angle was not measured.
2) The CCD angle was not measured, and the relative varus - valgus position of the femoral neck was therefore unknown.
3) The firmness of the soft tissues was not evaluated. Did the material include cases of familial joint laxity (Wynne Davies 1970)?

In group III of normal hips there was no change in rotation between flexion and extension. This probably reflected that there was no bony impingement in any of the extreme rotational positions. As the AcAV had not been measured, it only remains an educated guess that the instability index of le Damany (1908) in many hips of group I probably were near or above 60. If this was true, however, the posterior femoral neck would have impinged on the posterior acetabular margin in extension and consequently restricted external rotation as explained by le Damany (1908, Somerville 1957), and later demonstrated in a CT investigation by Reikerås et al. (1983). That no such impingement took
place in 90 degrees flexion is demonstrated by the average external rotation of 45 degrees in group I. Group II had nearer normal values, but also in this group external rotation was restricted in extension, but not in flexion. As these hips had normal femoral neck anteversion, it may be speculated that they had large acetabular anteversion (Kleiger 1968).

To complicate this explanation, the capsule of the hip joint must be taken into consideration. The capsule is fully stretched and stabilizes the hip in hyperextension (Johnston 1973). Restricted external rotation in extension could therefore be due to a tight, stretched capsule in this position. This may be, and probably is a contributing factor, but cannot be the only explanation, as the external rotation was unrestricted in the normal hips of group III.

The conclusion is that in cases with in-toeing, the difference found between the lateral rotation in flexion and extension, indicates that there was a considerable difference in the relative acetabular anteversion/retroversion, as all other factors except possibly the taughtness of the soft tissues remained the same. This may consequently be taken as an indication of the validity of the concept of a functional retroversion of the acetabulum in the flexed hip.

The biomechanical “resting” position of the hip
As the child grows there is a derotation of the femur (le Damany 1908, Saito et al.1980, Svenningsen et al.1989), and the average FeAV decreases from 30-40 degrees to a normal adult value of approximately 12 degrees (Kingsley & Olmstedt 1948, Terjesen et al.1982, Reikerås et al.1983). At the same time the AcAV increases from approximately 5 degrees to the normal adult value of approximately 18 degrees (McKibbin 1970, Paper I). To exactly “counteract” the FeAV value, a functional retroversion of 12 degrees would therefore seem desirable.
AcAV = AcAV max angle \cdot \text{Sine pelvic inclination angle.}

N\ AcAV of = 18 degrees indicate the average normal adult acetabular anteversion. R Retrov is the functional retroversion obtained by inclining the pelvis 60 degrees - or by flexing the femur 60 degrees. R Retrov = 12 degrees

This would occur if the pelvic inclination was increased (18 + 12) degrees \times 2 = 60 degrees. Or alternatively - if the femur was flexed 60 degrees. Correspondingly all hips will have a position with a specific flexion of the femur where the FeAV and functional AcAV match each other. This position is found by the formula:

4) \ (\text{FeAV} + \text{AcAV}) : 1/2 \quad \text{that is:} \quad 5) \ (\text{FeAV} + \text{AcAV}) \times 2

This is defined as the **biomechanical resting position of the hip**.

According to this concept will hips with high values of the biomechanical resting position be stable in extreme flexion, but poorly
adapted for extension, with a tendency to anterior dislocation of the femoral head in this position. Hips with small values, are adapted for extension, but poorly for flexion, with a tendency to posterior dislocation in this position.

The biomechanical resting position of the hip may be related to the angle of incidence of the hip as defined by von Lanz (1951). The angle of incidence is determined between the femoral head-neck and the opening plane of the acetabulum in 30 degrees flexion of the hip. Von Lanz (1951) maintained that the angle of incidence was 90 degrees in normal male and 92 degrees in female hips.

The instability index of the hip

According to formula 5 the femoral and acetabular anteversion can be added and multiplied by two to find the biomechanical resting position in the physiological range. For extreme values of AcAV and FeAV the relationship is more complicated, as the sine function of the curve (Fig 10) must be taken into consideration. Le Damany (1908) postulated that the sum of the AcAV and FeAV, later on called the instability index of the hip joint by McKibbin (1970), must never exceed 60. If this occurs, the joint will become unstable as the posterior acetabular rim will impinge on the posterior femoral neck (Fig 8), and force the femoral head out of the acetabular socket anteriorly. However, there are several ways in which the hip with such unfavourable values of the femoral and acetabular anteversion may adjust:

1: The functional femoral anteversion may be diminished by internal rotation of the femur, clinically observed as in-toeing (Alvik 1962).
2: The acetabular anteversion may be reduced by increasing the pelvic inclination (Paper II), i.e. by increasing the lumbar lordosis, which is easily observed clinically.
3: The functional situation may be improved by flexing the hip, thereby reducing the relative acetabular anteversion. Clinically this is observed as a tendency of the patient to assume a standing posture with a slight flexion of the hips - and knees (Somerville 1957).
Implications for total hip prostheses

It is suggested that the philosophy presented above, applies to all hips in children and adults, as well as in hip prostheses. It is a common clinical observation that the femoral head of a total hip prosthesis has a tendency to dislocate anteriorly in extension by external rotation (Ranawat & Figgie 1991), while posterior dislocation occurs in flexion, adduction and internal rotation (Ranawat & Figgie 1991). Malposition of the components of the total prosthesis are usually considered the cause; increased anteversion of the acetabular cup will lead to anterior dislocation and retroversion to posterior dislocation. From the discussion above, it follows that relative to the flexed hip, there is a retroversion of the acetabulum, even in the hip with a “normal” anteversion of the acetabular cup. The practical implications of this is not obvious, however. A theoretic discussion of the vector forces acting on the hip joint is considered necessary: In different positions changing forces act upon the hip. However, it is always possible to decompose the forces into: 1) An axial vector force acting along the mechanical axis of the femur. 2) A vector force acting perpendicularly to the axial component (Pauwels 1965). This second perpendicular force will have changing magnitude, and equally important, direction. It is the belief of the author that it is this perpendicular vector force that is the most important in causing dislocation of the hip, both in the neonatal dysplastic hip as well as in total prostheses. Weinberg & Pog Lund (1980) in a study of neonatal stillborns showed that the femoral head dislocated anteriorly and superiorly in extension. In flexion, dislocation occurred inferiorly through the opening of the acetabular notch. I believe that the mechanism is identical in dislocation of total prostheses. In flexion there is primarily a dislocation inferiorly due to an intermittent inferiorly acting perpendicular vector force.
Subsequently will the axial vector force bring the femoral head posteriorly, and this is the position which is observed by imaging methods or at reoperation. In light of this, it is suggested that changes in the design of total prostheses should be considered, reinforcing them with regard to the relative retroversion of the flexed hip (Olerud & Karlstrøm 1985).

The AcAV in dysplastic hips - dependency on the slice level

No consistent difference of acetabular version measured from the central slice through the femoral head was found in the dysplastic (Paper III) compared to normal hips (Paper I). This is in accordance with other reports (Høiseth et al.1989, Murphy et al.1990).

In normal adult hips (Paper I) the acetabular anteversion was measured at five different levels, and found to differ very little between the slices, in accordance with Visser et al.(1982). This indicated that the acetabular anteversion of normal adult hips was relatively constant and independent of the slice level.

The mean acetabular anteversion, however, increased considerably from the cranial to the caudal cuts of dysplastic hips (Paper IV). The difference between the AcAV of normal (Paper I) and dysplastic hips (Paper IV) was not significant, however, except at the lowest level which was 5mm below the centreslice. Also Terver et al.(1982) and Reikerås et al.(1983) reported a level dependency of AcAV in dysplastic hips. Neither group gave any indication of the numerical values of the observed changes. The majority of reports so far therefore seem to indicate a slight level dependency of CT measurements of AcAV, especially in dysplastic hips. It is therefore important to agree on a standardized level for this measurement, and it (Paper IV) is suggested as did Terver et al.(1982) and Reikerås et al.(1983) that the CT-slice through the centre of the femoral head should be used.
THE ACETABULAR SECTOR ANGLES

The acetabular sector angles in normal adult hips (Paper I) increased in cranial cuts, and decreased caudally. This may be explained by the

Figure 11

Drawing showing the spatial relations between the sector angles (AASA, PASA) and the CE-angle. Note that the centre of the femoral head (C1) is a common reference point. C2 is the centre of the contralateral femoral head.
slope of the acetabular rims and the sphericity of the femoral head. Høiseth et al. (1989c) found normal adult values corresponding to ours for both genders, as did Murphy et al. (1990) in their total material of normal adult hips by calculations of the sector angles from reconstructed three dimensional CT images. For normal females, however, Murphy et al. (1990) reported somewhat but not significantly, lower values of the sector angles.

The sector angles also changed with the pelvic inclination in a linear fashion in the observed range (Paper II). The approximate change was 0.7 degree per degree pelvic inclination. PASA decreased while the AASA increased with increase of inclination. The theoretical variation of the sector angles with inclination outside the measured range has not been assessed, but it may be speculated that also these angles vary according to sine functions?

Anterior acetabular support - AASA

We maintain that the anterior acetabular sector angle gives an adequate quantification of the anterior acetabular support offered to the femoral head (Paper IV), just as the CE-angle quantifies the lateral superior acetabular cover of the femoral head (Wiberg 1939). Published values of AASA are presented in table 6:

Table 6

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>mean</td>
</tr>
<tr>
<td><strong>Normal hips</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anda (I) (1986)</td>
<td>40</td>
<td>63</td>
</tr>
<tr>
<td>Høiseth (1989c)</td>
<td>R 17</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>L 17</td>
<td>64</td>
</tr>
<tr>
<td>Murphy (1990)</td>
<td>49</td>
<td>62.5</td>
</tr>
<tr>
<td>but of these were</td>
<td>14</td>
<td>58</td>
</tr>
</tbody>
</table>
Table 6 shows that the values of the AASA were almost identical in the three normal materials. Høiseth et al. (1989c) also measured from a slice through the centre of the femoral head, but used 10 mm cuts as opposed to our 5 mm cuts. Murphy et al. (1990) did not state their slice thickness, but as the transaxial CT slices were used for generation of three dimensional CT images, they must have used multiple thin slices, 2-3 mm or 4mm with overlapping. These results indicate that AASA does not appear to change appreciably with the slice thickness.

Høiseth et al. (1989c) found slightly higher values of the AASA in a patient material with increased FeAV.

In dysplastic hips Murphy et al. (1990) found values of AASA below ours (Paper III). There are two possible explanations for this, the first methodological: The sector angles of our dysplastic material (Paper III) were calculated by the angle measure program of GE CT 9800 (Method I). As shown under the intra- and inter-observer study, this method has a tendency to overestimate the sector angles. Second: The two dysplastic materials were probably different as Murphy et al. (1990) found a mean CE-angle of 5 degrees SD 6, while we noted 12.5 degrees SD 5. This would indicate that the hips in the report of Murphy et al. (1990) on average were more dysplastic than ours. Furthermore their material probably contained more hip subluxations.

Two thirds of the dysplastic hips had smaller AASA than the lower normal limit. This indicated that the anterior acetabular support to the femoral head was insufficient in most of the dysplastic hips, and is in
keeping with the 3D CT study of Murphy et al.(1990) of adult dysplastic hips. Both Gugenheim et al.(1982) as well as Edelson et al.(1984) in CT studies of children with CDH found an anterior, lateral superior defect in most hips. This defect became more prominent in older children, sometimes progressing to a true anterior, superior false acetabulum.

The posterior acetabular support - PASA
Just as the AASA quantifies the anterior acetabular support to the femoral head, we maintain that the PASA quantifies the posterior support (Paper IV). Published values of PASA are presented in table 7:

Table 7

<table>
<thead>
<tr>
<th>PASA</th>
<th>Values in degrees</th>
<th>R=right</th>
<th>L=left</th>
<th>n=number of hips</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Women</td>
<td>n</td>
<td>mean</td>
<td>SD (range)</td>
</tr>
<tr>
<td><strong>Normal hips</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anda (I)(1986)</td>
<td>40</td>
<td>105</td>
<td>8</td>
<td>(93-124)</td>
</tr>
<tr>
<td>Høiseth(1989c)</td>
<td>R 17</td>
<td>109</td>
<td>12</td>
<td>(94-130)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murphy (1990)</td>
<td>49</td>
<td>104.5</td>
<td>7</td>
<td>sex unspecified</td>
</tr>
<tr>
<td>Hips with suspected increase of FeAV=25 degrees ±10 (6-50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Høiseth (1989c)</td>
<td>26</td>
<td>115</td>
<td>12</td>
<td>(94-135)</td>
</tr>
<tr>
<td>Dysplastic hips</td>
<td>(CE-angle &lt;20 degrees)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murphy (1990)</td>
<td>20</td>
<td>80</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Anda (III)(1991)</td>
<td>33</td>
<td>92</td>
<td>11</td>
<td>(71-114)</td>
</tr>
</tbody>
</table>

The accordance between the normal materials was good, but Murphy et al.(1990) found slightly lower PASA values for normal females. Høiseth et al.(1989 c) found larger values at the upper range for both AASA and
PASA. This may possibly be due to the thicker slices, and consequently larger partial volume effect in their measurements.

Also for PASA Høiseth et al. (1989c) found slightly higher values in the patient material with increased FeAV.

The PASA was lower than normal (mean - 2SD) in one third of the dysplastic hips (Paper III). This indicated that the posterior support was better than the anterior in most dysplastic hips, in accordance with Murphy et al. (1990), who also found lower dysplastic PASA values than ours. The explanation is probably the same as proposed for the discrepancy of the dysplastic AASA values. Johnston et al. (1986) employed a special radiographic projection called the pelvic inlet view, and obtained results corresponding with ours as regards the posterior support. They especially warned against using the Salter osteotomy when the posterior support was poor, as it might become insufficient postoperatively.

**Sector angles at other levels**

Normal (Paper I) and dysplastic hips in adults were compared at three slice levels (Paper IV) in addition to the centre slice. It was found that the mean difference of the sector angles was virtually the same at all different slice levels. Consequently, important additional information regarding the sector angles could not be gathered by measuring at different levels. The conclusion was that one slice only, i.e. that through the centre of the femoral head, was sufficient to evaluate the anterior and posterior support. The condition is that the femoral head is spherical and the acetabulum relatively congruent with the femoral head.

**Correlations between acetabular angles**

Table 8

The correlations between acetabular angles in normal (Paper I) and dysplastic hips (Paper III). Dysplastic hips in parenthesis
All correlations were not calculated in the normal material. For those that were calculated, comparable correlations of acetabular angles were found in normal and adult dysplastic hips. No other reports of corresponding correlations have been found. Table 8 shows that the acetabular anteversion is independent of the degree of dysplasia as quantified by the CE-angle, in agreement with Murphy et al. (1990). There is a correlation between the CE angle, the anterior support and the total horizontal support as quantified by AASA and HASA, less with the posterior support (PASA). The correlation between the anterior and posterior support, AASA and PASA was small, higher between the anterior and total support (AASA vs HASA). The highest correlation was between the posterior and total support (PASA vs HASA). The acetabular anteversion (AcAV) was strongly correlated to the posterior support (PASA), and inversely moderately to the anterior support (AASA). This indicated that there was a global reduction of the acetabulum in most dysplastic hips, but single hips showed deviation from the general trend in agreement with Murphy et al. (1990). We therefore agree with Murphy et al. (1990) who found it necessary to examine each hip before the decision for a specific operative procedure was made.

### PRACTICAL IMPLICATIONS

As several operative procedures aimed at redirecting the acetabulum are in use, measurements of acetabular angles may prove to be an important preoperative procedure. A CT evaluation gives information as

<table>
<thead>
<tr>
<th></th>
<th>AASA</th>
<th>PASA</th>
<th>HASA</th>
<th>AcAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>0.68 (0.64)</td>
<td>0.29 (0.42)</td>
<td>0.17 (0.01)</td>
<td></td>
</tr>
<tr>
<td>AASA</td>
<td>0.05 (0.08)</td>
<td>(0.58)</td>
<td>-0.62 (-0.44)</td>
<td></td>
</tr>
<tr>
<td>PASA</td>
<td></td>
<td>(0.82)</td>
<td>0.76 (0.76)</td>
<td></td>
</tr>
<tr>
<td>HASA</td>
<td></td>
<td></td>
<td></td>
<td>(0.38)</td>
</tr>
</tbody>
</table>
to what may be achieved by various operations, and this may influence the choice of the operative procedure (Murphy et al.1990, Gerber et al.1991). Moreover, it is also possible to evaluate the effect of the operation by control measurements of acetabular angles postoperatively (Murphy et al.1990).

**OTHER MODES OF CT EVALUATION OF THE HIP**

Multiplanar reformations in other planes made from thin transverse CT-slices of the hip (Laffarty et al.1986, Sartoris et al.1986) have found application especially in the evaluation of acetabular fractures.

Three dimensional reconstruction and presentation of CT images (3D CT) made from thin transaxial slices (Totty & Vannier 1984), have been used to calculate the contact surfaces of the hip (Klaue et al.1988, Hohmann et al.1988), and to simulate the postoperative relations between the femur and acetabulum (Lang et al.1988, Klaue et al.1988, Hohmann et al.1988, Murphy et al.1990, Lee et al.1991, Gerber et al. 1991). Thus the results of alternative operative procedures may be tested three dimensionally by the computer, and the most appropriate operation chosen in accordance with the result of the 3D CT simulation. This consequently is a very promising approach.

However, as most CT machines in routine work to-day do not have 3D programs as standard, it will take time before these kind of evaluations will replace "old fashioned" transaxial CT. I believe, however, that future CT machines should have 3D programs as standard.

Still it may be disputed as to whether 3D CT is really necessary in clinical practice. Maybe conventional radiography of the hip with determination of the CE-angle and trans CT with calculation of acetabular angles and femoral neck anteversion will prove to be sufficient?
THE FEMORAL NECK “ANTEVERSION”

Anatomical considerations - conventional definitions

There has been much confusion as regards to the concept and measurement of femoral torsion (König 1972, König and Schult 1973, Fabry et al. 1973, Henriksson 1980, Høiseth et al. 1989 a,b,c). A survey is therefore considered necessary in order to put the relevance of the ultrasound measurements of femoral anteversion (Fig 12, Papers V-VII) into perspective.

In humans as in other mammals there is a torsion of the femur (le Damany 1908). As the femoral neck has a medial angulation relative to the femoral shaft, defined as the neck-shaft angle (The CCD angle), this will lead to an anterior (or posterior) deviation of the femoral neck. As an anterior torsion is far more common than a posterior, we usually speak of a femoral neck anteversion. Conversely, retroversion denotes a posterior angulation of the neck. The question is; how shall this version of the femoral neck be defined and measured?

First, a plane must be defined against which the angulation can be related. The femoral condyles are the natural points of reference, as they articulate with the tibial condyles through the knee, which is a modified hinge joint and alignes the leg and foot. Several transcondylar lines related to the femoral condyles have been suggested; anterior, in the middle, posterior and a combination of several lines (Weiner et al. 1978, Murphy et al. 1987). However, most methods use the posterior condylar tangent (or rather plane), defined as the plane which is parallel with the femoral shaft and touching the condyles posteriorly. Murphy et al. (1987) found this the most consistent base line for measurements of the femoral neck anteversion.
Figure 12  FeAV as usually defined.

The anteversion angle of the central femoral neck is the angulation of the line through the centres of the femoral head and neck with the posterior condylar plane, projected onto a plane perpendicular to the axis of the femur.

PCP = Posterior condylar plane  F A = Axis of the femur
C = Centre of femoral head  N = Centre of femoral neck

Second: The shaft of the normal femur has a relatively pronounced anterior convex curve as well as a smaller lateral convex curvature. Two principally different definitions have been used:

1) The long axis of the femoral shaft is defined as the line from the mass centre of the femoral condyles to the mass centre of the intertrochanteric region (Norman 1965).

2) The short axis of the femoral shaft is less precisely defined but is usually considered to be the axis of the proximal third of the femoral shaft (Billing 1954).

Third: Several concepts may be discussed for measurement of the anteversion of the femoral neck.

1) The centre of the femoral head seems logical as the proximal measuring point if the head is spherical and situated in a symmetrical
way in the continuation of the femoral neck.

2) When the femoral neck is concave both anteriorly and posteriorly, a midpoint may be identified where the neck is at its narrowest and used as the lateral measurement point. If the neck is short, or deviates from a symmetrical shape in other ways, as it regularly does (Edholm 1966), identification of a neck midpoint may be difficult.

3) If the head-neck line is continued laterally, Norman (1965) pointed out that it usually passed in front of the long axis of the femur. He therefore suggested that the line drawn to the intersection with the long axis of the femur should be used as the lateral point of measurement, instead of the line to the midpoint of the femoral neck.

To complicate further, one of these lines are projected on to a plane perpendicular to the long axis of the femoral shaft (Fig 12). Henriksson (1980) elaborated on this concept (Fig 13), and showed that the projected angulation of the line from the inter-trochanteric centre-point to the centre of the femoral head, called ANTEV 2, on average was larger than the commonly measured head neck FeAV (ANTEV 1). This has recently been confirmed by Høiseth et al. (1989b) who found a mean difference between the two angles:

![Figure 13](image-url)
It may be speculated that the ANTEV 2 angle is the more important of these two angles, as it better incorporates - lies closer to the muscle-insertions on the proximal femur. Kleiger (1968) even suggested that the line from the centre of rotation (the femoral head) to the centre of muscular insertion (the trochanter major) is the biomechanically important parameter.

However, as the relationship between these two commonly used anteversion angles seems to be relatively fixed, and it is much easier in practice to measure the ANTEV 1 angle = the FeAV angle than the ANTEV 2 angle, it seems sensible to continue to use the FeAV angle = the ANTEV 1 angle for routine purposes.

The rAT-angle, the "absolute" anteversion angle of König
König and Schult (1973) discussed different definitions of femoral torsion, and found that projections on to transaxial or lateral planes were confusing. As a consequence König (1972) conceived the following definition: The angle of femoral antetorsion is the angle between the axis of the femoral neck and its perpendicular projection onto the posterior condylar plane (Fig 14). This angle was called the real antetorsion angle (the rAT-angle) and represented the true spatial angulation of the femur according to König and Schult (1973). Furthermore König and Schult (1973) showed that the sum of the rAT-angle and the true neck-shaft angle (CCD angle) never could exceed 180 degrees. From this follows that in extreme valgus the rAT-angle has to be small. In other words; there is no such thing as large antetorsion in extreme valgus (König & Schult 1973). This is quite contradictory to the results of the usual definition of the FeAV angle. Figure 14 illustrates that the trigonometric relationship between the König angle
Three dimensional schematic drawing showing the relationship between the rAT angle as defined by König (1972), to the usually accepted and measured femoral neck anteversion (FeAV) angle. Note also the relationship between the real and projected femoral neck - shaft angle (CCD" and CCD).

The femoral head and neck and the usually measured FeAV angle is (Leger 1952, Magilligan 1956):

7) \[ \tan \text{FeAV} = \frac{\tan \text{rAT - angle}}{\cos (\text{CCD"} - 90 \text{ degrees})} \]
From this equation it follows that as long as the CCD angle is intermediate, there will be a constant relationship between the commonly measured FeAV and the rAT angle, concurring with our results from the radiographic investigation of dry normal adult femurs (Paper VI) where the correlation was r=0.97 between these two parameters (Table 10). The values of the rAT-angle were originally not included (Paper VI).

With the CCD'' angle approaching 90 degrees, i.e. a considerable varus, these angles coincide, otherwise the rAT angle will always be smaller than the FeAV. In valgus the difference will increase, as the usually defined FeAV is highly dependent on the CCD angle. When the CCD angle approaches 180 degrees, it follows (König & Schult 1973) that the FeAV will approach 90 degrees. This shows that the usual definition of the femoral neck anteversion is more or less meaningless in extreme valgus. To take a practical example, with the FeAV angle approximately 60 degrees and the CCD'' angle 160 degrees a varizing operation of 30 degrees will reduce the FeAV to 47 degrees with no derotation of the femur at all according to the conversion tables for the Dunlap/Rippstein method (Skandfer & Sudmann 1976). The usually defined FeAV certainly must be taken with reservations in femurs with extreme valgus! It is therefore suggested that ways of measuring the femoral torsion independent of the CCD angle may in fact give better representation of the femoral torsion than the commonly measured FeAV-angle, especially in femurs with extreme valgus.

**FeAV related to acetabular angles**

FeAV measurements were performed by CT in 17 dysplastic hips in addition to the acetabular measurements (Paper III). There was an increase of the mean femoral neck anteversion, and two hips had an
instability index of more than 60. Several other femurs had previous derotational osteotomies, however, and would probably have had increased FeAV and high instability indexes as well. Only a few investigations have compared femoral neck anteversion and acetabular angles:

**Table 9**

Femoral neck anteversion correlated to acetabular angles. Getz measured an anthropological material of normal Lapps. The other measurements were performed by CT.

<table>
<thead>
<tr>
<th>number</th>
<th>AcAV</th>
<th>CE</th>
<th>AASA</th>
<th>PASA</th>
<th>HASA</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Getz 1955</td>
<td>211</td>
<td>/0.1</td>
<td>no correlation to depth of acetabulum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Høiseth1989c</td>
<td>26</td>
<td>0.22</td>
<td>-</td>
<td>0.14</td>
<td>0.05</td>
</tr>
<tr>
<td>dysplastic children</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reikerås 1983</td>
<td>68</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>dysplastic adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper III 1991</td>
<td>17</td>
<td>0.23</td>
<td>-0.29</td>
<td>-0.28</td>
<td>0.14</td>
</tr>
</tbody>
</table>

It may be seen from table 9 that there was low correlation between FeAV and any of the angles measured from the acetabulum. This is in keeping with Getz (1955) who correlated femoral neck anteversion to the depth of the acetabulum, McKibbin (1970) who measured the FeAV and AcAV by anthropological methods in stillborns, Reikerås et al. (1983) who correlated the same angles by CT and Høiseth et al. (1989c). The conclusion must be that femoral torsion is largely independent of the spatial orientation and the development of the acetabulum both in normal and dysplastic hips in children as well as in adults.

**FeAV measured by US vs biplanar radiography in children**

When determining femoral AV by ultrasound and radiography, different landmarks are used, and, thus, different angles are consequently
measured (Fig 15). Various ultrasound equipments, techniques and
modes are available:

a) Real-time vs static (compound) ultrasound scanners
b) Linear vs sector or phased array real-time scanners
c) 3.5MHz, 5MHz or 7.5 MHz probes
d) The anterior head trochanter vs the femoral neck tangent
e) Tilted vs horizontal transducer

Points a-c were determined by the ultrasound equipment available to us
at the start of this investigation, as we possessed a real-time ultra­
sound apparatus with a 5 MHz linear probe. This was probably a fortun­
ate starting equipment. Compound scanners will soon be history, and
furthermore FeAV measurements by this equipment are very operator
dependent (Berman et al.1987).

Points d and e were consequently evaluated in a clinical material of
children with rotational disorders of the femur (Paper V). The biplanar
radiographic method of Dunlap/Rippstein was used as control. It was
realized that also this method contains inaccuracies, optimally ±5
degrees according to several authors (Gross & Haike 1970, Ruby et al.
1979, Henriksson 1980, Høiseth et al.1989a). It was found that it was
sufficient to orient the posterior femoral condyles by flexing the knees
90 degrees and strapping the legs vertically (Paper V). Thus one scan
only of the proximal femur was required. The anterior HT-tangent was
found to be more appropriate for US FeAV measurements than the
anterior neck tangent. Employing the tilted transducer and the HT-
tangent, ultrasound measurements were on average 4 degrees higher
than radiographic measurements in children below 12 years of age
(Paper V). Consequently, we propose that an approximation of the real
FeAV in clinical practice is obtained by subtracting 5 degrees from the
US HT value.

The results were taken as an indication that ultrasound with adequate
equipment and modifications was indeed appropriate for measurement
of the femoral anteversion in screening of children with rotational disorders of the femur (Paper V).

**Ultrasonography vs “direct” radiography**

Because the results of US methods had been unreliable in some reports, it appeared desirable to test ultrasound measurements under optimal conditions in dry bones. The results were compared with corresponding measurements from radiographic projections (Paper VI). In the US as well as the radiographic measurements, the posterior femoral condyles were oriented horizontally by placing the femur on a standard table. The most relevant data of the general table (Paper VI) follow. Note that also the values for the radiographically measured rAT angle, which were originally omitted in Paper VI, now have been included.

<table>
<thead>
<tr>
<th>FeAV</th>
<th>Rtg HT FeAV</th>
<th>US HT FeAV</th>
<th>rAT</th>
<th>CCD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>26</td>
<td>26</td>
<td>15</td>
<td>134</td>
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The correlation between the head-trochanter tangent measured by
ultrasound with the tilted transducer technique and radiography was very high (0.97). The mean discrepancy was 1.7 degrees (range 0 - 5 degrees), which indicated that the head-trochanter tangent measured by ultrasound was accurate within ±5 degrees in experimental settings.

It was furthermore found that the correlation between the HT-tangent measured by radiography and the real radiographic FeAV was high (r=0.95), as was the correlation between the HT-tangent by ultrasound and the FeAV by radiography (r=0.95). The material consisted of femurs with normal torsion, with a mean FeAV of 14 degrees. The angle of the HT US FeAV was always greater than the radiographic FeAV angle, and the mean discrepancy was 8.7 degrees. Consequently, femoral anteversion measured by ultrasound has to be adjusted by a correction factor in order to obtain an approximation to the real FeAV.

Lausten et al. (1989) in an anatomical study of dry femurs measured the femoral neck anteversion by real time ultrasound in a similar way, and used direct measurements and CT for comparison. They too found consistently greater AV angles with the HT-tangent than by direct measurements; the mean discrepancy was 9 degrees. Furthermore, the correlation between their ultrasound and direct measurements was high (r=0.88), in fact almost as high as between CT and direct measurements (r=0.91). However, Lausten et al. (1989) did not use any correction factor, and concluded that real-time ultrasound was not suitable for FeAV measurements. If, however, 10 degrees are subtracted from their ultrasound values, the mean discrepancy between ultrasound and direct measurements is only 2.7 degrees (0 to 8 degrees), which corresponds well with our values of 2.3 degrees (0 to 8 degrees-Paper VI). Thus, both studies indicated that femoral anteversion of dry bones could be reliably measured by ultrasound (Terjesen & Anda 1990).
Ultrasonography vs biplanar radiography in adolescents and adults

The ultrasound method was further tested in a clinical investigation of adults and adolescents with rotational disorders of the femur in comparison to the biplanar radiographic method of Dunlap/Rippstein (Paper VII). The best correlation was obtained with the tilted transducer technique and the head-trochanter tangent, as in the two previous papers. The results of this investigation indicated that 11.3 degrees should be subtracted from the US values to obtain an approximation of the real FeAV. As a consequence of the findings (Papers V-VII), we suggested that 10 degrees should be subtracted in adults and 5 degrees in children (Terjesen & Anda 1990) from the US measured value of the head trochanter tangent (Formulas 9 &10):

9) Adults: \( \text{Real FeAV} = \text{HT US FeAV} - 10 \) degrees

10) Children under 12 years: \( \text{Real FeAV} = \text{HT US FeAV} - 5 \) degrees

US FeAV - influence of the CCD angle

The correlation coefficients \( r \) between the rAT angle and other angles measured by radiography and US were (Paper VI): FeAV 0.97; Rtg HT 0.94; \( \text{US HT 0.93; CCD" O.34} \)

US HT FeAV measurements disregard the CCD angle just as does the rAT-angle, the "absolute' anteversion of König (1972). This means that in femurs with extreme varus or valgus the ultrasound measurements (Papers VI&VII) will differ from the "real" radiographic FeAV as given by:

\[ \text{real FeAV} = \text{US FeAV HT} - 10 \]
Figure 15 Drawing demonstrating the difference between central and anterior surface measurements of the femoral anteversion angle. Note that the FeAV indicated is just the apparent anteversion, the drawing is only intended to illustrate the general principle.

The difference will be higher in varus and lower in valgus. This approximation of adult hips therefore only applies to intermediate values of the CCD angle. (It is interesting in this context to note that the values of ANTEV 2 of Henriksson (1980) are usually intermediate between the US FeAV HT and the real FeAV.) Furthermore, the disregard of the CCD angle also indicates that the US FeAV HT, just as the rAT-angle, better describes the biomechanics in extreme valgus than the FeAV.

US measurements of FeAV - Clinical implications
To summarize, ultrasound has several desirable properties.
1. US is a method with no known adverse effects, and with no radiation hazard. This is important, especially in cases which requires repeated measurements.
2. US is an inexpensive method.
3. US FeAV measurements may be performed at the orthopaedic outpatient clinic, eliminating the need for an "extra" visit to the
radiographic department.

4. It is therefore suggested (Papers V-VII) that US FeAV measurements should be the first and main diagnostic method in patients with clinical signs of increased anteversion such as an in-toeing gait, and in patient with rotational disorder of the femur after femur fractures or other diseases. Furthermore it should be the main method in patients with increased femoral neck - shaft angle (CCD-angle).

5. If an operative procedure is considered, the US FeAV measurements should be supplemented by a CT-examination of the hips in addition to plain radiography, in order to evaluate the acetabulum.
1. The anterior and posterior support to the femoral head from the acetabulum as quantified by the anterior and posterior acetabular sector angles, was significantly lower in most dysplastic adult hips when compared to normals. The anterior support was more deficient than the posterior.

2. Variation of pelvic inclination/reclination changed the acetabular sector angles 0.7 degrees per degree of pelvic inclination in the examined range of 40 degrees.

3. Variation of pelvic inclination/reclination changed the acetabular anteversion 0.5 degree per degree of pelvic inclination in the examined range of 40 degrees. Outside the observed range, a sine curve probably better describes this change.

A new concept called the biomechanical resting position of the hip, defined as the hip flexion which corresponds to the sum of the femoral neck and acetabular anteversion multiplied by two was introduced. This concept may be of importance in understanding basic biomechanical aspects of the hip.
4. The pelvic inclination was found to be almost identical supine and standing in normal young adults. This indicated that hip angles measured by supine CT were equal to corresponding standing angles.

5. Acetabular measurements from one slice only through the centre of the femoral head appeared to characterize the acetabular anteversion and the anterior and posterior support in hips with relatively spheroid femoral heads. Consequently this was the only CT-slice required in addition to conventional radiographs.

6. Real-time ultrasound employing a linear probe with an attached clinometer for direct angle measurements was found to be reliable for measurements of femoral neck anteversion both in children and adults. With the patient properly positioned, one ultrasound scan only of the proximal femur was required.

7. A modification termed the tilted transducer technique and measurement of the anterior tangent to the central femoral head and the greater trochanter (The head-trochanter tangent) was found to be most appropriate. In children 5 degrees and in adults 10 degrees had to be subtracted from the values obtained by using the head-trochanter tangent to get an approximation of the “true” femoral neck anteversion as measured by biplanar radiography.

8. Indications were found that ultrasound measurements of femoral torsion were in fact more informative than the “true”
femoral neck anteversion measured by biplanar radiography in femurs with extreme valgus. Ultrasound is therefore recommended as the primary method for examination of femoral anteversion.

9. To make the diagnosis of hip dysplasia in adolescents and adults, it is still adequate to evaluate the CE-angle of Wiberg from a standard frontal radiograph of the pelvis.

10. In the preoperative evaluation of the adolescent and adult with hip dysplasia, the CE-angle is measured from plain radiography and the femoral neck anteversion is determined by ultrasound. For evaluation of the acetabulum and the femoro-acetabular relationship, CT through the centre of the femoral heads for determination of acetabular anteversion and sector angles should be performed.
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THE ACETABULAR SECTOR ANGLE OF THE ADULT HIP DETERMINED BY COMPUTED TOMOGRAPHY

S. ANDA, S. SVENNINGSEN, L. G. DALL and P. BLENUM

Abstract

A new set of angles measured on standard axial CT images of the hip joint is defined. The angles provide information on the support of the femoral head from the interior and the posterior part of the acetabulum. These angles have been measured in 82 adult hips, and correlated to a set of established parameters commonly measured at conventional roentgenography and on CT images of the hip joint. The defined angles may prove to be valuable in the total appreciation of hip joint function and stability.

Key words: Hip, CT: measurement.

Various parameters defining the geometry of the hip joint have been described. The acetabular angle in children (6) and the centre edge angle of Wiberg (15) are measured on standard a.p. radiographs of the hip joint. They give information on the shape of the acetabulum, and the cranial and lateral support of the femoral head. The anteversion of the femoral neck can be measured by the method of Dunlap et coll. (2) among others (3, 10), or by computed tomography on axial CT images of the hip joint (4, 5, 14). Furthermore, also the anteversion of the acetabulum can be assessed from axial CT images (12). If these CT measurements are combined, the stability index (7) of the hip joint can be calculated (12).

In a 17-year-old girl with voluntary posterior subluxation of the right hip (1), we found the commonly measured parameters to be normal, and this led us to consider the importance of the posterior support of the femoral head from the acetabulum in addition to the one of the anterior support. The aim of the present study therefore was to determine the anterior and posterior sector angles, which may be considered complementary to Wiberg's CE-angle, in normal hips.

Material and Method

Forty-one patients, who had had an abdominal or pelvic CT examination, were included in the investigation. Many of our patients were in poor physical condition suffering from malignant disease. There were 21 females and 21 males with a mean age of 45 years (range 17-73) and 48 years (range 20-74), respectively. Patients with hip joint abnormalities observed on the target scan or on the axial CT images were excluded.

The CT examinations were performed in the supine position with neutral rotation of the femurs and the hips and knees extended, except in a 70-year-old male who was examined prone because of severe pain from rectal carcinoma.

Guided by the target scan, contiguous 5 mm slices through both hips were obtained using a GE 9800 high resolution scanner with a 512 matrix (Fig. 1). The measurements were performed independently by two observers and obtained from enlarged film copies using the concentric circles on the Müller Ischiometer (8). Like Terver et coll. (11), we have defined the equatorial plane as passing axially through the centres of the femoral heads.

Because of oblique positioning in 21 patients, we had to measure through the centre of each femoral head on different images. The right to left difference did however never exceed 10 mm, corresponding to an obliquity of less than 2° (5 mm and 10 mm in 17 and 4 patients, respectively).

The following angles were measured in the equatorial plane (Figs 2-4):

Accepted for publication 25 January 1986.
AASA. the anterior acetabular sector angle:
The angle between the anterior acetabular margin (A), the centre of the femoral head (C1), and the intercapital centre line (C1-C2).

PASA. the posterior acetabular sector angle:
The angle between the posterior acetabular margin (P), the centre of the femoral head (C1) and the intercapital centre line (C1-C2).

HASA. the horizontal acetabular sector angle:
= AASA + PASA.

AV. the acetabular anteversion (Fig. 4).

CE. the centre edge angle of Wiberg, was measured from the target view (Fig. 1).

On the non-equatorial slices through the femoral head, the analogous angles AASA*, PASA*, HASA* and AV* were measured (Fig. 1). The asterisk indicates the number of millimetres the slice is above or below the equatorial plane. + representing cranial and - caudal slices.

As the femoral head is almost spherical, we found it sufficient to draw the intercapital centre line also in the patients with pelvic tilt, through the off centre image on the non-measured side.

The statistical evaluation was made by a paired t-test. Differences were considered significant when p≤0.05.

Results

The AASA, PASA and the acetabular AV angle are presented in Tables 1–3 and graphically shown in Fig. 5.

Discussion

Our criteria for normality were: CE angle larger than 20° (15), normal appearance of the hip joints on the a.p.
THE ACETABULAR SECTOR ANGLE OF THE ADULT HIP

Table 1
The anterior acetabular sector angle (degrees)

<table>
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<tr>
<th></th>
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<th>Range</th>
<th>SD</th>
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<tbody>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AASA+10</td>
<td>78</td>
<td>62-106</td>
<td>10.7</td>
</tr>
<tr>
<td>AASA+5</td>
<td>68</td>
<td>56-80</td>
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<td>AASA</td>
<td>64</td>
<td>50-76</td>
<td>6.1</td>
</tr>
<tr>
<td>AASA-5</td>
<td>61</td>
<td>42-72</td>
<td>6.6</td>
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<tr>
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<tr>
<td>Females</td>
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<td></td>
</tr>
<tr>
<td>AASA+10</td>
<td>81</td>
<td>63-112</td>
<td>12.9</td>
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<td>69</td>
<td>51-85</td>
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Table 2
The posterior acetabular sector angle (degrees)

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<tbody>
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<tr>
<td>PASA+10</td>
<td>115</td>
<td>95-142</td>
<td>11.6</td>
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<td>9.8</td>
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<td>77-109</td>
<td>8.2</td>
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<td>7.8</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PASA+10</td>
<td>120</td>
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<td>10.7</td>
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<td>90</td>
<td>78-103</td>
<td>6.2</td>
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Target view and on the axial CT images. Patients with suspected hip pathology were excluded. We consider our material to consist of normal or nearly normal hips. It is interesting to note that Wiberg (15) in his classical monograph raises question as to the normality of his material of 200 hips for the determination of the CE angle.

Furthermore, Wiberg (15) observed but did not explain why some of his normal patients had extremely high values of the CE angle, while the distance from the medial part of the femoral head to the acetabular floor was normal. He did not, however, take into consideration the acetabular anteversion, and consequently the lateral edge point E was not standardized. The point E will provide a good representation of the lateral support in cases with small and moderate acetabular anteversion. Wiberg obtained his a. p. films of the pelvis with 100 cm film-focus distance, and the spread of the rays therefore helped to minimize the error, as they approached the plane of normal acetabular anteversion. With increasing acetabular anteversion however, the error will become more pro-
nounced, and the point E on an a. p. film of the pelvis will
not adequately represent the lateral support of the femoral
head. It is actually a projection of a point located far more
posteriorly on the upper acetabular rim. It is for this
reason even possible that true dysplastic hips with a large
acetabular AV angle may present with a normal CE angle.

Different sources of error may influence the measure­
ments, pelvic inclination being the most important of
these. No method however, appears available to obtain a
reproducible position. Because of the slope of the acetab­
ular margin, AASA will increase and PASA decrease on
increase of the pelvic inclination and vice versa (Tables 1,

Non-identical right-left images of the hips because of
oblique patient positioning will have consequences for the
values of the measured angles. According to our observa­
tions, there will often be a minimal pelvic tilt. The mean
difference in the sector angles in each patient varies be­
tween 2.5° and 4.2° (Table 4), which probably chiefly
reflects a slight pelvic tilt. Because of the spherical shape
of the femoral head and the partial volume effect, all
paraequatorial CT images will come out with approxi­
mately the same diameter as that of the true equatorial
plane. The acetabular support increases cranially and this
is reflected by increasing values of the acetabular sector
angles. Because of these two factors it may be difficult to
determine the CT image best representing the equatorial
plane.

Assuming that we maximally choose one image wrong
in either cranial or caudal direction, it is evident from
Tables 1 and 2 that this will create an error of between 3°
and 7° (mean 5°) in the sector angles. We hold the opinion
that we never chose a completely wrong centre image, so
actually this error will be less than 5°, probably 3° at
a maximum.

Reikerås et coll. (9) found the calculated values of the
acetabular antever sion in children to depend upon the
selected section of the acetabular socket. Our investiga­
tion cannot confirm this observation, as we have found,
like Visser et coll. (13) that the adult acetabular ante­
version seems to be quite constant (Table 3), regardless
of the level of the axial CT image. This finding implies that
any axial CT image of an adult hip will be representative
of the true acetabular antever sion, with the exception of
those being most remote from the equatorial plane.

As shown previously (1), a shallow acetabulum may
have a normal antever sion. This indicates that the sector
angles give a better quantitative description of the ace­
tabulum in the unstable hip, than does the acetabular AV
angle. This may also be true in hip dysplasia, and we have
planned an investigation in order to clarify this matter.
Moreover, as discussed above, even a dysplastic hip with
a large acetabular AV angle may have a normal CE angle.
The sector angles should for this reason be a valuable
complement to the CE angle. The three-dimensional ori­
entation of a hip appears to be adequately characterized
by the AV angle of the femoral neck and the acetabulum.
the CE angle of Wiberg and the sector angles. All these
measurements can easily be obtained by properly chosen
CT images and an a. p. film of the pelvis, for instance the
target view.

Table 3

<table>
<thead>
<tr>
<th>Antever sion of the acetabulum (degrees)</th>
<th>Median</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (42 hips)</td>
<td></td>
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<tr>
<td>AV - 10</td>
<td>18.2</td>
<td>6.4</td>
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<tr>
<td>AV + 5</td>
<td>18.4</td>
<td>2</td>
</tr>
<tr>
<td>AV Equatorial</td>
<td>18.5</td>
<td>2</td>
</tr>
<tr>
<td>AV - 5</td>
<td>17.6</td>
<td>4.4</td>
</tr>
<tr>
<td>AV + 10</td>
<td>17.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Females (40 hips)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AV - 10</td>
<td>19.4</td>
<td>8.4</td>
</tr>
<tr>
<td>AV + 5</td>
<td>21.1</td>
<td>6.0</td>
</tr>
<tr>
<td>AV Equatorial</td>
<td>21.5</td>
<td>4.3</td>
</tr>
<tr>
<td>AV - 5</td>
<td>20.5</td>
<td>4.0</td>
</tr>
<tr>
<td>AV + 10</td>
<td>19.6</td>
<td>4.4</td>
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Table 4

<table>
<thead>
<tr>
<th>Right-left difference of the sector angles in degrees in each patient</th>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>AASA</td>
</tr>
<tr>
<td>PASA</td>
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PELVIC INCLINATION AND SPATIAL ORIENTATION OF THE ACETABULUM

A radiographic, computed tomographic and clinical investigation

S. ANDA, S. SVENNINGSIEN, T. GRONTVEDT and P. BENUM

Abstract

In a study of 20 young adults the pelvic inclination measured by a specially constructed inclinometer was found to be the same in the supine and standing positions when related to the horizontal and frontal planes, respectively. Consequently supine CT measurements of the hip are also representative of corresponding standing angles. The variations of the acetabular anteversion and the sector angles on CT of the hips in 5 adult corpses were measured by angulating the gantry in increments of 5° to ± 20°. An approximate linear relationship was found for all parameters, the acetabular anteversion varied ± 5° with pelvic rotation, and the sector angles ± 7°. A theoretic mathematical model for the variation of the acetabular anteversion outside the measured range employing a sine curve is introduced.

Key words: Hip, CT studies, acetabulum: anteversion

It is accepted that the spatial orientation of the acetabulum is dependent upon the pelvic inclination (1, 5, 8, 13). In order to standardize pelvic inclination, McKibbin (5) therefore defined a reference plane through the anterior pubic tubercles and the anterior superior iliac spines (2), and suggested that the acetabular anteversion (AcAV) should be measured in a transverse plane perpendicular to this reference plane. This definition has become somewhat of an axiom.

We have observed that the CE angle of Wiberg (15), the acetabular anteversion (5), and the acetabular sector angles (AASA, PASA) (1) change with pelvic inclination. Therefore the purpose of this study was to quantify the relationship between the pelvic inclination and the commonly measured parameters of the acetabulum on CT, and furthermore to investigate the angulation of the 'plane of McKibbin' (5) in the horizontal as well as the erect position.

Material and Methods

This investigation includes a radiographic study on a dried anatomic specimen, a CT study on corpses, and a clinical study.

Since planes and angulation may be confusing the following definitions are made: The frontal plane is defined as horizontal in the supine and vertical in the standing position. The pelvic inclination is the rotation of the pelvis around a transverse axis, for instance through the hip joints. Increased inclination (+) indicates a forward rotation of the pelvis, and reclusion (−) a backward rotation. Similarly radiographic projections and CT slices obtained in increased inclination are marked with (+) and reclusion with (−). Zero pelvic rotation occurs when the reference plane of McKibbin (5) is parallel to the frontal plane.

In the experimental study a pelvic anatomic preparation was radiographed at varying degrees of inclination after thin metal wires had been taped to the acetabular rims (Fig. 1). Antero-posterior projections were obtained with a vertical beam and a film-focus distance of 1 m. Radiographs were then obtained by rotating the pelvis about a transverse axis through the hip joints (Fig. 11), with 5° increments from +25° to −35°, using the plane of McKibbin (5) as reference.

CT was performed in 5 fresh cadavers. 2 females dead at the age of 33 and 67 years, and 3 males at 44, 60 and 67 years, respectively, with no known history of hip pathology. All had normal hips judged from the Scout view with CT angles above 20° 112, 15]. The corpses were placed supine on the table in a GE CT 9800. The angulation of the 'McKibbin plane' (5) was then measured using a specially constructed pelvic inclinometer (see below). Frontal and
lateral digital radiographs (Scout view) were then obtained. In all cases we had to adjust the corpse several times in order to get the required position, i.e. the femoral heads superimposed in the lateral projection (Fig. 2). The table height was adjusted until the iso-centre of the gantry was at the centres of the femoral heads (Fig. 2). From the lateral Scout view, 5 mm thick slices through the hip joints were selected. First one slice without gantry angulation, and then slices with increments of 5° angulation to ± 20°, which was the maximum gantry tilt (Fig. 2). From the CT images the AAcAV (1, 8, 9, 14), the AASA (1) and the PASA were determined as previously described (1). With the gantry in the vertical position, 5 mm slices were obtained through the femoral head and neck as well as through the femoral condyles in order to ensure that the femoral neck anteverision (range 6° to 20°) was normal (9, 14). The measurements were obtained either from the CT video monitor using computer programs or from multiformate film copies (1)

In the lateral study, 40 healthy young adults, 13 men and 27 women, with no apparent gross posture anomaly or leg...
length inequality were examined for the inclination of the plane of McKibbin, using a specially constructed pelvic inclinometer (Fig 3). This consists of three 10 cm blocks of wood attached to a sheet of plywood. On the other side of the plywood square two identical commercial angle measurers (Silva, Sweden) for maritime use were mounted, one for horizontal and one for vertical registration.

The wooden blocks were pressed firmly against the anterior pubic tubercle and the superior anterior iliac spine by the examined person holding his hands at the front of the plywood square. The pelvic inclination as determined by the inclination of the plane of McKibbin with the frontal plane could be read directly from one of the angle measurers. Three standing postures were measured: Standing barefoot and at ease, standing in maximum inclination, and finally in maximum reclinution. Three corresponding supine positions were measured with the subject lying on a hard bench. Relaxed, in maximum inclination, and finally in maximum reclinution.

In each person the measurements were made on the same day in a sequential order by two different examiners (S. S., T. G.), neither of them knowing the findings of the other until the whole material had been investigated.

Results

The radiographic study showed that the acetabulum opened up (Fig. 11) as the inclination increased and 'closed' with increasing inclination.

The CT study: The inclination of the plane of McKibbin was $-5^\circ$ in 4 of the corpses and $-7^\circ$ in the last, when measured by the pelvic inclinometer.

Fig. 4 shows the AcAV in corpse No. 2 with gantry tilts of $+20^\circ$ and $-20^\circ$. The variation of the AcAV with gantry angulation from $+20^\circ$ to $-20^\circ$ follows from Fig. 5 a. A curve through the mean values (not shown in Fig. 5 a) almost parallel with the curves of the single hips, shows that the change in AcAV is approximately $0.5^\circ$ with 1 pelvic rotation.

Both anterior and posterior sector angles change $0.7^\circ$ per degree of pelvic rotation (Fig. 5 b, c). Pelvic rotation will change the AASA and the PASA inversely. The AcAV and the PASA decrease with increasing inclination, while the AASA increases.
Table 1

Pelvic inclination in degrees in 13 men Mean SD range

<table>
<thead>
<tr>
<th>Standing</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relaxed</td>
<td>-6.0 ± 4.15</td>
</tr>
<tr>
<td>Maximum</td>
<td>18.0 ± 3.2</td>
</tr>
<tr>
<td>Inclination</td>
<td>15.0 ± 2.7</td>
</tr>
<tr>
<td>Reclination</td>
<td>14.0 ± 2.6</td>
</tr>
</tbody>
</table>

Table 2

Pelvic inclination in degrees in 27 women Mean SD range

<table>
<thead>
<tr>
<th>Standing</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relaxed</td>
<td>-4.3 ± 4.12</td>
</tr>
<tr>
<td>Maximum</td>
<td>16.0 ± 30.4</td>
</tr>
<tr>
<td>Inclination</td>
<td>13.0 ± 2.4</td>
</tr>
<tr>
<td>Reclination</td>
<td>10.0 ± 3.0</td>
</tr>
</tbody>
</table>

Table 3

Interobserver variation in degrees of the measured relaxed pelvic inclination of 40 volunteers

<table>
<thead>
<tr>
<th>Difference (degrees)</th>
<th>Standing (n)</th>
<th>Supine (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
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<tr>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

The clinical study. The standing and supine values were almost identical for all comparable positions in the 13 male and 27 female volunteers (Tables 1, 2). The interobserver variation in the measurement of the pelvic inclination in the relaxed standing and supine position of all 40 volunteers between the two examiners follows from Table 3.

Discussion

Measurements by the pelvic inclinometer. From Table 3 it can be seen that the interobserver variation is small. In 79 of the 80 measurements made in the relaxed positions the interobserver difference was less than 5°, and 60 measurements had a difference of less than 2°.

One set of observations showed a difference of 7°, which might be explained by faulty application of the inclinometer. The small interobserver variation indicates that the accuracy of the method was precise, and that the patient positioning was standardized. In thin and normal subjects the superior anterior iliac spines and the pubic tubercles are prominent on palpation and probably covered by approximately the same amount of soft tissue. This may not be so in overweight persons, and measurement of the reference plane may consequently be slightly inaccurate in these cases. However, this should not affect the comparison of the standing versus corresponding supine measurements in the same subject.

Vertical versus supine measurements. The clinical part of the investigation proved that in men the relaxed standing pelvic inclination was the same as the relaxed supine inclination related to the frontal plane (Table 1). In the women there was a mean difference of 2° (Table 2), and this may well be within the limits of measurement error of the method. This proves that supine CT angle measurements of the adult hip are equal to the theoretical corresponding standing angles.

Cadaver measurements—empirical formulas. In a previous paper (1) we discussed the sources of errors in the measurements of the acetabular sector angles. The error is probably never more than 5°, while the error of the AcAV measurements is 2° according to Vissers et al. (13, 14). From Fig. 5 it is seen that the curves of each hip is a variable line. The irregularities either reflect errors of measurements or deviations from a circular segment of the acetabular rim. RAB 16. 7) reported corresponding values for change of AcAV in Salter osteotomies (10, 11), where the anterior inferior pelvic quarter is brought laterally and rotated forward. There are no previous reports on the change in the sector angles related to the pelvic inclination. The curves are not straight lines (Fig. 5 b, c) and the factor of 0.7 must therefore be taken as an approximation.

Measurements according to McKibbin. In the clinical measurements a reclination of McKibbin's plane of approximately 6° was found to be the average in men (Table 1). AcAV measurements in men performed according to McKibbin (5) are on average 3° (0.5 x 6°) less than those measured by supine CT, a difference which hardly seems to be of practical consequence. In women the difference is even less. Therefore McKibbin's suggestion that the acetabular
Acetabular anteversion should be measured in a transverse plane perpendicular to the anatomic reference plane through the anterior pubic tubercles and the anterior superior iliac spines is precisely defined and sufficiently accurate for practical work.

Other measurements from the literature. RIEKERS et al. (9) found 17° and ANDA et al. (11) 20° as the mean normal adult value for supine CT-measured AcAV. McKIBIN (5) found 16.5° by anthropometric measurements, which should be corrected by adding 1.3° according to the previous discussion. The corrected values then being 18.5° and 19.5°. However, other authors give completely different values. Thus GERTZ (3) and von Lanz (4) reported 38° and 42° as mean normal values. Regardless of the absolute values of the acetabular anteversion, all authors mentioned (1, 5, 9) agreed that females have a slightly greater acetabular anteversion than men. The difference being 2°-5°. Can these widely different values be reconciled? GERTZ and von Lanz measured the acetabular anteversion in a plane parallel to the pelvic plane, which is the terminal line. From measurements of our anatomic preparation we have, like GERTZ, also found this plane to be at an angle of about 60° with the standing horizontal plane. Supine transversal AcAV CT measurements are therefore made at an angulation of approximately 60° with the measurements of GERTZ and von Lanz. With 0.5° change of AcAV for each degree of pelvic rotation, 30° should be subtracted from the values of GERTZ and von Lanz. The corrected values will then be 8° and 12° respectively. These values are considerably lower than those reported by others (1, 5, 9). This is an indication that our results cannot be extrapolated outside the measured range (Fig. 5).

Mathematical model. In order to explain the spatial orientation of the acetabulum as a function of pelvic inclination, a new theoretic parameter called the maximum acetabular anteversion (AcAV-max-angle) is introduced. A simplified model of the acetabular rim can be considered as part of a circle, which is the case in the acetabular component of a total hip prosthesis. In humans there are usually irregularities and often an 'overhang' of the lateral acetabular edge. A plane may be constructed through this idealized circular segment. The acetabular anteversion is an anterior-posterior line contained in this plane. Now imagine that the acetabular anteversion is 0°, a situation which may be found in some patients both in normal hips and in total hip prostheses. The plane is now viewed 'on edge'. As the pelvis is rotated backwards and the acetabulum faces more and more ventrally, the acetabular anteversion increases as pointed out by McKIBIN (5). At 90° pelvic rotation, the AcAV is at its maximum value, and this is the definition of the AcAV-max-angle. With the pelvic rotation being defined as zero in a hip when AcAV is zero, the transition between AcAV 0° to AcAV-max follows a sine curve (Fig. 6) according to the equation

\[ \text{AcAV} = \text{AcAV-max-angle} \times \sin(\text{pelvic rotation angle}) \]

When the pelvis is rotated forwards, the retroversion of the acetabulum changes inversely, resulting in a maximum value which is reciprocal to the AcAV-max-angle (Fig. 6). This may be observed from three-dimensional CT of the pelvis and hips employing a flip mode, or by rotating the acetabular cup of a total hip prosthesis. Most normal adult hips have an AcAV-angle of 15°-20° (1, 5, 9). Consequently they are located somewhere upwards on the curve (Fig. 6). For these hips zero pelvic rotation should be started at this level. According to this curve, the measurements of GERTZ (3) and von Lanz (4) can be reconciled with those of other reports (1, 5, 9). This is taken as a proof for the validity of the equation.

Conclusion

In the normal adult hip the angle of acetabular anteversion, and the anterior and posterior acetabular sector angles were found to change with pelvic rotation in a linear fashion in the observed physiologic range. By pelvic rotation outside the measured range, a mathematical model using a sine curve is probably more adequate. The pelvic inclination is the same compared with the frontal plane both in standing and supine positions. An anatomic reference plane passing through the superior iliac spines and anterior pubic tubercles reclined 2°-6° with the frontal plane.

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REFERENCES

Paper III
Acetabular Angles and Femoral Anteversion in Dysplastic Hips in Adults: CT Investigation

Svein Anda, Terje Terjesen, Kjell Arne Kvistad, and Svein Svenningsen

Abstract: Transpelvic CT was used to quantify the relationship between the acetabulum and proximal femur in 21 adult patients (33 hips) with congenital hip dysplasia (defined by a center edge angle of < 20°). The anterior and posterior acetabular sector angles (AASA and PASA) were measured, as well as the degree of acetabular and femoral anteversion. The results demonstrated deficient anterior acetabular support (i.e., decreased AASA) in two-thirds of the dysplastic hips and reduced posterior support (i.e., decreased PASA) in one-third. The acetabular anteversion was normal. The femoral anteversion, however, was greater than normal in most hips. As important additional information is obtained by CT compared with conventional radiography. CT is recommended when operative procedures aimed at preventing or postponing osteoarthrosis are considered. Index Terms: Joints, hip—Joints, diseases—Hips, diseases—Joints, abnormalities—Computed tomography.

The center edge (CE) angle of Wiberg (1), measured on standard pelvic radiography, remains the most widely used angle for the determination of acetabular dysplasia and subluxation of the femoral head in older children and adults (2-5). However, with the introduction of CT, a more complete evaluation of the hip was made available. The anteversion of the acetabulum (AcAV) could be measured accurately (6,7), and the anterior and posterior acetabular supports of the femoral head assessed (8,9). Guggenheim et al. (8) measured the anterior and posterior acetabular angles on the CT image through the triradiate cartilage in children. The shortcoming of these angles is that only the acetabulum is measured. Consequently, they provide no information of the size, shape, and concentricity of the femoral head. The anterior and posterior acetabular sector angles (AASA and PASA) (9) indicate the anterior and posterior support of the femoral head by the acetabulum. They are measured in the horizontal plane on standard transverse CT slices through the centers of the femoral heads (Fig. 1).

In the present investigation we compared the sector angles in adult dysplastic hips with those of previously published normals (9) and correlated the sector angles and the CE angle with the angles of acetabular and femoral anteversion. The aims of the study were (a) to evaluate to what extent useful additional information could be obtained by CT in dysplastic hips compared with measurements of the CE angle only on standard pelvic radiography; (b) to examine if the anterior or posterior support was deficient in adult dysplastic hips; and (c) to investigate if there was any abnormality of AcAV or femoral anteversion (FeAV).

MATERIALS AND METHODS

Twenty-one patients with dysplasia of one or both hips defined by a CE angle of <20° were studied. The median age of the patients was 33 years (range 14-56 years). There were 6 males (16-56 years) and 15 females (14-48 years). Twelve patients had bilateral and nine unilateral hip dysplasia, five on the right and four of the left side. Altogether 33 dysplastic hips were included in the study. Seven contralateral hips had a borderline CE angle between 20 and 25° (1-3), and only two contralateral hips were distinctly normal with CE angles of 26 and 34°.

The main symptom was pain in the hip and thigh. Dysplastic hips in five patients had indications of reduced joint spaces and subchondral sclerosis su-
AASA

FIG. 1. Drawing shows the sector angles of the hip: AASA, PASA, and HASA.

Statistics

Student's *t* test and Pearson's linear correlation coefficient were used to assess differences in mean angles and correlations between angles. The lower limits of normal for AASA, PASA, and HASA were calculated as mean - 2 SD from the previously published normal material (9) in women (Table 1). We chose the values of normal women as standard since dysplasia occurs predominantly in females.

RESULTS

The results of the analysis of the acetabular angles and the angle of FeAV of the dysplastic hips are displayed in Table 2. The mean AASA, PASA, and HASA were significantly smaller in the dysplastic hips than in the normal hips of Table 1 (p < 0.01). There was no significant difference in the means of the AcAV angles. The mean FeAV angle of 19.5° was larger than in normal adult hips (6.7°) but not significantly. The sum of AcAV and FeAV,

FIG. 2. a: A circle fitting the outline of the femoral head is marked on the centerimage—the axial image at the level of the center of the femoral head on the ScoutView (Fig. 4). fhC, the center of the circle and center of the femoral head. A, anterior; P, posterior. b: The circle and its center are kept on the monitor screen and superimposed on the image through the middle of the femoral neck. A line, the head-neck line, is drawn from fhC, the center of the femoral head, to mmp, the midpoint of the transverse diameter of the femoral neck. The orientation of the head-neck line indicates the apparent femoral anteversion. c: The FeAV is derived by comparing the orientation of the head-neck line to the orientation of the posterior condylar line (black line). The posterior condylar line is the tangent to the posterior surfaces of both femoral condyles drawn on an axial image through the femoral condyles. FeAV is defined as the angle between the head-neck line and the posterior condylar line.
FIG. 3. The intercapital centerline is marked on the centerimage through the femoral heads. The acetabular anteversion (AcAV) is the angle between the perpendicular line and the line connecting the anterior (A) and posterior (P) acetabular margins.

usually called the instability index of the hip after le Damany (13), was <60° in two and between 50 and 60° in three dysplastic hips.

Twenty-four of the 33 dysplastic hips (72%) had AASA below the lower normal limit, indicating a poor anterior acetabular support. Eleven of these hips also had low PASA and HASA, which means that the acetabulum was shallow in all directions (Fig. 5). Ten hips, however, had low AASA and HASA, whereas PASA was within normal limits (Fig. 6). This subgroup with deficient anterior and normal posterior acetabular support tended to have increased AcAV and FeAV (mean AcAV 27°, mean FeAV 26°).

Twenty dysplastic hips had PASA below the lower normal limit of 90°. The seven hips with the lowest values of PASA had small acetabular anteversion ranging from 11 to 17°. Three of the five hips with osteoarthrosis belonged to this subgroup, although the two remaining osteoarthritic hips showed no specific pattern. These seven hips also were among the first subgroup identified under AASA (Fig. 5).

In Fig. 7 the median anterior and posterior sector angles of the normal material have been plotted on a circle against the median angles of the dysplastic hips. It is evident from the figure that the anterior support is relatively more deficient than the posterior in the average dysplastic hip.

Correlations of the various angles are shown in Table 3. There were high correlations between PASA and HASA and somewhat less between AASA and HASA. There was no correlation between AASA and PASA. Femoral anteversion was poorly correlated with the acetabular angles. The CE angle was correlated with AASA, PASA, and HASA, but there was no correlation with AcAV and FeAV.

Eight dysplastic hips had normal acetabular angles, and the AcAV and FeAV were also within normal limits in all except one (FeAV 45°). The mean CE angle of these hips was 16° (range 13-19°), which means that these hips were only moderately dysplastic.

**DISCUSSION**

**Selection Criteria of the Material**

Many adults with dysplasia or other pathologic condition of the hip had to be excluded. Wiberg (1)

**TABLE 1. Acetabular angles (degrees) from previously published normal material of 20 women**

<table>
<thead>
<tr>
<th>Angle</th>
<th>Median</th>
<th>Mean</th>
<th>Range</th>
<th>SD</th>
<th>Mean</th>
<th>25D</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>13</td>
<td>15</td>
<td>11-31</td>
<td>28</td>
<td>22</td>
<td>90</td>
</tr>
<tr>
<td>AASA</td>
<td>63</td>
<td>62.5</td>
<td>46-76</td>
<td>6.1</td>
<td>50</td>
<td>14</td>
</tr>
<tr>
<td>PASA</td>
<td>105</td>
<td>105</td>
<td>93-124</td>
<td>7.0</td>
<td>90</td>
<td>13</td>
</tr>
<tr>
<td>HASA</td>
<td>136</td>
<td>136</td>
<td>115-155</td>
<td>15</td>
<td>174</td>
<td>19</td>
</tr>
<tr>
<td>AcAV</td>
<td>21</td>
<td>21</td>
<td>10-31</td>
<td>7.1</td>
<td>11.5</td>
<td>6.5</td>
</tr>
</tbody>
</table>

AASA: anterior acetabular sector angle, AcAV: acetabular anteversion, CE: center edge angle, HASA: horizontal acetabular sector angle, PASA: posterior acetabular sector angle

**TABLE 2. Acetabular angles (degrees) and femoral anteversion in dysplastic hips**

<table>
<thead>
<tr>
<th>Angle</th>
<th>N</th>
<th>Median</th>
<th>Mean</th>
<th>Range</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
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<td>10.7</td>
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<td>1.09</td>
<td>4.3</td>
</tr>
<tr>
<td>AASA</td>
<td>32</td>
<td>45</td>
<td>46.2</td>
<td>27-60</td>
<td>7.5</td>
</tr>
<tr>
<td>PASA</td>
<td>32</td>
<td>92</td>
<td>91.5</td>
<td>71-114</td>
<td>10.7</td>
</tr>
<tr>
<td>HASA</td>
<td>32</td>
<td>136</td>
<td>138.6</td>
<td>112-154</td>
<td>14.6</td>
</tr>
<tr>
<td>AcAV</td>
<td>32</td>
<td>22</td>
<td>22.1</td>
<td>11-38</td>
<td>5.9</td>
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<tr>
<td>FeAV</td>
<td>17</td>
<td>19.5</td>
<td>19.5</td>
<td>2-45</td>
<td>11.5</td>
</tr>
</tbody>
</table>

See Table 1 for definitions.

"Anteversion of 1° unrotated femurs."
found it meaningless to measure the CE angle on grossly abnormal or deformed hips; we have the same point of view regarding the sector angles. As coxarthrosis is advanced even at the first examination in many adult dysplastic patients, it proved difficult to find suitable candidates for this study.

Anterior Acetabular Support

The values of AASA indicate that the anterior acetabular support is "inadequate" in most adult dysplastic hips. This is in accordance with the CT study of Gugenheim et al. (18), who demonstrated an anterior deficiency in congenital dysplasia of the hip in children. Edelson et al. (14) in a CT study of dysplastic hips in children <3 years of age observed an anterior, lateral superior defect in most hips. This defect became more prominent in older children, sometimes progressing to a true anterior, superior, false acetabulum.

Bombelli et al. (15), by analyzing the weight bearing surface (WBS) of the acetabulum and vectors of the forces acting between the femur and acetabulum, calculated that the most frequent migration pattern of the dysplastic hips should be anterior superior, and the second most common dislocation pattern should be medial and posterior. Hayward et al. (16) in a CT study also found that these were the most frequent migration patterns in veterans with primary osteoarthritis of the hip.

Thus, vector force analysis of the dysplastic hip and CT studies in children with hip dysplasia and in veterans with osteoarthritis point to the crucial importance of the anterior acetabular coverage of the femur. This is confirmed by our findings.

Posterior Acetabular Support

The posterior acetabular support was better than the anterior. Still, one-third of the dysplastic hips had deficient posterior support. Gugenheim et al. (8) in a series of children disagree with this result and reported no deficiency of the posterior acetabulum. Edelson et al. (14), however, found a defect in the posterior inferior ischial part of the acetabulum in the youngest children. This defect was unchanged or absent in older children. One possible explanation of this discrepancy may be the level of the CT scans. The scan through the triradiate cartilage used by Gugenheim et al. (8) is located relatively cranially in the hip, whereas Edelson et al. (14) probably observed the posterior ischial defect in a more caudal image. Our measuring slice is also considerably more caudal than the CT scan through the triradiate cartilage, and we found poor posterior

| TABLE 3. Linear correlation coefficients of acetabular angles and femoral anteversion in dysplastic hips |
|---------------------------------|----------|----------|----------|----------|
| CE    | AASA     | PASA     | HASA     | AcAV     |
| CE   | 0.64     | 0.42     | 0.65     | 0.03     |
| AASA | 0.06     | 0.56     | 0.44     | 0.06     |
| PASA | 0.82     | 0.76     | 0.38     | 0.12     |
| HASA | 0.79     | 0.28     | 0.14     | 0.04     |
| AcAV | 0.23     | 0.02     | 0.18     | 0.25     |

See Tables 1 and 2 for definitions.
support in many hips in adults. Although we have no proof, it is tempting to speculate that this may be the remnants of the defect found by Edelson et al. (14).

We have found no CT investigation of the posterior acetabular support in adults. Johnston et al. (7) used a special radiographic projection for this evaluation, however, and found results corresponding with ours.

Acetabular and Femoral Anteversion

The AcAV was almost equal in the dysplastic and normal hips. This indicates that hip dysplasia is not associated with any consistent change of the acetabular version. in agreement with previous reports (7,8,14). However, there was an obvious trend toward low AcAV in shallow hips with poor posterior support. Most of the hips exhibiting coxarthrosis belonged to this group. Whether this is coincidental or not is unsettled.

The mean FeAV in the normal population is 13° (7,8,14). Hip dysplasia has been associated with increased FeAV (7,19-21), consistent with our results. In the hips with previous rotational osteotomies, the FeAV would probably have been higher than the average of 19.5° in the nonrotated hips. This would have increased the mean FeAV angle even more.

There was poor correlation between FeAV and AcAV, in agreement with previous reports (6,7). No good correlation was observed between either anteversion and the other measured parameters of the acetabulum. This suggests that femoral torsion is relatively independent of the development and the spatial orientation of the acetabulum.

Le Damany (13) suggested an instability index of 60° as the upper limit compatible with normal function of the hip. This figure should probably not be taken literally, but the concept of high instability index is deleterious for the hip seems reasonable. Two of 17 hips had instability index >60° in our material. Some of the hips with previous rotational osteotomy would probably also have had high indexes if they had not been operated on. Derotational osteotomy of the femur would seem the sensible operation in such hips, especially in cases with large FeAV.

Are CT Measurements of the Acetabulum Necessary in Dysplasia of the Adult Hip?

Are there any practical consequences of measurements by CT in hip dysplasia, or is conventional radiography sufficient? To establish the diagnosis of dysplasia, we think that conventional radiography and measurement of the CE angle are sufficient. However, if operative procedures are considered, CT provides important additional information.

The deficient anterior coverage is the rationale for performing innominate osteotomies ad modum Salter (22). The lower pelvic quadrant with the acetabulum is rotated forward using the pubic symphysis as fulcrum. This increases the CE angle and reduces the AcAV ~0.5° per degree rotation (23,24). The AASA increases and the PASA decreases 0.7° per degree rotation (24). This operation should probably not be used if the posterior acetabular support is too small, as it may become insufficient postoperatively (17). In these hips, shelf or other operations to improve the anterior and lateral support should be used.

REFERENCES


Computed tomography measurements of the acetabulum in adult dysplastic hips: which level is appropriate?

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Abstract. A study has been performed to evaluate whether one or several levels are needed with computed tomography (CT) study to provide sufficient information regarding anteversion and acetabular support to the femoral head. A total of 23 hips in 14 adults with uni- or bilateral congenital hip dysplasia (center-edge angle less than 20°) were assessed by obtaining 5-mm contiguous CT slices and performing acetabular measurements at four levels. Both anterior and posterior acetabular supports as quantified by the anterior and posterior acetabular sector angles were significantly lower than normal at all levels. The sector angles increased in the proximal cuts, whereas the acetabular anteversion increased caudally. Because no important additional information was gained by measuring at different levels, we conclude that CT study at one level is sufficient for acetabular measurements and suggest that the slice through the center of the femoral head is the most appropriate one.

Key words: Hip dysplasia Computed tomography Acetabular measurements Anteversion

The weight-bearing surface of the acetabulum is an important concept and functional parameter of the hip joint. Bombelli et al. described it as a horizontal line of subchondral bony condensation of the acetabulum on a frontal radiograph [3], and in most cases it stretches to the lateral acetabular edge [11]. The centre edge (CE) angle of Wiberg [22] thus quantifies it. Coverage [2, 6, 8, 11, 17, 18], cover [11, 15, 16], and support (Unterstüzung) [1, 2, 7, 22] have been used more or less synonymously to describe how the acetabulum contains the femoral head. A distinction should be made between acetabular coverage (cover) and support. Consequently, in the present paper acetabular coverage is defined as the part of the acetabulum primarily concerned with weight-bearing in the standing position. However, in the flexed hip, as for instance when sitting or squatting, other parts of the acetabulum are weight-bearing. Furthermore, different parts of the acetabulum bear weight during walking [13].

In order to stabilize the hip, additional support is provided by soft tissues such as the capsule, ligaments, tendons, and muscles, as well as by the parts of the acetabulum which are not weight-bearing. Consequently, acetabular support is defined as deriving from the nonweight-bearing parts of the acetabulum which contribute towards containing the femoral head in the acetabulum. In the standing position, support for the femoral head from the acetabulum occurs not only medially but also anteriorly and posteriorly: acetabular sector angles [1] quantify this support. It is therefore important that measurements are done at the most appropriate level. Clinically, the acetabular sector angles and anteversion together are useful for deciding the correct indication for iliac bone osteotomy [14, 18] in dysplastic and subluxated hips [2].

Transaxial computed tomography (CT) of the pelvis may give valuable information in congenital dysplasia of the hip (CDH) [2, 5, 6, 9, 12, 16, 21]. In order to minimize radiation exposure, some authors obtain CT slices at only a few relevant levels [4-6, 11, 12, 16, 20, 21]. Others find it desirable to examine the entire hip joint to obtain maximal information [1, 2, 9, 10].

In this investigation, we measured the anterior and posterior support offered by the acetabulum to the femoral head and the spatial orientation of the acetabulum on contiguous CT slices through adult dysplastic hips. The aims were: To find out whether sufficient information regarding acetabular support and anteversion could be obtained by CT scanning at one or a few transverse levels only and, if this was the case, to determine the most suitable measurement level.

Material and methods

The patient group consisted of 14 adults (12 women and 2 men) with 23 dysplastic hips. The mean age was 30 years (range 14-54
Nine patients had bilateral and 5 unilateral CDH, as determined by a CT angle of 3. Where of less than 29° [19, 22]. Only patients with spherical femoral heads were included.

A continuous transverse 5-mm supine CT slice through the hips from the top of the femoral head to the middle of the femoral neck (10–14 slices were obtained using a GI CT 9000. The acetabular anteversion angle (ACVA) [16, 20, 21], the anterior acetabular sector angle (AASA), and the posterior acetabular sector angle (PASA) were measured on the CT slice through the center of the femoral head as previously described [1, 2]. The corresponding angles were also measured on the two slices proximal as well as on the slice caudal to the center image (Fig. 1). As hip dysplasia occurs predominantly in women, we used the previously published normal material of adult women [1] as a standard for comparison.

Normal distribution and differences of means were calculated by Students t-test. Values of P < 0.05 were considered significant.

Results

The acetabular sector angles were significantly lower at all four levels in the dysplastic patients when compared with normals (P < 0.001) (Tables 1, 2). AASA increased with each slice level in the proximal direction in normal as well as dysplastic hips. Graphically presented, the mean values of AASA at each level were almost parallel to the abscissa. As a result, AASA becomes more negative, indicating posterior shift of the acetabulum.

Table 1. Anterior acetabular sector angle (AASA) in 23 dysplastic adult hips and 40 normal female hips. Level 0 is the cut through the center of the femoral head.

<table>
<thead>
<tr>
<th>Level of CT slice (mm)</th>
<th>Dysplastic Mean (°) (SD)</th>
<th>Normal Mean (°) (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>56 (9)</td>
<td>11 (3)</td>
</tr>
<tr>
<td>5</td>
<td>52 (7)</td>
<td>12 (9)</td>
</tr>
<tr>
<td>10</td>
<td>46 (8)</td>
<td>14 (10)</td>
</tr>
<tr>
<td>15</td>
<td>40 (8)</td>
<td>12 (9)</td>
</tr>
</tbody>
</table>

Table 2. Posterior acetabular sector angle (PASA) in 23 dysplastic adult hips and 40 normal female hips.

<table>
<thead>
<tr>
<th>Level of CT slice (mm)</th>
<th>Dysplastic Mean (°) (SD)</th>
<th>Normal Mean (°) (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>94 (10)</td>
<td>120 (10)</td>
</tr>
<tr>
<td>5</td>
<td>94 (10)</td>
<td>112 (8)</td>
</tr>
<tr>
<td>10</td>
<td>96 (10)</td>
<td>105 (6)</td>
</tr>
<tr>
<td>15</td>
<td>98 (10)</td>
<td>100 (7)</td>
</tr>
</tbody>
</table>
in the two groups (Fig. 2), and the difference of the means was approximately 17°. The increase was comparatively larger between the most cranial cuts than between the lower levels.

Dysplastic hips had a lower PASA than normal hips at all levels (Table 2, Fig. 3). It increased cranially, but less in the dysplastic group, in which the increase was 3°-4° between the cuts. In the normals, it was 5°-7°.

The mean AcAV increased from 17° to 25° in the dysplastic hips as the slices moved more caudally (Table 3). The acetabular anteverision of the dysplastic hips was not significantly different from that of normal hips except at the lowest slice level, where the AcAV was larger ($P < 0.001$).

**Discussion**

*Imaging planes and techniques*

The weight-bearing surface of the acetabulum is almost perpendicular to a vertical line in the standing position [3]. Consequently, imaging planes perpendicular to it are optimal for direct visualization and measurement of the surface and acetabular coverage; in practice, these are the coronal and possibly sagittal planes. In order to measure the anterior and posterior support, transverse planes are optimal, while vertical planes are inadequate.

Plain frontal radiography of the hip provides information in the coronal plane and consequently shows the relation between the femoral head and the cranial and lateral acetabulum including the weight-bearing surface, while the CE angle provides useful information on the coverage of the hip [3, 11, 22]. For determination of acetabular support and anteverision, however, conventional radiography is obviously inadequate.

CT slices are obtained approximately parallel with the weight-bearing surface and one slice will be tangential to the top of the femoral head: this is not adequate for gaining direct information of the acetabular coverage and reformatting in a vertical plane. For instance coron-
The CT data may also be presented in a 3-dimensional mode [9, 10], whereby all planes are incorporated in the image, but measurements are not necessarily easy. However, both these methods rely on thin transaxial slices for sufficient spatial resolution, and such an increase of radiation exposure is undesirable in routine evaluation of dysplastic hips. Ogata et al. [11] addressed this problem by superimposing the image of the center of the femoral head on a slice through the ilium, just above the top of the femoral head, probably in the region of the weight-bearing surface. The percentage of the acetabulum overlying the femoral head was calculated, and an index for femoral head coverage was established.

It was concluded that CT is not suited for the direct evaluation and quantification of the acetabular coverage of the femoral head. In contrast, for evaluating anterior and posterior acetabular support and anteversion, transverse CT slices are ideally suited.

**Acetabular measurement**

The center of a spherical femoral head is easy to identify on a frontal radiograph of the pelvis, on the CT scout view, and on the central CT image of the femoral head. The center point of the femoral head is used both in the measurement of the CE angle in radiography and of the acetabular sector angles in CT (Fig. 4). Many dysplastic hips have nonspherical femoral heads, and the determination of their center point may be difficult and subjective. The problem increases with the degree of deformity. If the deviation from a spherical shape was too great, Wiberg [22] found it meaningless to measure the CE angle. We feel that the same applies to the acetabular sector angles. In these cases, it is suggested that the entire hip joint should be scanned in order to make a qualitative evaluation.

It posed no problem to measure the acetabular sector angles and anteversion on the two slices proximal and the one distal to the center image; this involves a range of 2 cm. It was possible to measure on slices more distant from the center with large femoral heads but not in those of moderate size; this was, therefore, not done in any of the hips. Measurements of the sector angles consequently have to be carried out on one or more of these four 5 mm slices, as measurements at other levels may be unfeasible in some hips.

**Acetabular support**

In the three lowest cuts, the mean increase of AASA was $6^\circ$ between each slice in both the dysplastic and normal hips.

The anterior acetabular support therefore increases evenly in a cranial direction. Consequently, measurements performed at any of these levels will be representative of the others, and measurements of the central cut will give information on the posterior acetabular support at adjacent levels. In the most cranial cut, there was a moderate tendency for a relative increase of the AASA, indicating that extrapolation of the anterior acetabular support at this level from measurement of the central cut may not be acceptable.

The PASA also increased cranially but to a lesser extent in the dysplastic group. The central cut may therefore not be entirely appropriate for evaluation of the posterior acetabular support at adjacent levels in dysplastic hips. However, important additional information is not lost by measuring one level only, and in the cause of standardization we recommend that sector angles be measured on the image through the center of the femoral head.

**Acetabular anteversion**

In adult dysplastic hips the acetabular anteversion increased considerably from the cranial to the caudal cuts in keeping with the study of Edelson et al. [5]. Furthermore, Reikerås et al. [16] in a CT study of 40 children, 34 with increased femoral anteversion and 6 with CDH, observed that the calculation of the acetabular anteversion was not constant for different acetabular sections. Based on these observations, dysplastic hips appear to have a trend towards increasing anteversion as the slices move more caudally.

In our previous CT study of normal hips [1], we found both in men and women that the acetabular anteversion did not change with different levels. These results were concordant with Visser et al. [21], who performed CT studies on a pelvic preparation of a 50-year-old male cadaver with normal hips and found that "at all slices through the acetabulum. the acetabular fossa torsion was the same as at the level of the proper cut through the femoral neck." However, Terver et al. [20] reported that the acetabular anteversion in normal hips changed with the slice level. The majority of reports therefore seem to indicate a level dependency for the estimation of the acetabular anteversion, and this applies especially to dysplastic hips. Scanning at one level only seems to give sufficient information, and we suggest as others have [16, 20] that this should be the image through the center of the femoral head.

In conclusion, measurements by CT of the acetabular support from the center of the femoral head are representative in hips with relatively spherical femoral heads and should be used for measurements of the AASA, PASA, and acetabular anteversion; this is the only transpelvic CT image needed to supplement a standard frontal radiograph for quantification of the acetabulum. In hips with nonspherical femoral heads, acetabular measurements are difficult or unfeasible, and contiguous slicing through the entire hip is required to make a qualitative evaluation.

**References**

Femoral anteversion in children measured by ultrasound

Terje Terjesen and Svein Anda

The femoral anteversion was measured by ultrasound and biplanar radiography in 57 children, most of whom had clinical signs of increased anteversion. A modification of previously reported ultrasound techniques was introduced, as the transducer was tilted instead of being kept horizontally. Four different modes of ultrasound examination were evaluated. The most appropriate technique involved only one ultrasound scan at the hip level. The correlation between the results of ultrasound and radiography was good with less than 10° discrepancy in the majority. Ultrasound is suitable for screening children with rotational disorders of the femur. The main advantage of the method is that exposure to radiation is avoided.

The femoral anteversion (AV) angle can be determined by various conventional radiographic techniques, of which the biplanar technique appears to be the most useful one (LaGasse & Staheli 1972, Ruby et al. 1979). Accurate measurement of the AV angle can be obtained by computed tomography (CT) (Weiner et al. 1978, Peterson et al. 1981). However, exposure to radiation is a disadvantage associated with all radiographic methods, including CT. Thus, non-ionizing techniques for determining femoral anteversion are desirable, and ultrasound has recently been introduced for this purpose (Moulton & Upadhyay 1982). So far, no patient series with increased anteversion examined by ultrasound has been reported.

We have studied the following problems: 1) Is ultrasound suitable for determining femoral anteversion in children? 2) What is the correlation between the AV angles measured by ultrasound and radiography? 3) What modification of various ultrasound techniques is the most appropriate for clinical use?

Patients and methods

The material comprised 47 girls and 10 boys, 7 (3-14) years of age, and most of them were admitted because of clinical signs of increased femoral anteversion.

The radiographic examination was carried out according to the biplanar method of Dunlap, modified by Rippstein (1955). The apparent angles of AV and inclination were measured by the same radiologist (S.A.). The true AV angles were determined with the aid of a standard conversion table.

When measuring the AV angles by ultrasound, the patients were supine. A real-time ultrasound apparatus with a 5 MHz linear transducer was used (Sonoline SL-2, Siemens). Four different modes of measurements were tested.

Group A. The children had their knees flexed 90° over the edge of the table, and the lower legs were strapped in the vertical position (Figure 1). Thus, it was assumed that the posterior tangent of the femoral condyles was in the horizontal plane. An ultrasound scan along the axis of the femoral neck was performed, showing the anterior contours of the femoral head and neck, as well as the intertrochanteric region. The correct scanning level was easily recognized after a search with the ultrasound transducer. Because the femoral neck in children is short, a double-size enlargement on the monitor-screen image was used. The transducer was tilted until the outline of the femoral neck appeared as a horizontal line on the monitor screen (Figure 2). The degree of tilt of the transducer was assessed with a clinometer, which was held along the transducer. The AV angle was equal to the angle of tilt.
Figure 1. The position of the legs used in Groups A and D: the knees flexed 90° over the edge of the table and the lower legs strapped in the vertical position. The angle of tilt of the transducer was read on the scale of the clinometer.

Figure 2. Ultrasound image showing the anterior contour of the femoral head (H) and neck (N) and the intertrochanteric region (I). The femoral neck is seen as a horizontal line.

Figure 3. The position of the legs used in Groups B and C permitting transverse scanning of the posterior femoral condyles.

Figure 4. Ultrasound image showing the transverse outline of the posterior femoral condyles (mc - medial. lc - lateral). The tangent of the condyles appears to be horizontal.
Group B. The children had their knees extended, and the lower legs were resting on an additional table and strapped (Figure 3), permitting transverse scanning of the posterior femoral condyles. The angle between the posterior tangent of the femoral condyles and the horizontal plane was measured by tilting the transducer until the tangent appeared horizontal on the monitor (Figure 4). In this position the tilt angle was measured as previously described. The angle between the femoral neck and the horizontal plane was measured as described for Group A. The AV angle was calculated by adding or subtracting the tilt angles of the two scans. When the leg was in internal rotation, the angles were added; if the leg was externally rotated, the angle of the femoral condyles was subtracted from that of the femoral neck.

Group C. A similar procedure as described for Group B was used. However, because the transducer was kept in a somewhat more transversal position, the anterior outline of the greater trochanter was included (Figure 5) instead of the intertrochanteric region used in Groups A and B. The transducer was tilted until the tangent of the greater trochanter and the center of the femoral head appeared horizontal on the monitor. The AV angle was obtained by combining the angles of the knee and the hip scan, as previously described.

Group D. The legs were flexed 90° over the edge of the table, as was done in Group A. Only one ultrasound scan of the hip region was needed. The AV angle was determined according to the angle of tilt when the anterior tangent of the femoral head and the greater trochanter appeared horizontal on the monitor.

All the ultrasound measurements were performed by the same examiner (T.T.). The ultrasound measurements, as well as the radiographic angles, were determined without the examiner knowing the results of the other method. Sixteen children were examined by the methods used in the C and D groups to assess the correlation between the two modifications. Two children were examined by the methods of both Groups A and B. In 46 out of 75 ultrasound examinations, the AV angles were measured twice to find the variation between two consecutive measurements.

Differences between ultrasound and radiographic measurements determined with the $t$ test were considered significant at $P$ values $< 0.05$. The coefficient of correlation of the two methods was calculated.

Results

In most cases there was good agreement between the ultrasound and radiographic measurements of the AV angles (Table 1); the coefficients of correlation in Groups A-D ranged from 0.57 to 0.88. The mean difference between the two methods was 1° in both Groups A and B. However, in Groups C and D, the AV angles determined by ultrasound were on an average 4° greater than those obtained by radiography. The difference between ultrasound and radiography was less than 5° in more than half of the measurements and more than 10° in only one tenth (Table 2). There was no asymmetry between the right and left hips in any of the groups.

In patients where the AV angles were measured twice by the same ultrasound examination, the mean difference between two consecutive

<table>
<thead>
<tr>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>36 (12-47)</td>
<td>28 (16-51)</td>
<td>46 (14-56)</td>
</tr>
<tr>
<td>Radiography</td>
<td>32 (3-51)</td>
<td>40 (20-58)</td>
<td>36 (14-47)</td>
</tr>
</tbody>
</table>

Table 1. Femoral anteverision angles determined by ultrasound and radiography. Values are mean (range)
Table 2. The differences in femoral anteversion angles between ultrasound and radiography, expressed as the number of hips according to the magnitude of the difference

<table>
<thead>
<tr>
<th>Difference</th>
<th>Group A n 36</th>
<th>Group B n 28</th>
<th>Group C n 46</th>
<th>Group D n 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5°</td>
<td>24</td>
<td>17</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>6-10°</td>
<td>6</td>
<td>9</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>&gt;10°</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

measurements was 3° (0-10°). The difference was < 8° in 95 per cent of the measurements. Two patients were measured twice with an interval of some months, and the differences ranged from 3° to 7°.

The correlation of the AV angles determined by ultrasound and radiography in Groups C and D are shown in Figure 6. Only 2 of the 40 AV angles in Group D and 5 of the 46 angles in Group C were outside the range of the mean difference of 4° ± 10°.

The difference between the AV angles determined by the ultrasound techniques of Groups C and D in 16 patients examined by both methods was on an average 3° (0-9°).

Discussion

The AV angle is usually defined as the angle between the posterior tangent of the femoral condyles and the line connecting the midpoints of the femoral head and neck, projected on a plane perpendicular to the long axis of the femur. By ultrasound, the anterior outline of the proximal femur is scanned and AV is measured as the angle between the condylar plane and the anterior tangent of the femoral neck or the tangent of the femoral head and greater trochanter. Thus, AV determined by ultrasound and radiography does not represent the same anatomic angle. Studies on dry femora have shown a very good agreement between ultrasound and direct measurements (Moulton & Upadhyay 1982, Zarate et al. 1983), and also between ultrasound and CT (Clarac et al. 1985). In the latter study, a series of patients was also examined: the difference between the values determined by ultrasound and CT was less than 5° in 90 out of 93 hips. Our investigation confirms that ultrasound is reliable for measuring femoral AV, although the agreement with radiography was not as good as that reported by Clarac et al. (1985).
The accuracy of the method of Rippstein (1955) is approximately ± 5° (Ruby et al. 1979, Henriksson 1980). Because the precision of the ultrasound method in our study was approximately ± 7°, a discrepancy less than 10° between ultrasound and radiography appears satisfactory.

The mean AV angles in our subjects were rather high. This was not unexpected, considering that most patients were admitted for disturbances of gait pattern owing to increased femoral anteversion.

In previous reports the ultrasound transducer was kept in the horizontal position, and the AV angle was measured on the monitor-screen image (Moulton & Upadhyay 1982, Zarate et al. 1983, Clarac et al. 1985). This method is satisfactory for measuring AV angles within the normal range. However, in patients with increased anteversion, the horizontal position of the transducer is not appropriate. The transducer tends to lose its contact with the skin over the trochanteric region, and the outline of the lateral part of the femoral neck and the trochanteric region is not adequately depicted. This was the reason why we tilted the transducer until it was parallel with the desired line, which then became horizontal on the monitor screen. Thus, the bony contours are always clearly seen, no matter whether the anteversion is increased or within the normal range.

Moulton & Upadhyay (1982) and Zarate et al. (1983) used two ultrasound scans, one of the knee region and one of the hip. However, only one scan at the hip level was performed by Clarac et al. (1985), assuming that the knee axis was in the correct position when the knees were flexed 90° and the lower legs kept vertical. We evaluated both modifications and found no difference. The use of only one scan is simpler and less time-consuming.

Whereas the tangent of the femoral neck was used by Zarate et al. (1983) and Clarac et al. (1985), the tangent of the femoral head and greater trochanter was used by Moulton & Upadhyay (1982). We found both modifications equally reliable. However, the determination of the proximal and distal limits of the femoral neck is often uncertain, making the tangent of the neck more difficult to define. In children, where the femoral neck is short, this is a greater problem than in adults. This drawback is eliminated by using the head-trochanter tangent, which usually is easy to determine. When using the head-trochanter tangent, the AV angles determined by ultrasound in children should be corrected by subtracting 4° from the measured values.

An important advantage of ultrasound is that exposure to radiation is avoided. The examination is rapid, safe, and painless. Ultrasound scanning is recommended for screening children with rotational disorders of the femur. In patients with obvious discrepancies between clinical findings and AV angles determined by ultrasound, additional radiographic examinations are needed, preferably by CT.

References


FEMORAL ANTEVERSION MEASURED BY ULTRASONOGRAPHY AND RADIOGRAPHY

An anatomic investigation

S. Anda, T. Terjesen, S. Sundalsfoll and A. Tangrud

Abstract

Radiographic and real-time ultrasound measurements of femoral anteversion were compared in an anatomic study of 20 dried adult femurs. The real anteversion (AV) angle was determined by biplanar radiography. In four ultrasound measurements, the linear transducer was kept either horizontal or tilted. The measuring lines were either the anterior tangent of the femoral head—greater trochanter or the anterior tangent of the femoral neck. With the tilted transducer, the correlation between the head-trochanter AV angle and the real AV angle was high (r=0.9452), and slightly less when the anterior neck AV angle was used (r=0.9142). The clinical relevance is that the tilted transducer technique with the head-trochanter tangent is recommended for AV screening in patients with clinical signs of increased femoral anteversion. In adults, 1.5° has to be subtracted in order to obtain an approximation of the real AV angle.

Keywords: Hip, femoral anteversion; US studies; radiography.

Lower extremity function including the hip joint is influenced by femoral torsion, which is usually measured by the anteversion (AV) of the femoral neck. Biplanar radiographic methods have proven useful and reliable for the measurement of this angle, and especially the method of Dunlap et al. (4) as modified by Rippstein (12) has found wide acceptance. The anteversion angle may also be measured by computed tomography (CT), when proper transaxial slices are obtained (16, 17), and with CT it is also feasible to evaluate the spatial orientation of the acetabulum (1, 11, 16). Since these techniques pose a radiation hazard to the patients, simple and reliable imaging methods using non-ionizing techniques are desirable. Consequently, ultrasound (US) has recently been introduced for the measurement of femoral neck anteversion (7, 10, 18). Some reports have compared ultrasound and biplanar radiography (10, 14) or CT (2, 3), but these studies show poor consensus in the results. As we have increasingly used real-time ultrasound measurements of femoral neck anteversion for screening in children (14), we found a necessity for evaluating our ultrasound method. The AV angles measured by ultrasound are based on surface contours of the femur, and are therefore not identical with the radiologically measured AV angle.

The purpose of the present investigation, which was performed on adult dried femurs, was to provide answers to the following questions: 1) What is the correlation between the corresponding angles on the femoral surface measured by ultrasound and by radiography? 2) What is the relation between the AV angle measured by ultrasound and by axial radiography? 3) Which modification of the different ultrasound techniques is most appropriate for AV angle measurement?

Material and Methods

Ten pairs of well-preserved adult femurs were chosen from among 398 skeletons, excavated from a medieval burial ground in central Trondheim and stored at the town's historical museum. The criteria for inclusion in the material were that the femur appeared normal on gross inspection, that no part of the femur was missing, and especially that the subchondral bone of the joints was intact.

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Four different angles were measured by ultrasound and or radiography. The real AV angle was calculated from two of the radiographic measurements. All measurements were obtained after the dry femur had been placed horizontally on a table with the posterior condyles touching distally and with the most dependent point contacting proximally.

Definitions of angles

1) The projected head-neck-diaphyseal angle (the CCD' angle): The angle between the central lines through the head-neck and the femoral shaft projected onto the horizontal plane. The CCD' angle gives information on the varus-valgus of the femoral neck.

2) The real AV angle: The angle between the axial projection of the head-neck centre-line and the horizontal line. This is the commonly measured AV angle (4, 12, 16, 17).

3) The 5° AV angle: The angle between the axial projection of the central head-neck line and the horizontal plane but with 5° lateral deviation of the femoral shaft.

4) The head-trochanter angle: The angle between the anterior tangent of the femoral head and the anterior outline of the trochanter major and the horizontal plane.

5) The anterior femoral neck angle: The angle of the tangent to the anterior femoral neck with the horizontal plane.

Angles 1, 3, 4 and 5 were measured by radiography. Angle 2 was calculated from angles 1 and 3. Angles 4 and 5 were measured by ultrasound.

Radiographic methods

A frontal radiograph (film-focus distance 1.5 m) was obtained with a vertical beam in order to measure the projected CCD' angle, followed by three axial radiographs (FFD = 1.73 m) with a horizontal beam. In the axial projections, the femoral head was positioned 10 cm from the film cassette, which was secured in a vertical bucky, while the centre of the trochanteric region was placed over the centre of a grading scale with 0° perpendicular to the film. Thus, the femoral shaft could be angled for the desired number of degrees in a controlled fashion. A straight metal wire was taped on the table top in front of and parallel to the film (Figs 1–3), radiographically marking the baseline for angle measurements. The three axial projections were obtained in the following fashion:

Projection A: The femoral condyles were moved 5° laterally in order to measure the 5° AV angle (definition 3, Fig. 1).

Projection B: The femoral condyles were moved laterally in order to bring the femoral neck parallel to the film. In this way the anterior femoral neck angle (definition 5) could be determined (Fig. 2).

Projection C: A long, straight 19 gauge needle was taped to the anterior surface of the femoral head and the anterior aspect of the greater trochanter. The femur was pivoted until the needle was parallel to the film. In this way a radiographic projection (Fig. 3) of the head-trochanter tangent was obtained and the corresponding angle (definition 4) could be measured.

All measurements were carried out independently by two radiologists (S. A. and S. S.), using a Müller Ischiometer (8), without knowledge of the results of the ultrasound measurements.
Ultrasound images of the inferior femur at the level of the femoral head (F), the femoral neck (N), and the greater trochanter (G; in a), and the intertrochanteric region (H; in b). Images obtained with the transducer tilted (T) and horizontal (H).

Fig. 4. Ultrasound images of the anterior femur at the level of the femoral head (F), the femoral neck (N), and the greater trochanter (G; in a), and the intertrochanteric region (H; in b). Images obtained with the transducer tilted (T) and horizontal (H).

The real anteversion (definition 2) was calculated by the formula (K, 12, 13):

\[ \text{tg real AV angle} = \frac{\text{tg} 5^\circ \times \text{AV cost} \times \text{projected CCD angle} - 95^\circ}{\text{cost} \times \text{projected CCD angle} - 90^\circ} \]

Ultrasound methods

The ultrasound measurements were performed without knowledge of the radiographic results. Real-time ultrasound equipment (Sunoline, Siemens) with a 5 MHz linear transducer was employed. The femur was resting horizontally on the table. Angles of the anterior proximal femur were measured in relation to the horizontal plane. A waterbag connected to the transducer was used in order to obtain adequate contact towards the irregular bone surface. First the head-trochanter angle (definition 4) and then the anterior collum angle (definition 5) were measured with a tilted transducer. In this modification the transducer was tilted until the line of interest (head-trochanter tangent or the anterior neck tangent) appeared horizontal on the monitor (Fig. 4a), and the corresponding angle could be read directly from an attached clinometer (14).

1) The head-trochanter tangent was brought to horizontal on the monitor (Fig. 4a) and the angle of tilt was observed from the clinometer.

1) Thereafter the anterior neck tangent was brought to horizontal and the corresponding angle read off (Fig. 4b).

The same angles were measured ultrasonographically with a horizontal transducer. The horizontal position of the probe was ensured by the clinometer. In these modifications the angulation of the line of interest was measured against the baseline of the monitor from the hard print polaroid copy (Fig. 4).

For statistical evaluation of the measured angles Pearson's test for correlation coefficients (r) was used.

Results

In most cases the values of the two radiologists were identical or within a variance of two degrees. In these cases the intermediate values were calculated. In two instances the values were three degrees or more apart. The relevant radiograph was then reexamined, the possible cause for the discrepancy evaluated, and a new intermediate value agreed upon. Six measurements were inad-
Dylar line against which the inclination of the femoral neck
ments that it is sufficient to orient the posterior condylar tangent most consistent and appropriate as a reference line for AV measurements. We have shown in a previous report on ultrasound AV measurements that the posterior condylar plane in children by keeping the legs vertical and flexed 90° over the edge of the table, as also advocated by others.

Proximal femur. Which line should be evaluated as the most representative for determination of the femoral neck AV? The real AV angle of definition 2 is usually used at radiographs (4, 12) and at CT (9, 17). With ultrasound examination the choice of a representative measuring line is somewhat more uncertain. In some reports the head-trochanter tangent has been used (2, 7, 10, 15) while others have used the anterior femoral neck tangent (3, 18).

In a previous publication we compared these parameters (14). Both lines are easy to define. However, we have often found it difficult to decide where to place the neck tangent at radiography as well as with ultrasound, and we therefore consider this parameter more operator-dependent than the placement of the head-trochanter tangent.

Radiography. In the dry specimen, the accuracy of direct radiography is reported to be within ±2°. Consequently, we used the radiographic measurements as reference values against which the ultrasound measurements were compared. As in the cited reference (16), we obtained the axial AV projection with a 5° lateral deviation of the femoral shaft, thus making it easier to define the appropriate measuring points on the femoral neck.

Ultrasound. When employing static B-mode scanners, it is possible to obtain good images of measuring lines of the femoral head, neck and trochanter regions (2, 7, 15). B-mode static scanning is generally held to be very operator-dependent, however (2). The ultrasound measured AV values of the femoral neck may differ considerably if the inclination of the probe is varied, as shown by Berman et coll. (2). They also compared compound ultrasound with CT in a clinical material, and concluded that the results obtained with a static compound scanner were not sufficiently accurate for clinical use. Moreover, real-time ultrasound equipment is presently replacing compound scanners. As a consequence, we maintain that ultrasound AV measurements in the future should be done with real-time equipment.

| Correlation coefficients between angles determined by radiography and by ultrasound. |
|----------------------------------------|----------------------------------------|----------------------------------------|
| Radiography                           | Ultrasoundometry                      |                                       |
|                                       | Anterior neck                          | Head-trochanter                       | Anterior neck                          |
|                                       | Head-trochanter                        | Tilt                                   | Tilt                                   |
|                                       |                                       | Horizontal                            | Horizontal                            |
| Real AV                               | 0.7787                                | 0.9452                                | 0.9142                                |
| Head-trochanter—AV angle              | 0.9478                                | 0.9284                                | 0.9142                                |
| Anterior neck—AV angle                | 0.9089                                | 0.9623                                | 0.6753                                |
|                                       |                                       |                                       | 0.5542                                |

Discussion

In order to achieve a satisfactory discussion on femoral torsion, it is important to deal with the spatial orientation of the femoral condyles. Several authors found it necessary to measure different condylar planes, posteriorly and/or anteriorly, in order to construct a central transcondylar line against which the inclination of the femoral neck was measured (7, 15, 17). However, Murphy et coll. (19), in a recent CT study of femoral anteversion, evaluated four different modes of placing a condylar line, and found the posterior condylar tangent most consistent and appropriate as a reference line for AV measurements. We have shown in a previous report on ultrasound AV measurements (14), that it is sufficient to orient the posterior condylar plane in children by keeping the legs vertical and flexed 90° over the edge of the table, as also advocated by others.
monitor or the hard print copy as was done by PHILLIPS et coll. (110). The angles may come out correctly in cases with a small femoral neck AV. In cases with large AV angles, however, the distortion of the deep portion of the image, i.e. the trochanter region, may lead to incorrect measurements. Thus, PHILLIPS et coll. (110) found ultrasound measured AV unreliable above 40°. If a linear probe is held horizontally, it will again be adequate in measuring small AV angles (3, 14, 18). This was confirmed in the present study. In cases with large AV angles, however, the linear probe has a tendency to lose contact with the skin laterally when kept horizontal. Large AV angles are often found in children with hip dysplasia or an in-toe gait, as well as in other patients with rotational disorders of the femur.

The problem of large AV angles led one of us (T. T.) to develop the method of the tilted linear probe with a clinometer attached for a direct reading of the AV angle. The probe is tilted until the line of interest appears horizontal on the monitor. With this modification, adequate skin contact with the probe is always ensured, and the contour of the desired line is clearly shown irrespective of the magnitude of the AV angle. When using the head-trochanter tangent, the present study showed good accordance between the AV angles whether the transducer was horizontal or tilted, as well as when compared with the measurements of the same angles at radiography. The real AV angles of the femurs in our study (Table 1) were in the range given as normal by other authors (5, 11), and the present investigation therefore does not elucidate the preferential method in cases with increased AV angles.

**Conclusion**

The present study showed that real-time ultrasonography with a linear transducer may be used for AV angle measurements in adult femurs when proper techniques are employed. The results corresponded well with measurements by radiographic methods.

The anterior head-trochanter tangent was more appropriate, when measuring the AV angle, than the anterior femoral neck tangent. The AV angle by ultrasound using the head-trochanter tangent averaged a figure of 8.5° higher than the real AV angle determined by radiography.

In femurs with anteversion in the normal range, both the technique of the tilted and of the horizontally held transducer were appropriate. With femoral neck anteversion above 30° to 40°, the tilted transducer method is recommended. We suggest that this should be the future standard measuring method for screening in children with clinical signs of increased femoral anteversion. Radiography and CT being reserved for dubious cases.

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Femoral Anteversion in Adolescents and Adults Measured by Ultrasound

TERJE TERJESSEN, M.D., SVEIN ANDA, M.D., AND SVEIN SVENNINGSEN, M.D.

Femoral anteversion (AV) was determined by ultrasound in 40 adolescent and adult patients with rotational disorders of the femur, and the results were compared with AV measurements by biplanar roentgenography. With the patients supine, their knees flexed 90°, and their lower legs strapped in the vertical position, one scan only of the proximal femur was needed to measure the anteversion by ultrasound. The transducer was tilted until the desired measuring line appeared horizontal on the monitor screen. The angle of tilt of the transducer, which represented the AV angle, was measured with an attached clinometer. The correlation between ultrasound and roentgenographic AV angles was high, indicating that reliable results were obtained by ultrasound. The preferred reference line was the head–trochanter tangent, which is recommended for clinical use. Consistently greater AV values were measured by ultrasound than by roentgenography. Thus, 10° should be subtracted from the ultrasound values in order to obtain the real AV angles. One of the benefits of ultrasound is the elimination of radiation hazards to the patients. Ultrasound is recommended as a screening technique for patients with rotational disorders of the femur.

Measurement of femoral anteversion (AV) is desirable in the evaluation of patients with rotational disorders of the femur. Although femoral AV can be reliably measured by computed tomography and conventional roentgenographic techniques, these methods involve a radiation hazard to the patient. Consequently, ultrasound has in recent years been employed for such measurements.1-3,5,6,9,10 Measurements on dry femora have revealed a very good agreement between ultrasound and roentgenography regarding femoral AV.1,10 However, different conclusions have been reported regarding the reliability of ultrasound measurements in clinical studies.2,3,6,9 This discrepancy might be due to differences in ultrasound techniques. Thus, further studies are needed in order to establish the optimal technique when measuring femoral AV.

The present study reports the results of our ultrasound modification9 in a clinical series of adolescent and adult patients. The aims of the study were to answer the following questions. (1) Is ultrasound appropriate for determining femoral anteversion in adolescents and adults? (2) What is the correlation between ultrasound and biplanar roentgenographic measurements? (3) Which modification of real-time ultrasound measurements should be preferred in clinical practice?

MATERIALS AND METHODS

The study consisted of 40 patients. 27 females and 13 males, with a mean age of 16.5 years (range, 12-44 years). The reasons for including patients in the study were: follow-up study of patients with increased femoral AV (13 patients), follow-up study after derotational osteotomy for increased AV (13 patients), in-toeing and clinical signs of increased AV (six patients), pain in the hip or thigh regions (seven patients), and rota-
ional deformity after femoral fracture (one patient).

Roentgenographic examination was carried out according to the biplanar method of Dunlap, as modified by Rippstein. The apparent AV and head-neck-shaft (caput-collum-diaphysis) angles were measured, and the AV angles were determined by a standard conversion table.

A real-time apparatus with a 5-MHz linear transducer was used for ultrasound measurements (Sonoline SL-1, Siemens AG, Erlangen, Federal Republic of Germany). The transducer was rectangular in shape, which is a condition for the described method. The patients were in the supine position, with their knees flexed 90° over the edge of the table and their lower legs strapped in the vertical position (Fig. 1). In this position it was assumed that the tangential plane of the posterior femoral condyles was horizontal. This presupposition is also applied in the biplanar roentgenographic method, which is the most widely used conventional technique for femoral AV measurements. Accordingly, only one ultrasound scan of the anterior aspect of the proximal femur was needed to determine the femoral AV. However, to evaluate which reference line was most appropriate (the anterior tangent of the femoral head and the greater trochanter or the anterior tangent of the femoral neck), two scans of each hip were performed.

To determine the head-trochanter (HT) tangent, the transducer was kept over the anterior aspect of the central part of the femoral head and the greater trochanter. The correct scanning level was easily recognized after a search with the transducer. The transducer was kept vertical in the plane perpendicular to the ultrasound beam. The transducer was tilted in the plane of the ultrasound beam until the tangent of the femoral head and the greater trochanter appeared horizontal on the monitor screen (Fig. 2). The degree of tilt of the transducer was assessed with a clinometer, which was kept firmly along the side of the transducer.

Fig. 1. The patient is correctly positioned with her knees flexed 90° over the edge of the table and her lower legs strapped vertically. The angle of tilt of the transducer is read on the scale of the clinometer, which is firmly held along the side of the rectangularly shaped transducer.

Fig. 2. Ultrasound image showing the anterior contours of the femoral head (H), femoral neck, and the greater trochanter (T). The HT tangent appears to be horizontal.

Fig. 3. Ultrasound image showing the anterior outlines of the femoral head (H), femoral neck (FN), and the intertrochanteric region (I). The tangent of the central part of the FN appears horizontal.
TABLE 1. Femoral Anteversion Measured by Biplanar Roentgenography and Ultrasound in 80 Hips

<table>
<thead>
<tr>
<th>Technique</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HT tangent</td>
<td>32.5°</td>
<td>-6° to 56°</td>
</tr>
<tr>
<td>FN tangent</td>
<td>28.4°</td>
<td>-5° to 47°</td>
</tr>
<tr>
<td>Roentgenography</td>
<td>21.3°</td>
<td>-12° to 52°</td>
</tr>
</tbody>
</table>

ducer (Fig. 1). The measured AV angle was equal to the angle of tilt.

To determine the femoral neck (FN) tangent, the transducer was kept in a slightly more longitudinal position than described for the HT tangent, showing the anterior outline of the central parts of the femoral head and neck. The transducer was tilted in the plane of the ultrasound beam until the anterior tangent of the central part of the femoral neck appeared horizontal on the monitor (Fig. 3); the angle of tilt represented the femoral AV measured by this modification. The HT tangent was always measured before the FN tangent.

All ultrasound and roentgenographic measurements were performed without the examiner knowing the results of the other method. For statistical evaluation, Pearson's test for linear coefficients of correlation \((r)\) was employed.

RESULTS

The femoral anteversion angles measured by ultrasound and roentgenography are shown in Table 1 and Figures 4 and 5. The correspondence of the values by the two methods was very good; the coefficients of correlation using the HT tangent and the FN tangent were 0.94 and 0.92, respectively.

![Fig. 4. The relationship between AV angles measured by biplanar roentgenography and ultrasound with the HT tangent. The lines indicate the mean difference of 11° ± 10°.](image-url)
Greater AV values were measured by ultrasound than by roentgenography in all hips except one when the HT tangent was used, and the mean difference was 11.2°. When employing the FN tangent, greater values were measured by ultrasound in all hips except six, and the mean difference between the two methods was 7.1°. Consequently, femoral AV measured by ultrasound must be adjusted by a correction factor in order to obtain an approximation of the AV measured by roentgenography. When this was done, the discrepancies between the methods are shown in Table 2. The difference between ultrasound (measured angle minus the correction factor) and roentgenography was less than 5° in approximately 75% of the hips, and the discrepancy was less than 10° in 79 of 80 hips when the HT tangent was used and less than 10° in 76 of 80 hips when using the FN tangent. The greatest discrepancy was 15° in the FN group and 12° in the HT group.

No trend toward greater discrepancy between roentgenography and ultrasound occurred when large AV angles were measured as compared to small AV angles (Figs. 4 and 5).

**DISCUSSION**

When determining femoral anteversion by roentgenography and ultrasound, different anatomic landmarks are used and, thus, different angles are measured. For the purpose of the present study, the real femoral AV was assumed to be determined by biplanar roentgenography, although certain errors of mea-
TABLE 2. The Differences in Femoral AV Angles Between Ultrasound and Roentgenography Expressed as the Number of Hips According to the Magnitude of the Difference

<table>
<thead>
<tr>
<th>Difference</th>
<th>HT Tangent</th>
<th>FN Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number Hips</td>
<td>Percentage</td>
</tr>
<tr>
<td>0° to 5°</td>
<td>61</td>
<td>76.3</td>
</tr>
<tr>
<td>6° to 10°</td>
<td>18</td>
<td>22.5</td>
</tr>
<tr>
<td>11° to 15°</td>
<td>1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

The corrected AV angles were used for ultrasound (measured AV angle minus correction factor).

measurement are involved with this method.3,7,8 By ultrasound, the angle of the anterior outline of the proximal femur in relation to the posterior condylar plane represents the measured AV. The present results show a high correlation between ultrasound and roentgenographic measurements, which confirms the experience of two other clinical studies.3,9 However, Berman et al.2 using a static scanner, reported that ultrasound measurements were not sufficiently accurate in clinical practice, and Phillips et al.6 found ultrasound less accurate with high degrees of femoral AV in dry bones as well as in patients. Since other measurements on dry femora have shown a very good correspondence between ultrasound and roentgenography,1,10 the discrepancy in the results is probably due to the differences in the employed ultrasound techniques. The authors have no experience with the static B-mode scanner that was used in some reports.2,5 However, the method was considered to be very operator dependent, and it was not recommended for routine clinical application.2 Thus, real-time ultrasound should be preferred.3,6,9,10

One reason why inaccurate AV values were measured by ultrasound with greater degrees of AV (AV angles above 40°)9 might be that the transducer was kept in a horizontal position. With increasing AV, the images of the base of the femoral neck and the greater trochanter were indistinct, because of the relatively posterior position of the greater trochanter region.6 In addition, the linear transducer tends to lose its contact with the skin over the lateral neck and trochanter regions in patients with large AV angles. These were the reasons why the technique was introduced of tilting the transducer until the desired measuring line appeared horizontal on the monitor screen.9 Thus, the bony contours of the head, neck, and trochanter region are always clearly outlined in small as well as in large AV angles, so this technique is strongly recommended in clinical practice.

Which of the two measuring lines should be employed? The HT tangent was preferred in some studies,6,9 while the FN tangent was used in others.3,10 When measuring dry femora, the HT tangent showed better correlation with roentgenographic values than did the FN tangent,1 and this was confirmed in the present study. The FN tangent is more operator dependent, since it is often difficult to decide where to place this line both roentgenographically and with ultrasound.1 This is due to the difficulty in exactly assessing the distal and proximal margins of the FN, as well as its central part where the tangent should be drawn. The HT tangent is, however, usually easily determined: consequently, this is recommended as the preferred reference line in clinical practice.

Since different anatomic angles are determined by ultrasound and roentgenography, a correction factor must be introduced. In children it was found that the values obtained by ultrasound using the HT tangent should be adjusted by subtracting 4° from the measured angles.9 When dry femora of adults were tested,1 the AV angles measured by ultrasound with the HT tangent were also consistently greater than the real AV, and the correction factor was 8.7°. These femora were obtained from a medieval burial ground, and the results could hardly be directly compared to those of the present study. Nevertheless, there was a fairly good
agreement, since ultrasound employing the HT tangent measured AV values on average 11.2° higher than roentgenographic AV angles in the present study. Thus, 10° should be subtracted from the measured angles in order to obtain the real AV angles in adolescents and adults. When using the FN tangent, the present results indicate that 7° should be subtracted in order to obtain the AV angle. This does not correspond with the results of the study on dry femora, since the values with the FN technique on average were only 1.2° greater than the AV angle. This discrepancy supports the HT tangent as the preferred reference line.

The accuracy of the biplanar roentgenographic method of Rippstein is approximately ± 5°. Since the discrepancy between roentgenography and the corrected AV values by ultrasound was 10° or less in 79 out of 80 hips when the HT tangent was employed, the accuracy of the latter method is assumed to be ± 5°, which is in accordance with previous findings in children.

The measurement of femoral AV by ultrasound is rapid, safe, and painless, with no radiation hazards to the patient. Since the results are reliable, ultrasound is recommended as a screening technique in patients with clinical signs of increased femoral AV and other rotational disorders of the femur. Provided that the orthopedic surgeon has satisfactory experience in orthopedic ultrasound examinations and that adequate equipment is available, referred patients can preferably be examined in the outpatient department at the same time as the clinical evaluation. This policy saves time and is less expensive compared with the conventional procedure of separate roentgenographic and clinical examinations. However, if surgical procedures of the femur are considered, biplanar roentgenography should also be performed, since the correct degree of rotational deformity is more adequately evaluated by two different techniques than by one.

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