THE THREE-DIMENSIONAL ANATOMY OF THE PROXIMAL FEMUR IN PERTHES' DISEASE

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A new method of recording the three-dimensional anatomy of the proximal femur from a single anteroposterior radiograph is described. This technique shows that in Perthes' disease the femoral head and neck are in significant anteverision and true varus. This anatomical configuration may be important in the pathogenesis and treatment of this disorder.

Femoral neck anteverision has been implicated in the pathogenesis of several hip conditions and numerous methods of measuring it have been devised. In concentrating on this one aspect of the anatomy of the femoral neck its three-dimensional nature has been ignored. Current knowledge of anteverision is reviewed below; a new method of measuring it is described together with its application to Perthes' disease.

The femoral head and neck have a complex relationship with the shaft of the femur, pointing forward (anteversion) and upward (the neck-shaft angle). There is no accepted definition of these terms, each of which has been applied to a number of different angles in the past. The appearance of the femoral neck on an anteroposterior (AP) radiograph is a composite of both these variables which are in fact independent.

Dunn (1952), Dunlap et al. (1953) and Ryder and Crane (1953) defined femoral neck anteverision as the extent to which a vertical plane through the femoral neck and shaft was inclined to the plane through the shaft and femoral condyles. This is equivalent to 'looking up' the femoral shaft from below and these authors developed radiographic techniques to measure this angle. Dunn's method is the most direct, but is impractical because of positioning difficulties and the high x-ray exposure required. There is little difference however in the results that these three techniques achieve (Ruby et al. 1979).

Many authors have applied the Dunlap and Ryder methods to a large number of subjects to establish normality (Magilligan 1956; Crane 1959; Fabry, MacEwen and Shands 1973); this is approximately 30° of anteverision at birth, declining to 10° at skeletal maturity. Other radiographic techniques have been variations on the biplanar methods such as that of Wientroub et al. (1981) involving stereophotogrammetry.

When applied to congenital hip dislocation (Fabry et al. 1973), Perthes' disease (Dunlap et al. 1953) and in-toeing (Crane 1959) these methods show that there is a consistent increase in anteverision compared with normal subjects whilst in slipping capital femoral epiphysis it is decreased (Dunlap et al. 1953).

Biplanar radiography requires co-operation from the patient and two radiographs which entail considerable x-ray exposure. Computed tomography (CT) using transverse cuts measures the same parameter as defined above (Hernandez et al. 1981) but introduces the problem of determining the middle of the femoral neck from oblique cuts through it. The results largely agree with those of earlier authors (Weiner et al. 1978; Peterson et al. 1981) and the method allows simultaneous measurement of both hips as well as the anteverision of the acetabulum (Visser and Jonkers 1980). CT also entails considerable x-ray exposure (usually three cuts through the femoral neck region and one through the knees) which cannot easily be justified, especially in normal subjects.

Ultrasound is non-invasive and apparently safe. As originally described (Moulton and Upadhay 1982) it uses a transverse scan through the femoral neck and so 'looks up' the femoral shaft. The values obtained for normal subjects are consistently higher than those obtained by radiographic means (Moulton and Upad-
hyay 1982; Zarate, Cuny and Sazos 1983; Upadhyay, Moulton and Burwell 1985; Berman, Mitchell and Katz 1987) and the method is unreliable when compared to CT (Berman et al. 1987). Most authors do not specify the use of transverse scans, but erroneously imply the use of scans made along the line of the femoral neck (Zarate et al. 1983). These may be easier to interpret because of femoral neck definition but measure an entirely different angle from a transverse scan. The latter relies on recognition of the tip of the greater trochanter and the anterior surface of the femoral neck which tends to result in an overestimate of the degree of anteversion. The relative safety of the method however has led to its widespread popularity.

Studies which have concentrated on measuring anteversion have largely ignored the anatomy in the vertical plane. It is accepted that the normal neck–shaft angle is of the order of 135° in adults, measured on dry bones (Parsons 1914). That this angle is not that which is seen on an AP radiograph, because of the foreshortening effect of anteversion, was appreciated by Ryder and Crane (1953) who termed this apparent neck–shaft angle the 'projected inclination'. Thus the three-dimensional anatomy precludes direct measurement of the true anatomy from plain AP radiographs.

Therefore, two parameters are necessary to describe the anatomy of the femoral neck adequately: anteversion, most easily defined as above, and the neck–shaft angle which is the inclination of the femoral neck to the shaft in the plane of the femoral neck and shaft. Defined in this way, two angles in orthogonal axis systems describe the femoral neck anatomy.

There is conflicting evidence that anteversion is increased in Perthes' disease. Dunlap et al. (1953) and Katz (1968) found higher values than normal, but Fabry et al. (1973) have suggested that this is a secondary phenomenon. The deformity in the vertical plane has less frequently been considered and has usually been described as varus (Calvé 1910; Katz 1980). This estimate is based on the apparent neck–shaft angle from the AP radiograph which is erroneous for the reasons described above. The problems of definition, measurements on plain radiographs and the interrelationship of anteversion and the neck–shaft angle on the radiographic appearance have not been comprehensively considered in the past.

The epiphyseal plate in children is easily visible on an AP radiograph. It is a circular disc (Rang 1969) whose radiographic projection is an ellipse. The lower border of this ellipse is not always completely visible because of superimposition by the femoral neck but the upper border is reliably seen. The shape of this ellipse can be measured, as can its angle of inclination to the femoral shaft from which its relative attitude in three dimensions can be derived.

This study addresses these problems fully by a combination of theoretical, laboratory and clinical studies and describes a new way of defining the three-dimensional anatomy of the proximal femur using solely an AP radiograph.

MATERIALS AND METHODS

The orientation of the ellipse created by the epiphyseal plate on an AP radiograph depends on that of the femoral head. Furthermore the 'ellipticality', i.e., the ratio of the major and minor axes depends on the extent of anteversion. The relationship between 'ellipticality', anteversion (defined in the same way as Dunlap) and the true neck–shaft angle is a trigonometric one definable thus:

$$E = \sin a \cdot \sin b,$$

where $E$ = 'ellipticality' (the ratio of major and minor axes), $a$ = true anteversion, and $b$ = the true neck–shaft angle. Similarly, the measured inclination (I) of the femoral neck is related to the true neck–shaft angle and anteversion as follows:

$$\tan I = \frac{1}{\tan b \cdot \cos a}$$

Thus, from the inclination of the epiphyseal plate and the ratio of the major and minor axes of the ellipse it is theoretically possible to derive both anteversion and the true neck–shaft angle from a single AP radiograph.

In practice the exact measurement of the axes of this ellipse can be difficult because of problems in defining both its edges; an 'image-watching' technique was therefore adopted. The superior border of the bony metaphysis and the growth plate can be reliably seen and are crescent-shaped. Using the formulae described above a computer was used to draw this crescent at various attitudes corresponding to small increments of
Figure 2 - Correspondence between the theoretically-derived relationship governing anteversion and apparent neck–shaft angle (continuous line) and that measured from radiographs of the model using the shape of the 'growth plate' (marked points). The formulae described in the text were used to derive the three lines which represent three different true neck–shaft angles of the model, 126, 134 and 148°. Figure 3 - Anteversion at each age in the affected hip (continuous line) and unaffected hip (dotted line) in the children with Perthes' disease, and in the reference group (broken line), mean ± 2 s.e.m. Figure 4 - Anteversion at each phase of the disease in the affected hip (continuous line) and unaffected hip (dotted line) in the children with Perthes' disease, mean ± 2 s.e.m. Figure 5 - Anteversion at each phase in the affected hip of the good result group (continuous line) and poor result group (dotted line), mean ± 2 s.e.m. Figure 6 - Real neck–shaft angle at each age in the affected hip (continuous line) and unaffected hip (dotted line) in the children with Perthes' disease, mean ± 2 s.e.m.

Anteversion and neck–shaft angle; the radiographic appearance was matched as closely as possible to one of these images (Fig. 1). The inclination of the crescent and hence of the ellipse was measured directly.

In order to verify this technique a physical model was constructed using plastic ‘bones’. An epiphyseal plate was simulated by incorporating a thin foil disc into a subcapital osteotomy; by inserting a variable blade-plate device into an intertrochanteric osteotomy the neck–shaft angle of the model could be varied. Radiographs of the model were taken at different angles of rotation to simulate anteversion (Fig. 1).

The radiographs of 33 children with unilateral Perthes' disease treated throughout the course of the disease by observation alone were available for study. On the basis of the final radiographic appearance these were graded into good and bad end results using the classification of Stulberg, Cooperman and Wallensten (1981) which they showed to reflect the long-term clinical outcome. The radiographs taken during the clinical course were classified according to the four stages of the disease as described by Waldenstrom (1923) and subsequently by Somerville (1971).

A reference group was formed from the radiographs of the unaffected hip of 30 children investigated for transient synovitis of the hip ('irritable hip') of compar-
able age and sex distribution. Rotation of the femur was graded from similar measurements of the lesser trochanter and any radiographs in which a significant difference existed between the two sides were rejected. All radiograph measurements were made by two observers independently and a mean of their observations taken.

RESULTS
The calculated figures for anteversion and neck–shaft angle of the physical model derived from their apparent values on the AP radiograph as above showed significant correlation with the actual position of the model (Fig. 2).

Figure 3 shows derived values for anteversion in the Perthes’ groups of children and in the reference group. At each age it is greater in the Perthes’ group. These results are similar if either the chronological age or the radiological stages of Waldenstrom (1923) and Somerville (1971) are considered (Fig. 4). Furthermore, anteversion is greater at each stage in the bad result group than in the good (Fig. 5).

There is no marked difference in the true neck–shaft angle between the two groups and the reference group (Fig. 6) but in those with bad results there is a tendency to varus in Perthes’ disease.

DISCUSSION
The measurements made from our model bear out the validity of the analysis derived from purely theoretical considerations. When applied to the clinical situation the figures show a trend towards increasing anteversion with age. This variance from the literature (Crane 1959; Fabry et al. 1973) may be due to our method which considers the epiphyseal plate as a basis for measuring anteversion of the femoral head rather than the femoral neck. The femoral neck is in effect the history of the epiphyseal growth plate but it could be anticipated that assuming the neck to be perfectly straight is unjustified. This would be unusual in nature (Thompson 1917) and has been demonstrated not to be the case (Garden 1961). However, in Perthes’ disease it is the femoral head which is primarily at fault (Catterall 1971), so that our method which measures its anteversion may be more relevant than the historical record of femoral neck growth. With mechanical conditions such as traumatic posterior hip dislocation where femoral neck anteversion is increased (Upadhyay et al. 1985) the anatomy of the femoral neck may be more relevant.

In Perthes’ disease we have demonstrated a consistent tendency to varus and anteversion which appears to be related to the radiographic severity of the disease. That this combined anatomical arrangement has not been demonstrated previously in the literature may be due to these factors:
1. Our method of measurement relies only on the attitude of the epiphyseal plate and so differs from previous methods. Nevertheless, the Perthes’ group differs from our reference group measured in the same way; this difference does not prove a causal link, although a possible pathological sequence is of anteversion and varus deformity causing uncovering of the epiphysis and nutritional impairment.
2. The amount of anteversion is age-related and also changes through the course of the disease, whereas previous reports have not considered the stage of the disease as important.
3. The three-dimensional nature of the deformity has been addressed. Anteversion is only one aspect of the deformity and previously has not been consistently defined or measured in relation to the neck–shaft angle. Increasing anteversion will cause an apparent increase in valgus.

It is clear from a consideration of Figure 1 that a more circular epiphyseal appearance is the result of more anteversion, but it also leads to an apparent loss of epiphyseal height. It has been assumed that this loss of height is always a result of the pathology in the epiphysis (Catterall 1971; Mose 1980) but it can be seen that in part at least it is a spurious consequence of observing the epiphysis obliquely. This three-dimensional aspect may also be relevant to the pathogenesis. If uncovering the femoral head is important in Perthes’ disease (Somerville 1971) then it is important to realise that it is uncovered in two planes. The situation is analogous to idiopathic scoliosis in which a three-dimensional deformity is rendered two-dimensional by conventional radiography (Deacon, Flood and Dickson 1984), resulting in a misunderstanding of the nature of the condition and its treatment (Dickson 1985). In Perthes’ disease surgical correction of anteversion or varus alone does not address all aspects of the deformity (Axer 1965).

In this study we have disregarded the acetabular anatomy but it is possible that any anatomical deformity on the femoral side of the joint could be compounded by a reciprocal pelvic deformity. Dunlap, Swanson and Penner (1956) extended the biplanar technique to measure anteversion of the acetabulum and Ackland, Bourne and Uhthoff (1986) measured the orientation of acetabular total hip replacement components. We consider that by application of the principles described in this paper the three-dimensional orientation of the acetabular rim may similarly be derived from a single AP radiograph.

The gradation of anatomical abnormality in the transverse plane, from retroversion in slipped capital femoral epiphysis (Dunlap et al. 1953), to anteversion in Perthes’ disease, is comparable to the spectrum of the sagittal plane shape in idiopathic scoliosis and Scheuermann’s disease. It may be that deviation from ‘normality’ in femoral neck geometry at a crucial stage of growth predisposes a child to a pathological process resulting in these hip disorders.
The ease of application of our new and verified method means that large scale studies can be undertaken which may then point the way to a theory of causation and treatment.

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REFERENCES


