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Measurement of Femoral Neck Anteversion and Inclination

A radiographic study in children

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MEASUREMENT OF FEMORAL NECK ANTEVERSION AND INCLINATION
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ABSTRACT. A general computer-based method for determination of anatomical angles from roentgenograms was developed. This method is especially designed for determination of anteversion and inclination of the femoral neck. The x-ray exposures are performed with the child in a constant supine position and the lower leg hanging freely. Three films are exposed for each leg – a frontal and a lateral view of the hip and a third lateral view of the knee. By the three films the orientation of the femur is defined relative to a coordinate-system. From coordinates on the films of the axes and points of the femur the angles are calculated by mini-computer. The computer program (ANTEV in FORTRAN) is based on the general principles for central projection. The present computerized method does not presuppose an exactly defined position of the patient. The accuracy of measurement is $\pm 2^\circ$ (SD) for inclination and $\pm 3^\circ$ (SD) for anteversion. The angles have been defined relative to the long ideal axis of the femoral shaft.

All measurements of anteversion presuppose a plane of reference – the anteversion is defined as the angle between the femoral neck and the plane of reference. Two planes of reference were studied, the frontal plane and the tangential plane to the dorsal parts of the femoral condyles measured by fluoroscopy.

The anteversion and inclination in normal children between the age of 3 and 16 years were determined with special reference to magnitude and biological variation. In normal children the anatomical anteversion, i.e. the angle between the femoral neck and the tangential plane to the femoral condyles, diminishes slightly in girls, but not in boys, during childhood. However, in both sexes there is an evident decrease of the functional anteversion, i.e. the angle between the femoral neck and the frontal plane. This decrease has been found to be a result of a change in the neutral position of the femur, which changes from a relative outward rotation to a relative inward rotation during childhood. Both the anatomical and functional anteversion have a wide biological variation $15^\circ - 20^\circ$ (2SD). During childhood inclination decreases slightly in both sexes.

A consecutive follow-up study in children with CDH, treated with a von Rosen splint in the neonatal period, was performed. As a group the children in this series appear to have normal angles of anteversion and inclination at the age of 6 – 9 years.

Torsion in healed femoral fractures was measured as the difference in anteversion between the non-fractured and fractured side. In a consecutive series of femoral fractures outward torsion of the distal fragment was found to be most frequent. The torsions did not exceed 30°. A screening procedure has been proposed. In supine with the lower leg hanging freely, the inclination of the tangential plane to the femoral condyles is determined by fluoroscopy. If the inclinations are mainly symmetric, a torsion is unlikely to be present in the fracture. On the other hand, if there is an evident asymmetry between the two sides, a torsion exceeding 10° is probable.

The accuracy of measurement of conventional biplanar radiographic methods for determination of anteversion was studied theoretically. By applying the Gaussian law for propagation of errors to the trigonometric formula for the Rippstein method, the accuracy of measurement was estimated. The accuracy of measurement was found to be $\pm 5^\circ$ (SD), compared with $\pm 3^\circ$ (SD) for the computerized method, when determining anteversion of the femoral neck.

Key words: Accuracy of measurement, radiography; angle, radiography; anteversion; femur; femoral neck; functional anteversion; hip dislocation, congenital; inclination; torsion, fractures.

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INTRODUCTION

Many radiological methods for determining anatomical angles, in particular the anteversion angle of the femoral neck, have been published since Drehmann (1909) who determined anteversion by fluoroscopy.

Measurement of femoral neck anteversion is usually performed according to the biplanar method described by Ryder & Crane (1953) and Rippstein (1955). Cyvin (1977) used the Rippstein method in a follow-up study of children with hip instability at birth and this method was also used recently by Benum et al. (1979) who measured femoral torsion after fractures.

The possibility of correct determination of angles is reduced by the many sources of error in the measurement procedure. Errors of measurement on the x-ray films and incorrect positioning of the object are factors of fundamental importance. A third source of error is incorrect adjustment of the x-ray apparatus. Estimation of the magnitude of these errors is necessary in order to be able to assess how accurately angles can be determined from x-ray films.

Earlier authors have estimated the errors and their sources in the biplanar methods (Ryder & Crane 1953, Dunlap et al. 1953, Rippstein 1955, Gross & Haike 1970, Elsasser & Walker 1973) but the accuracy of measurement expressed as the standard error (SD) has not been fully established for clinical use in these studies. The biplanar determination of anteversion is frequently performed by trigonometric calculations from films by means of tables, formulas or nomograms (Leger 1952, Dunlap et al. 1953, Ryder & Crane 1953, Billing 1954, Rippstein 1955, Edholm 1972).

A simple biplanar method, based on descriptive geometry, for determination of the anteversion has been elaborated by Norman (1965). This method also renders determination of the inclination and fracture angles possible.

A general solution to the problem of determination of angles from x-ray films taken in two directions has been presented by Edholm (1966). This author provides a comprehensive analysis of the possibilities of the nomographic method. On the basis of his results an instrument meeting the needs for accurate measurement in routine radiological work was constructed.

Developments in the field of computer technique during recent years, with increased access to computers, make it natural to replace the nomographic methods by computer processing. Computer evaluation of the results of measurements makes it possible to calculate the above mentioned errors of measurements without additional manual work, as well as to determine additional angles from the data given.

The aim of this study was:

1. To elaborate a method for the determination of anatomical angles from roentgenograms using a computer technique.
2. To establish the accuracy of this method with special reference to the anteversion and inclination of the femoral neck.
3. To study the variation of anteversion and inclination in normal children.
4. To perform a follow-up study of children with congenital dislocation of the hip (CDH) treated with a von Rosen splint in the neonatal period.
5. To study torsion in healed femoral shaft fractures in children.

Chapter I

COMPUTERIZED DETERMINATION OF ANGLES

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The analysis presented here represents a new general principle, using computer technique, for the determination of different anatomical angles from x-ray films. Therefore it was found necessary – first to make a theoretical analysis of the general principles for determination of angles from x-ray projections, and then to apply this method and evaluate its reliability by computer technique using a model and an anatomical preparation.

Theoretical considerations

The image obtained on an x-ray film is a central projection of the object in one plane (the film) with its centre at the focus (the radiation source). Straight lines in the object are projected as straight lines on the film. If a line 1 in the object is reproduced in a projection with its centre F_1 on plane Π_1 in the line 1', the line 1 will be positioned in the plane that passes through the point F_1 and the line 1' (fig. 1). This plane may be denoted Π (F_1, 1').

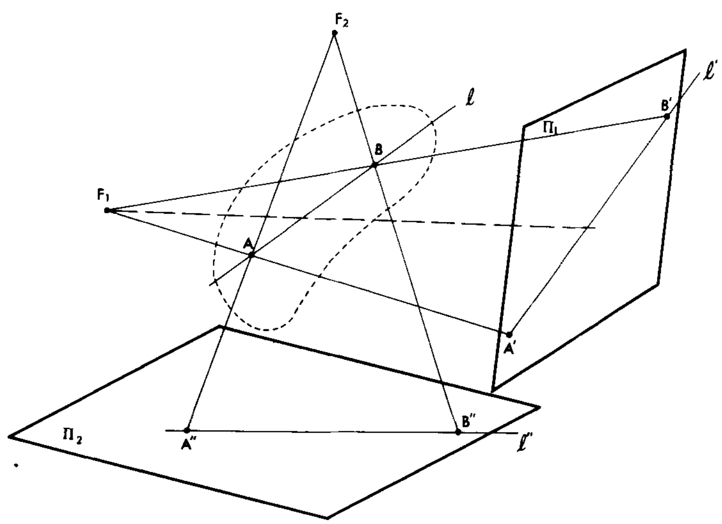

Fig. 1.

If the projections 1' and 1'' of the line 1 in two different planes, Π_1 and Π_2, using the centres F_1 and F_2, respectively, are known, the line 1 can be calculated as the intersection between the planes $\Pi(F_1, 1')$ and $\Pi(F_2, 1'')$. Thus, a line is defined if its projections in two different planes are known.

An angle between two lines in a reproduced object can be calculated if the projections of the two lines in two different planes are known. The directions of the two lines in space are determined and from them the angle can then easily be calculated (the scalar product of the normed directional vectors for the two lines gives the cosine of the angle). Calculations of this type are laborious to perform manually but can easily be performed on a computer. The computer must be fed with coordinates for suitable points on the various films and some angles and distances determining the position in space for the films and foci concerned.

An alternative method for determining the line 1 from the projections in plane Π_1 and Π_2 is as follows. Let us assume that A'' and B'' are projections in plane Π_2 of two given points A and B on 1.(fig. 1). Starting from points A'' and B'' and the projection 1' above, the line 1 can be determined. We begin by determining the plane $\Pi(F_1, 1')$, which passes through line 1 and point F_1, and then determine point A as the central projection of point A'' in plane $\Pi(F_1, 1')$ using F_2 as the centre. Thus A is determined as the point of intersection between plane $\Pi(F_1, 1')$ and the line passing through points A'' and F_2. In analogy with this, the point B can be determined and the line 1 will be the line joining A and B.

An advantage of the latter method of determining line 1 is that the points A'' and B'' can be made to contain information on the positive direction of the line if this is defined. A and B may, for example, be chosen so that the positive direction of the line corresponds to the direction from A to B. This is of importance when determining angles between lines since it may otherwise be difficult to distinguish between an angle and its supplementary angle.

The latter method of determining the line 1 can be generalized by using the projection B''' of point B in a third plane Π_3 and a third centre F_3 instead of B''. (This way of determining a line will be used for the diaphyseal axis below).

The above considerations form the foundation for determination of angles that can be seen directly on the films, i.e. the sides of the angle can be identified directly on the films. Such an example is the inclination of the femoral neck (see below). It is also of interest, however, to study angles determined indirectly from quantities (lines, points and planes) other than two angle sides. Certain lines, points or planes in the object can be identified on the x-ray films, and the angle can then be calculated from these. An example is the determination of anteversion angles (see below).

The determination of planes and points from projections will now be discussed and we will revert to indirect determinations of lines and angles later.

The only case in which a plane can be seen in a projection is when the plane passes through the centre of the projection (the focus) and can be represented in the projection plane (the film) by a line.

A point A in an object can be defined in several ways. The most direct method is to define its central projections A' and A'' in two planes Π_1 and Π_2 with respect to the centres F_1 and F_2 (fig. 2). The point A can in this case be determined as the point of intersection between the line through A' and F_1, which may be denoted by $A'F_1$, and the line between A'' and F_2, denoted by $A''F_2$. This raises a special problem in practice. Let us assume that the points A' and A'' have been defined by determining coordinates (x', y') and (x'', y'') in planes Π_1 and Π_2. Owing to errors of measurement, the two lines $A'F_1$ and $A''F_2$ will generally not intersect. The natural procedure in this case is to estimate A as the midpoint P of the section P_1P_2, with the points P_1 and P_2 on the lines $A'F_1$ and $A''F_2$ which is at right angles to these lines (fig. 2). We call this point P the crossing point of the lines $A'F_1$ and $A''F_2$.

In this case the sought point is overdetermined. Three coordinates suffice to define the point. From, for example, x', y' and x'', A can be determined as the intersection between the line $A'F_1$ and the plane $\tilde{\Pi}$ that passes through F_2 and the line $\tilde{1}$ in the plane Π_2 with the equation x = x'' in the corresponding coordinate system. This is an asymmetric method of determining the point A and does not utilize the information carried by the coordinate y''. The estimate P as the crossing point defined above, on the other hand, is a symmetric estimate and may be regarded as a sort of least square fit. The distance $d = PP_1 = PP_2$ (fig. 2) may be used as an indication of the degree of accuracy with which point A can be determined.

The above mentioned asymmetric estimation of the point A suggests another way of determining a point. Let us assume that we have two projections (films) of an object and that the point sought can be seen in the first film but not in the second. In the second film, however, a line on which the point is known to lie can be seen. In this case, the point A must be determined from a point A' in a plane (film) Π_1 and a line l'' in another plane Π_2 (fig. 3). A is determined in this case as the point of intersection between the line $A'F_1$ and the plane $\tilde{\Pi}(F_2, l'')$ through F_2 and the line l'' on which point A is known to lie. This method of identifying the point may be said to be indirect, in contrast to the former direct way with points on the two films.

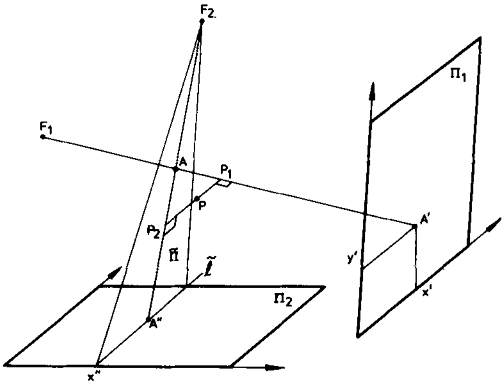

Fig. 2.

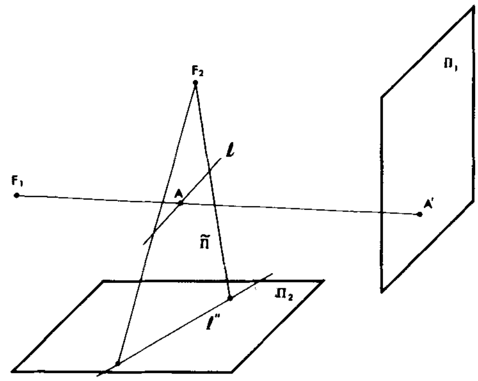

Fig. 3.

Let us now revert to the problem of determining angles. Two examples of methods for determining angles from two projections will be given. These definitions have been used in practical tests with steel triangles (page 14). Several examples of definitions of angles of the femur will be given in the following.

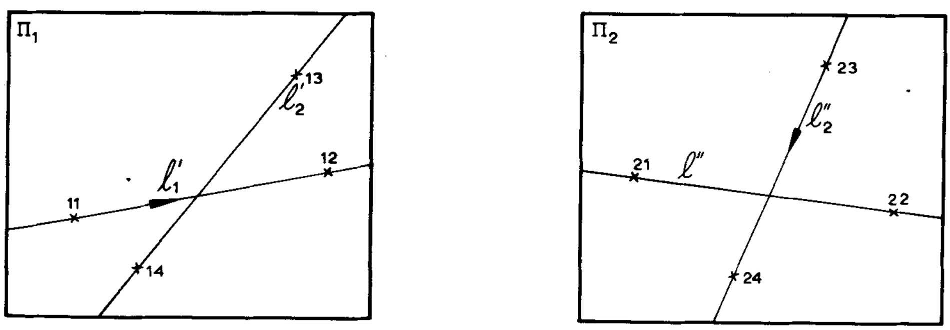

Fig. 4.

The first example corresponds to direct determination of an angle, denoted V_1, both sides being assumed to be visible in both projections (fig. 4). The projection l_1' of the first side l_1 in plane Π_1 passes through points 11 and 12 and corresponds to the positive direction of the line. The projection of l_1 in plane Π_2 passes through the points 21 and 22. These points can be suitably chosen after marking the line l_1'' and need not correspond to the points 11 and 12. Similarly, the side l_2 is assumed to be given by the points 13, 14, 23 and 24, the positive direction of l_2 corresponding to the direction from 23 to 24.

In the second example which is an indirect determination of an angle, we assume that the side l_1 is visible in both films and that its positive direction can be identified in film 2. We assume that the side l_2 is visible in film 1 but not in film 2, but that the projection P'' of a point P that is known to lie on the side l_2 is visible (fig. 5). The positive direction of the line l_2 is assumed to correspond to the direction from the point of intersection of these lines (apex of the angle) to the point P. With this information, an angle, denoted V_2, is uniquely defined.

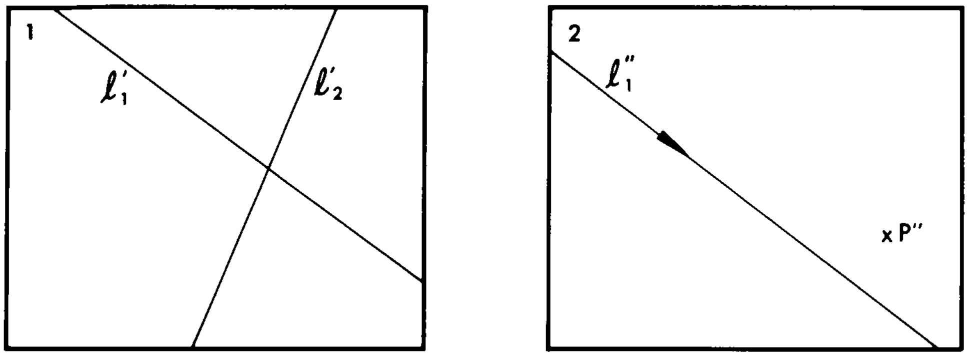

Fig. 5.

The angle V_2 can be determined as follows. The point P can be determined as the point of intersection between the line $P''F_2$ and the plane $\Pi(F_1, l_2')$. This is equivalent to the above described indirect determination of a point. The side l_1 is directly equivalent to definition of a line as discussed above, and the apex of the angle can be determined as the point of intersection Q between l_1 and the plane $\Pi(F_1, l_2')$. The other side, l_2 of the angle V_2 sought will then be given by the line Q P (fig. 6).

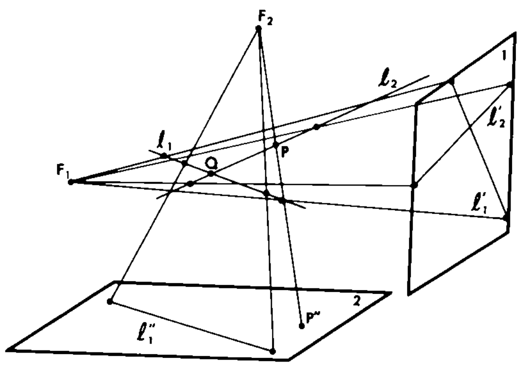

Fig. 6.

Definitions for determination of angles of the femoral neck

The determination of two femoral angles, the anteversion and the inclination will be discussed.

The method we have studied is based on examining the patient in the supine position with the femur horizontal and the lower leg hanging freely. Three x-ray projections are taken: the frontal projection at the hip with vertical beam direction, the lateral projection at the hip and the lateral projection at the knee, both with horizontal beam direction. Figures 7 – 9 show these three projections for a bone preparation positioned so as to correspond to the patient position described above. For definitions of angles the long femoral axis was used. The short proximal femoral axis can also be used but angles relating to this axis are not discussed in this paper.

In frontal projection the femoral-diaphyseal axis is readily identified as the midline of the diaphysis, marked by the two points 11 and 12. In the lateral projection, however, the diaphysis is curved. Two films are therefore used to determine the so called ideal shaft axis (Billing 1954). A point 21 is indicated in film 2 (fig. 8) as the hypothetical point of intersection of the proximal extension of the midline of the diaphysis with the femoral neck and a point 31 in the midline of the condylar mass on the distal extension of the midline of the diaphysis (fig. 9). The femoral diaphyseal axis is thereby determined. The positive direction of the axis is defined as the direction from the hip to the knee.

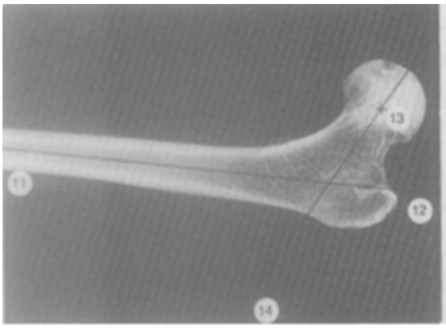

Fig. 7. (Film 1) frontal projection of the hip with the centre of the femoral head, the midaxis of the femoral neck and the proximal part of the longitudinal axis of the femur marked.

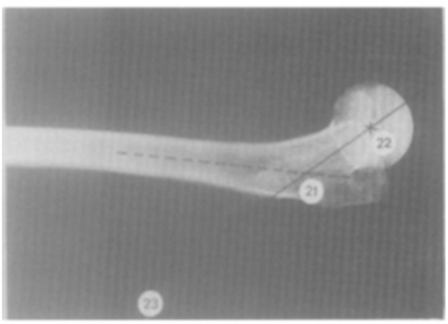

Fig. 8. (Film 2) lateral projection of the hip. The centre of the femoral head, the midaxis of the neck and the intersection between the axis of the proximal femur and the neck axis (point 21) are marked.

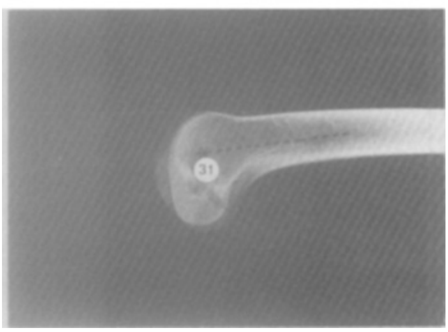

Fig. 9. (Film 3) lateral projection of the knee with a point, 31, on the longitudinal axis of the femur at the centre of the condylar mass.

In both projections the centre of the femoral head is relatively easily defined with the aid of a template with concentric circles. The projection of the centre of the femoral head on the films 1 and 2 is denoted by 13 and 22, respectively. The centre of the head is defined as the crossing point of the two lines through 13 and 22, respectively, and the corresponding foci.

In the frontal projection the axis of the femoral neck is readily defined as a straight line corresponding to the midline of the femoral neck and passing through the projection of the centre of the femoral head. This line is given by the point 13, as discussed above, and another point, 14, and it is used with both definitions of the axis of the femoral neck.

Determination of the midaxis of the femoral neck in the lateral projection is a somewhat greater problem since it is rather difficult to define. Two different definitions of the axis of the femoral neck have therefore been studied.

In definition 1 of the axis of the femoral neck a line is drawn on film 2 through the projection of the centre of the femoral head and the middle of the femoral neck. This line on film 2 is given by point 22 above and another point, 23. The axis of the femoral neck is then determined from its projections on films 1 and 2, corresponding to direct determination as discussed above. With this definition it is not assumed that the midaxis of the femoral neck intersects the femoral diaphyseal axis. This definition is in line with the anatomical conditions since the axis of the femoral neck for a normal femur is positioned in front of the proximal part of the femoral diaphysis, as pointed out by Norman (1969). In accordance with this definition of the axis of the femoral neck an inclination CD 1 is defined as the angle between this axis of the femoral neck and the femoral diaphyseal axis.

It should be noted that the point 21 on film 2 is used only to determine the position of the femoral diaphyseal axis. Errors in defining this point because of difficulty in defining the axis of the femoral neck will have relatively little influence on the femoral diaphyseal axis.

Definition 2 of the femoral neck is indirect and dependent only on the midaxis of the femoral neck in the frontal projection. The midaxis in the lateral projection is drawn only to construct the point 21 above. The axis of the femoral neck is assumed in this case to intersect the femoral diaphyseal axis at a point O. The point O is the intersection between the femoral diaphyseal axis, which is already determined, and the plane $\Pi(F_1, 13, 14)$ which passes through focus F_1 for film 1 and the points 13 and 14 on film 1 (fig. 7). The axis of the femoral neck is thereby defined as the line through the point O and the centre of the femoral head. The positive direction of the axis of the femoral neck is defined as the direction from O towards the centre of the femoral head.

In accordance with this definition of the axis of the femoral neck we define an inclination CD 2 as the angle between the positive direction of this axis of the femoral neck and the positive direction of the angle of the femur.

Every definition of an anteversion angle assumes a definition of a condyle reference plane parallel to the axis of the diaphysis. This can be chosen in two ways. One way is to let the reference plane pass through the axis of the condyle. This is achieved by placing the patient in the horizontal position with his lower leg hanging freely, so that the direction of the reference plane at right angles to the axis of the diaphysis is horizontal.

Another way is to let the condyle reference plane be the tangential plane to the dorsal parts of the condyles. In this case the slope of the reference plane can be measured by fluoroscopy. The angle can be read off on a graduated scale, when the central beam is tangential to the dorsal parts of the condyles (Norman 1969). This method was used in this study.

The anteversion angle signifies the slope of the axis of the femoral neck towards the reference plane seen in the direction of the femoral diaphyseal axis. The two definitions of the axis of the femoral neck discussed earlier correspond to two definitions of the anteversion angle, ANTEV 1 and ANTEV 2. It should be noted that the two definitions of the anteversion angle represent two different angles (fig. 10).

ANTEV 1 corresponds to the anatomical direction of the axis of the femoral neck while ANTEV 2 corresponds to the angle of the direction to the centre of the femoral head seen in the longitudinal direction of the femur (fig. 10).

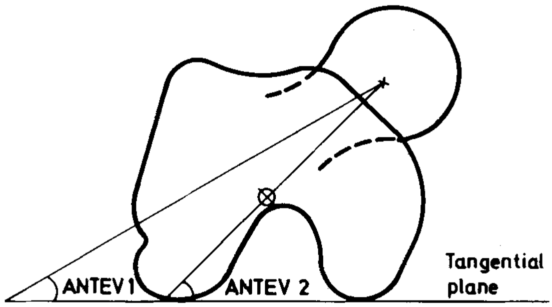

Fig. 10. A femur seen in axial direction from the knee with the two anteversion angles ANTEV 1 and ANTEV 2.

A computer-based method for measurement of angles

The x-ray apparatus for which the method was developed is the Mimer III, but the method can, of course, be adapted for use with other similar devices.

The Mimer III is so designed that the radiation source and the film in its cassette, which are firmly attached to each other, can be rotated around a horizontal axis and a vertical axis. These axes of rotation pass through a point lying on the central ray which strikes the centre of the film (actually the centre of the aperture) at right angles to the film and is situated at a constant distance from the focus and the film plane. The corresponding angles of rotation can be read off on scales. The radiation-source-film system can also be translated horizontally and this translation can also be measured. For each film the two angles and the translation are noted. The point of intersection of the central ray with the film can be determined as the centre of the rectangular image of the aperture. This point is taken as the origin of a coordinate system on the film. The directions of the axes of the coordinates are so chosen that one axis (the x axis) is parallel to the above described horizontal rotational axis. The coordinate system established in this way is used for measuring points on the film (fig. 7 – 9). When the method is used for determination of the angle of a steel triangle, two orthogonal projections are used. For measurements on the femur a lateral projection of the knee is used in addition to two orthogonal projections over the hip (Fig. 7 – 9). The slope of the condyle reference plane (tangential plane to the dorsal margin of the condyles) has been determined by fluoroscopy and read off on a graduated scale on the Mimer III. In order to carry out the geometrical calculations necessary to be able to calculate angles in accordance with the above considerations from machine settings and coordinates measured on films, two computer programs have been developed. The programs are written in FORTRAN.

The first program, called ANGLE, can be used for determination of an angle that is directly visible and calculates the angle according to the two alternatives V_1 and V_2, which are defined previously.

The second program, called ANTEV, has been developed for measurements on the femur. In this program the two anteversion angles, ANTEV 1 and ANTEV 2, and the two angles of inclination CD 1 and CD 2 defined are calculated. A minicomputer PDP 11/40 was used for the calculations.

The programs are generally applicable in that the x-ray apparatus setting corresponding to the angles of rotation and the translation discussed above can be chosen arbitrarily for each individual film. They should, however, be chosen so that unfavourable projections in relation to the angle to be determined are avoided.

Evaluation of the method

The reliability of the method has been investigated in two ways: firstly, a theoretical calculation of the error based on the computer-based calculation of angles, and, secondly, statistical estimation of the error, based on practical experiments with a number of series each comprising 10 determinations.

Theoretical calculation of error

The computer program calculates four angles V_i, i = 1, 2, 3, 4 from a number of measured variables Xj, j = 1, n (n = 24). The resulting V_i are given functions $V_i = f_i (X_1, \ldots\ldots, X_n)$ of the variables X_j. Each measured variable is assumed to be associated with an error of measurement δj. We assume that these errors of measurement are statistically independent. The denotation 'partial error' is introduced for the quantity

$$e_{i,j} = f_i(X_1, \ldots\ldots, X_j + \delta_j, \ldots\ldots, X_n) - f_i(X_1, \ldots\ldots, X_j, \ldots\ldots, X_n)$$

This is an expression for how sensitive V_i is to errors in the variable X_j. The program makes it possible to print out these errors, which is of great value for analyses of the measurement technique. In accordance with Gauss' formula for the propagation of errors, the formula

$$e_i^2 = \sum_{j=1}^{n} e_{i,j}^2$$

for estimation of that part e_i of the total standard error in V_i deriving from errors of measurement in the variables X_j, is obtained. The program provides automatic print-out of these calculated errors of measurement e_i for each calculated quantity V_i. For errors of measurement in measured variables δ_i = 0.5 mm is assumed for distances and $\delta_i = 0.5^\circ$ for angles. Tables 1 – 4 show the mean values for calculated theoretical errors.

Experimental tests of reliability

A number of practical tests have been carried out using the method described, both as a check on its practical applicability and to determine the magnitude of the errors of measurement associated with this way of determining angles. The experiments were divided into two parts. In the first part the method was used to determine an angle defined as V_1 or V_2 above in a steel triangle. In the second part the applicability of the method for determining different femoral angles was tested. The measurements were carried out on a steel model of the femur and on a femur preparation. Orthogonal projections were used in all cases, and for measurements on the femur preparation, the preparation was placed in a position corresponding to that in the description of the method.

Determination of angles in a steel triangle

Three known angles, 22.5°, 45° and 90°, were each measured 10 times. The triangles were positioned more or less arbitrarily for the individual measurements. The calculations were carried out using the program ANGLE. The results, expressed as mean values and estimated values of the standard errors of the individual measurements, are given in table 1. The standard error of the individual measurements was estimated according to the following formula:

$$\sigma^2 = \frac{\sum_{1}^{n}(V_i - V)^2}{n - 1}$$

For certain positions of the steel triangle the angle is sensitive to changes in the measured variables. Since the steel triangle was positioned arbitrarily, occasional measurement values showed relatively large deviation from the true value and this is reflected in the standard error. In one case the value of 29. 34° was obtained for the angle V_2 = 22.5°, with a theoretical error of measurement of 3.65°.

When the method is used for practical purposes, standard positions are chosen so as to provide minimum sensitivity to errors of measured variables.

A special series of 10 determinations was therefore performed on an angle of 45° in order to determine the reproducibility of measurements with slight changes of position of the steel triangle. The mean values and corresponding standard errors for V_1 and V_2 are given in Table 2. The standard errors are considerably lower in this case.

The tests with the metal angles thus gave an accuracy of measurement of 0.5° – 1°, provided that the angle was not placed in too adverse a position in relation to the directions of projection.

Determination of femoral angles

For determinations of femoral angles measurements have been carried out in a steel model of a femur and in a bone preparation. The results are shown in tables 3 and 4. For measurements of steel models of the femur (table 3) the standard errors of anteversion angles exceed those for the corresponding inclination determined according to the method for direct visible angles by about 0.5° – 1°. This difference is mainly explained by the fact that the slope of the condylar plane established by fluoroscopy was read off on a scale graduated in whole degrees, i.e. with a reading error of ± 0.5°. A further source of error was the difficulty in aligning the tangential plane of the condyles during fluoroscopy. Thus the condylar reference plane can not be determined with greater accuracy than ± 0.5° – 1°. For the bone preparation the accuracy was less (table 4). This is natural since the difficulty in defining lines and points in an irregular anatomical object constitutes a further source of error over and above errors in determining the condylar reference plane.

For anteversion angles an accuracy of about 3° was achieved and for inclination the accuracy was 1.5° – 2° for measurements on the femur preparation. It seems that ANTEV 1 can be measured with somewhat greater accuracy than ANTEV 2.

Comparison between theoretical and experimental errors of measurement

The calculated error of measurement, e_i, was compared with the statistical standard error in a number of experiments. The values obtained are given in tables 1 – 4. It will be seen that the two types of errors are related. The total error of measurement derives from two kinds of errors, errors in measured variables and errors intrinsic for the apparatus. The dispersion depends on the measurement position, but, for a given position, the individual deviations arising from the two kinds of errors may be assumed to be statistically independent. With the designation $e_{i,\,tot}$ for the total standard error and $e_{i,\,app}$ for the standard error from the apparatus, the following equation is then obtained:

$$e^2_{i,\,tot} = e^2_i + e^2_{i,\,app}$$

The correlation between $e_{i,\,tot}$ and e_i in a series of experiments is shown in Fig. 11. Theoretical estimation of $e_{i,\,app}$ is not possible. It would seem fairly reasonable to assume, however, that $e_{i,\,app}$ is roughly proportional to e_i, which would give an approximative relationship of $e_{i,\,tot} = k \cdot e_i$. According to Fig. 11, this seems consistent with a value of k of the order of 2. This indicates that the calculated error of measurement may be used to obtain a rough estimate of the total error for an individual reading.

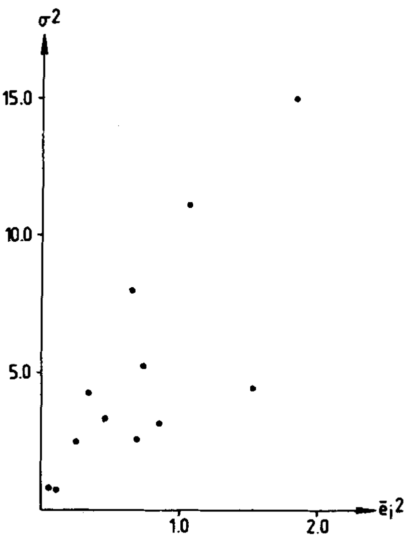

Fig. 11. Twelve series of measurements, each comprising 10 determinations of anatomical angles in a femur preparation. σ = standard error in relation to the mean value obtained experimentally. $\bar{e}_i$ = mean value for the theoretically calculated error of measurement. There is a rough correlation between the two quantities σ and $\bar{e}_i$ (degrees).

Table 1. Results (degrees) of measurements in steel angles arbitrarily positioned.

Angle	Model	Mean value	Standard error (σ) in relation to mean value	Mean value ($\bar{e}_i$) of theoretical error of measurement
V_1	22.5	22.44	0.92	0.93
	45	44.95	0.42	0.54
	90	90.06	0.83	0.56
V_2	22.5	23.91	2.90	1.49
	45	45.29	0.96	0.54
	90	90.89	2.27	0.66

Table 2. Reproducibility of measurements of a 45° angle with slight changes of position between the determinations. Results in degrees.

Angle	Model	Mean value	Standard error (σ) in relation to mean value	Mean value ($\overline{e}_i$) of theoretical error of measurement
V_1	45	44.89	0.33	0.23
V_2	45	45,53	0.40	0.27

Table 3. Results (degrees) of measurements in steel models of the femur arbitrarily positioned.

Angle	Mean value	Standard error (σ) in relation to mean value	Mean value ($\overline{e}_i$) of theoretical error of measurement
ANTEV 1	52.37	1.26	0.77
ANTEV 2	54.85	2.19	0.89
CD 1	135.00	0.46	0.27
CD 2	135.06	1.56	0.44

Table 4. Results (degrees) of measurements in a femur preparation arbitrarily positioned.

Angle	Mean value	Standard error (σ) in relation to mean value	Mean value ($\overline{e}_i$) of theoretical error of measurement
ANTEV 1	25.91	2.84	0.63
ANTEV 2	37.23	3.35	1.07
CD 1	126.11	1.58	0.28
CD 2	125.08	1.78	0.85

Discussion

In direct measurements of given metal angles the present method has an accuracy of 0.5° – 1°. These results are comparable with the control experiments in the monograph by Edholm (1966).

All the methods described for determination of anteversion presuppose a defined orientation of the diaphyseal axis of the femur in relation to one or both projections and the experiments on models have been performed under these conditions. Most published reports on accuracy of measurement concern the biplanar methods (Dunlap et al. 1953, Ryder & Crane 1953, Rippstein 1955). Dunlap et al. carried out measurements on wooden models of the femur with wire axis and obtained variations up to 2° for the anteversion angle. Rippstein found the error of measurement to be of the same order in experiments with models. These results largely accord with the error of measurement of 1.3° for the anteversion ANTEV 1 and 2.1° for the anteversion ANTEV 2 found in the present study in measurements on steel models of the femur. Reports are lacking in the literature concerning measurements on femoral bones without indicators. For the present method the standard error was found to be 3° when determining anteversion and 2° for inclination.

Ruby et al. (1979) who tested the Ryder-Crane method found a standard error of 2.7° when measuring anteversion on bone models in which the transcondylar axis was identified by a steel wire which simplifies the determination of the plane of reference at the knee.

In clinical use inadequate positioning of the femur renders further errors in the anteversion calculated (Gross & Haike 1970) when using the biplanar methods. The standard error of these methods has been found to be 5° in clinical practice (Ruby et al. 1979). Ryder and Crane reported that the directional error of the femoral axis could be as large as ± 10°. These authors calculated that such an error gives a corresponding error of the anteversion of 10°. This large error is, of course, related to the method of measurement used in this technique. Errors of this type have also been discussed by Dunlap et al. and have been shown to be unacceptably large.

A method in which the direction of the femoral axis is of less importance has been described by Norman (1965). Instead of measuring angles on the film, the distance from the centre of the femoral head to the diaphyseal axis in the two projections is measured in two projections at right angles to one another. If the distances are denoted by a_1 (lateral projection) and a_2 (frontal projection), the anteversion angle is given by arctan $\frac{a_1}{a_2}$, which is then adjusted according to the slope of the femoral condylar plane. This method assumes that the diaphyseal axis is parallel to either the horizontal or the sagittal film (not necessarily both). In the practical application of this method various magnification factors for the different projections, owing to differences in distance between the centre of the femoral head and the film, may constitute a further source of error.

A technique in which the anteversion angle is relatively independent of the direction of projection has been described by Schultz (1924) and Budin & Chandler (1957). The femoral neck axis is projected here into a film plane at right angles to the longitudinal axis of the femur. The anteversion angle is read off directly as the slope of the femoral neck axis in relation to the femoral condylar plane. In practice, however, it is difficult to identify the femoral neck axis in projections in the longitudinal direction of the femoral axis, which limits the applicability of this direct method. Arthrographic reproduction of the femoral head in the axial projection was used by Edgren & Laurent (1956). Bernageau & Bourdon (1968) endeavoured to improve the reproduction by means of tomography.

The error of measurement in axial tomographic determinations of the anteversion angle has been reported to be 2° – 3° (Hubbard & Staheli 1972). The method presented here does not assume, in principle, any exact position in relation to the projection directions. The projection directions need not be at right angles either. As with Norman's method, distances are measured on the films, not angles. Our determination of ANTEV 2, according to the above definition, may be regarded as a generalization of Norman's method. ANTEV 1, on the other hand, resembles most other methods and is based on marking the neck axis in two projections. Although the femoral neck axis seems to be difficult to define in lateral projections, ANTEV 1 seems to be associated with less error of measurement than ANTEV 2.

All definitions of the anteversion angle assume a specified condylar reference plane. Two such planes have been defined previously. In both cases, the determination of the condylar reference plane is associated with errors of measurement of the order of 1°, which are directly reflected in the anteversion angle. This is an inevitable source of error in all determinations of anteversion angles and is reflected in the fact that the standard error for anteversion angles is about one degree greater than for inclination.

The essential difference between our method and conventional methods is a considerable generalization at the calculation stage i.e. conversion of points and lines on the film to final results in the form of anteversion and inclination. It is based on similar physical measurement apparatus to that used in conventional methods and is therefore associated with essentially the same errors of measurement as are associated with this type of apparatus. With the use of this type of apparatus and measurement procedure, an accuracy of about 0.5° – 1° would seem to constitute a lower limit for the accuracy of measurement. The general computer-based method of calculation allows simultaneous calculation of an arbitrary number of results and automatic estimation of the error. The method used for determination of femoral angles here is also directly applicable to other anatomical measurements e.g. determination of scoliosis angles.

Conclusions

1. A general computerized method for accurate determination of angles from roentgenograms has been established.
2. The accuracy of measurement expressed as the standard error (SD) is ± 3° for anteversion and ± 2° for inclination.
3. Several angles defined can be determined simultaneously together with theoretical estimations of the errors of measurement.
4. The computerized method does not require an exact position of the object to be measured.

ANATOMY AND GEOMETRY OF THE FEMUR PRACTICAL MEASURING METHOD

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Anatomy and geometry of the femur

The anatomy of the femur can be described by points, axes and planes in the following way (fig. 12): The longitudinal femoral axis forms a curved midline in the sagittal plane between point K and point O, where K is the centre of the condylar axis and O is the point on the longitudinal axis of femur being at the shortest distance from the centre axis of the femoral neck. The longitudinal axis of femur and the axis of the neck do not intersect each other. At the proximal straight part of the femoral axis is point D. The straight line OK is called the ideal shaft axis (Billing 1954). In the frontal view the centre axis of the femoral diaphysis can be considered straight.

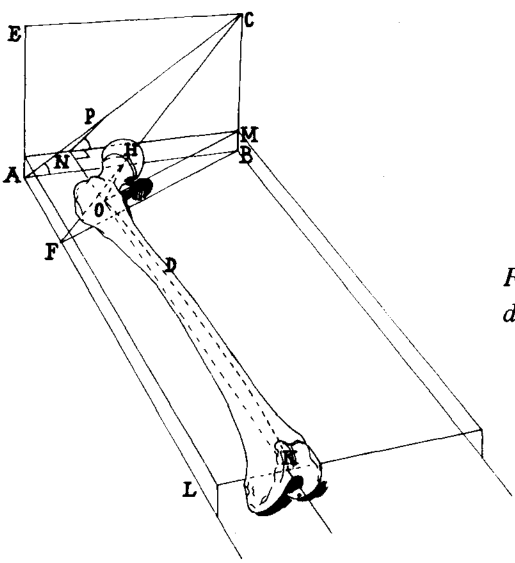

Fig. 12. Perspective view of a femur with different axes and reference planes.

The cross section of the femoral neck is almost circular in that part close to the head, but changes laterally to a more elliptical shape (Backman 1957). The femoral head can be considered part of a sphere with centre H.

The midaxis of the femoral neck is defined as a line through the centre of the head H and the geometrical centre of the neck, i.e. the intersection of the short and long axes of the elliptical cross section of the femoral neck (line CHF in fig. 12). A plane BAL is defined as the tangential plane to the femoral condyles parallel to the ideal axis. The condylar axis of the knee through K is defined as parallel to the tangential plane BAL perpendicular to the ideal axis of the femur. The plane AECB towards which the ideal axis of femur is perpendicular is used as a projection plane when determining the anteversion angles. The direction of the projection is along the ideal axis. This axis intersects the plane AECB in the point N. The line HO connects the capital centre H with the point O on the longitudinal axis of the femur situated at the shortest distance from the centre axis of the femoral neck. This line is projected as PN on plane AECB.

The nomenclature is not uniform concerning the concepts anteversion and antetorsion. The most unambigous definitions were given by Lange & Pitzen (1921), who described anteversion as a turning of the neck and/or the head round an axis perpendicular to the plane BFC equivalent to a change of the angle BFC. Torsion was defined as a rotation of the head and the neck round the longitudinal axis of femur and was defined as a change of the angle BAC.
In cases where the femoral neck axis forms an angle dorsal to the frontal plane, the angles were called retroversion and retrotorsion respectively. A correct use of these conceptions presupposes that a change of the anteversion of the antetorsion really has taken place and also a knowledge about which axis the rotation has occurred. These facts are as a rule not known in the individual case. Some authors (Johansson 1934, Dooley et al. 1938, Laage 1953, Metz 1964, König 1972) have defined the angle BFC as the anteversion or the antetorsion angle. However, most earlier authors defined anteversion or antetorsion as the angle BAC (Schultz 1924, Rogers 1931 and 1934, Dunlap et al. 1953, Ryder & Crane 1953, Billing 1954, Rippstein 1955, Magilligan 1956, Budin & Chandler 1957, Backman 1957, Shands & Steele 1958, Reynolds & Herzer 1959, Hubbard & Staheli 1972).
The same angle is as a rule used in clinical practice in Scandinavia and we have found it natural to use this one. Distinction between antetorsion and anteversion is not made in the following and the term anteversion will be used. Henceforth we will call the angle BAC the anatomical anteversion of the femoral neck, ANTEV 1. The angle of the projected femoral neck axis (PA in fig. 12) towards the frontal plane, i.e. the horizontal plane with the individual supine will be defined here as a functional anteversion and is denoted F ANTEV 1 (fig. 13).

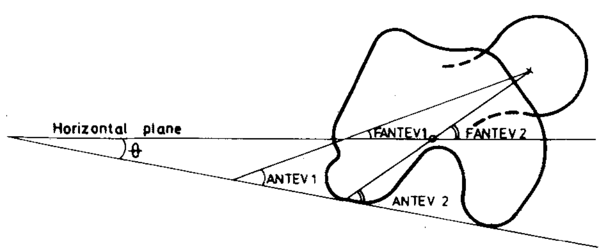

Fig. 13. Axial view of the right femur with the angles of anatomical anteversion (ANTEV 1 and ANTEV 2) and functional anteversion (F ANTEV 1 and F ANTEV 2). Θ is the angle between the horizontal plane and the tangential plane to the dorsal parts of the femoral condyles.

Norman (1969) has found, when studying femoral preparations that the central axis of the femoral neck usually passes in front of the longitudinal axis of the femur. To avoid calculation difficulties he defined the anteversion angle as the angle between the tangential plane of the femoral condyles and the line through the capital centre intersecting the longitudinal axis of the femur HO and projected on the plane AECB (PN in fig. 12). This anatomical anteversion is here denoted ANTEV 2 (fig. 13). The directional angle to the capital centre relative to the frontal plane of the body is called F ANTEV 2 (fig. 13).

The rotation of the tangential plane to the condyles relative to the horizontal plane is given by the relations

$$\text{F ANTEV 1} - \text{ANTEV 1} = \Theta$$
$$\text{F ANTEV 2} - \text{ANTEV 2} = \Theta$$

($\Theta > 0$ outward rotation, $\Theta < 0$ inward rotation)

Earlier authors either used the longitudinal axis of the femur KD, or the short one when defining the inclination. Our measurements refer to the angle CFL and HOK respectively in fig. 12 and they are called CD1 and CD2. The line LA is parallel to the ideal axis KO.

Fig. 14. Arrangements for the lateral x-ray of the femur.

Practical measuring method

A Mimer III (Siemens–Elema) was used for the x-ray examinations. The child was placed supine with the femur horizontal and the lower leg hanging freely outside the edge of the examination table (fig. 14). The trunk and pelvis were placed symmetrically without visible rotation. Three x-ray films were taken (24 x 30 cm), a frontal view of the hip, a horizontal lateral view of the hip after rotating down the tube 90° and a lateral view of the distal femur including the femoral condyles. This last film was exposed after horizontal translation of the tube and film. The rotation (Θ) of the dorsal parts of the femoral condyles towards the frontal plane was measured by fluoroscopy by angling the x-ray tube so that the posterior contours of the two femoral condyles coincided. The angle was read off from the protractor of the x-ray apparatus. The calculation was done by the computer using the coordinates of the three films (chapter I, fig. 7 – 9).

The following angles can be calculated:

1. The anatomical anteversion of the femur (ANTEV 1) i.e. the angle between the projection of the middle axis of the femoral neck on plane AECB and the femoral condyle tangential plane (fig. 12).
2. The functional anteversion of the femur (F ANTEV 1) i.e. the angle between the projection of the middle axis of the femoral neck on plane AECB and the frontal plane of the body.
3. The anteversion angle according to Norman's definition (ANTEV 2) i.e. the angle between the projections on plane AECB of a line through the capital centre intersecting the ideal axis of the femur and the tangential plane to the femoral condyles.
4. The functional anteversion (F ANTEV 2) of the femur calculated according to 3 above.
5. The inclination with the same points of reference as in 1 and 3 above (CD1 and CD2).
6. ANTEV 1, F ANTEV 1, ANTEV 2 and F ANTEV 2 relative to the proximal axis of the femur (OD in fig. 12).

It should be noted that when measuring according to 1 and 2 it is not assumed that the femoral neck axis intersects the longitudinal femur axis. In these cases calculation of the shortest distance between the neck axis and the ideal femoral axis was included in the computer program.

The sources of errors in this calculation of angles are principally limited to the x-ray apparatus itself, to its adjustment and to the precision with which the points of reference can be identified on the x-ray film. The patient must also be lying totally still during the examination. The error of measurement of the method is 2° – 3° (standard error) (chapter I). When measuring relative to the short proximal axis of the femur the error of method is 3° – 4°. The doses of radiation at each examination were calculated with the assumption that the gonads were in the primary field when the two films of the hip-joint were exposed. At the age of 4 the doses of radiation were calculated to 2 mGy, at the age of 7 to 3 mGy and at the age of 15 to 10 mGy.

Chapter III

FEMORAL NECK ANTEVERSION AND INCLINATION IN NORMAL CHILDREN

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Introduction

When treating certain pathological conditions in the hip joint and the proximal femur it is necessary to know the magnitude of the anteversion angle as well as the inclination of the femoral neck. Determination of these angles is of great value when planning osteotomies in coxa plana and congenital hip dislocations and when forming an opinion on secondary changes of the hip caused by cerebral paresis or myelomeningocele. Many methods have been elaborated in order to measure these angles. However, it is hard to evaluate their reliability as studies regarding the error of method are often missing or are uncertain. This makes it impossible to determine the biological variation. Lack of precision regarding the anatomical definitions is a further source of error in many earlier works. Normal values based on roentgenological determination of the angles of anteversion and inclination have been published by Rogers (1934), Dunlap et al. (1953), Billing (1954), Shands & Steele (1958), Teinturier & Dechembre (1968) and Fabry et al. (1973). All these authors have found that the anteversion angle decreases with age, but the results are inconsistent regarding the magnitude of the anteversion angles at different ages. Measurements of anteversion angles have also been done on femur preparations taken from individuals of varying ages by among others Lange & Pitzen (1921), Kingsley & Olmsted (1948) and von Lanz (1951). However, the number of such investigations in children is small and the determinations of age is uncertain in the study of Kingsley & Olmsted.

We here report a study in children between the ages of three and sixteen. The method of measurement used has been described in chapter I and II.

Statistics

Standard statistical methods were used when calculating mean value, standard deviation, linear regression and covariance analysis. For tests of significance the quote of variance was calculated as follows:

$$F = \frac{s^2 \text{ (due to regression)}}{s^2 \text{ (about regression)}}$$

Significant levels for found relations are accounted for with * for $p < 0.05$ ** for $p < 0.01$ and *** for $p < 0.005$.

Material

123 children (70 boys, 53 girls) from 3 to 16 years were examined. Children were chosen who had been referred for radiological examination with suspicion of fracture of the leg and in whom no fracture was found at the radiography. Children with a history of previous hip injury or hip disease were excluded. All measurements concern the right femur as there is no support in the literature about asymmetry of the hips in healthy individuals. However, during this investigation Cyvin (1977) reported on asymmetry of anteversion in normal children. An additional series consisting of 10 healthy children was therefore measured bilaterally. There was no significant difference between the two sides concerning anteversion and inclination in this investigation. The angles of the tangential planes to the condyles had a difference between right and left side of $\leqslant 3^\circ$.

The results are presented in table 5 (page 29) and the following differences between right and left hips were obtained (means ± SD):

ANTEV 1 = $0.5^\circ \pm 4.4^\circ$	
CD 1 = $-1.3^\circ \pm 2.3^\circ$	no significant difference
ANTEV 2 = $-0.6^\circ \pm 5.7^\circ$	
CD 2 = $-1.7^\circ \pm 4.0^\circ$	

Results

Anteversion angles

The values of the angles defined in chapter II were measured for each child. The results are presented in table 7 (page 30). The linear regressions are presented in table 6 (page 29).

There is a decrease (*) in anteversion (ANTEV 1) with age in the whole material (fig. 15). Regression analysis of ANTEV 1 demonstrates that in girls the average value decreases (*) from 34° at the age of 3 to 23° at the age of 16. For boys the angles are 27° and 22° respectively. This decrease is not significant. Girls have higher anteversion than boys of the same age (*). The average value of regression for the functional anteversion F ANTEV 1 is 34° at the age of 3 and 17° at the age of 16 (***). Boys and girls are presented together as there is no significant difference between them (fig. 16).

ANTEV 2 does not vary significantly with age in either boys or girls. Also here girls have higher anteversion than boys (*). The functional anteversion, F ANTEV 2, like F ANTEV 1, has no significant difference between boys and girls. There is a decrease (***) with age, as for F ANTEV 1, from 36° at the age of 3 to 23° at the age of 16.

ANTEV 1 and F ANTEV 1 using the short proximal femoral axis have also been calculated. The results are not presented here as the variation is somewhat greater than using the long ideal axis.

The biological standard deviation (Biol SD) for the different anteversion angles has been estimated from the relation $(\text{Biol SD})^2 = (\text{Total SD})^2 - (\text{Method. error})^2$. ANTEV 1 (girls) = 9.4°, ANTEV 1 (boys) = 7.7°, F ANTEV 1 = 6.9°, ANTEV 2 (girls) = 9.1°, ANTEV 2 (boys) = 8.5° and for F ANTEV 2 = 7.4°.

The middle axis of the femoral neck has been found to pass ventrally to the longitudinal axis of the femur. The shortest distance between the two axes is separated from 0 (***). The shortest distance of the femoral neck axis to the ideal axis increases with age from 1.7 mm at the age of 3 – 4 to 4.2 mm at the age of 15 – 16. When comparing the values of ANTEV 1 and ANTEV 2 for the same hip the following regression was found for the whole material. ANTEV 1 = 0.84 ANTEV 2. $r = 0.90$ $F = 14.4$ $p < 0.005$ $SD = \pm 3.8°$.

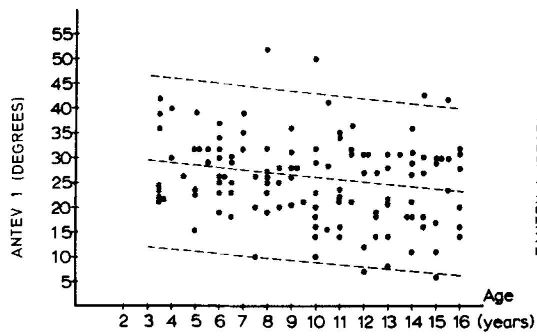

Fig. 15. Anatomical anteversion (ANTEV 1) in 123 normal children, 3 – 16 years old. The regression line and the ± 2 SD limits are marked.

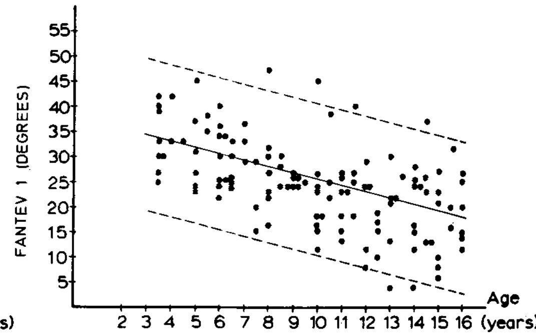

Fig. 16. Functional anteversion (F ANTEV 1) in 123 normal children, 3 – 16 years old. The regression line and ± 2 SD limits are marked.

Anteversion and rotation of the femur

The angle of the femoral condylar tangential plane towards the frontal plane (Θ) of the individual forms of a measure of the neutral rotation of the femur. With increasing age the neutral position is changed from relative outward rotation to relative inward rotation (fig 17) which explains the difference between functional and anatomical anteversion.

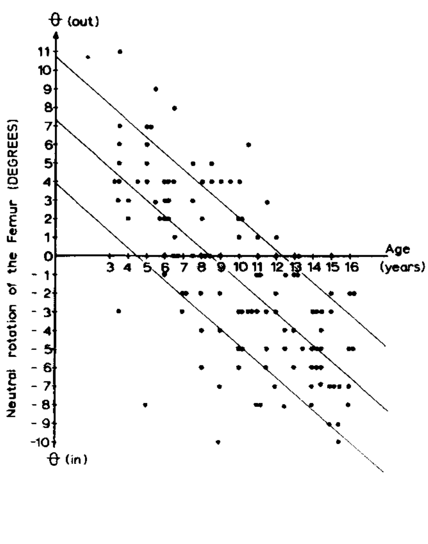

Fig. 17. The neutral rotation (Θ) of the femur in 123 children, 3 – 16 years old. The regression line and the ± 1 SD limits are marked. The frontal plane of the body is the plane of reference and positive angles (Θ) mean outward rotation from this plane and negative angles inward rotation.

To elucidate the connection between anatomical anterversion and the neutral position of the femur in rotation those individuals whose neutral position differs more than ± 1 SD from the average value of regression of the age class (fig 17) were chosen. These children's anatomical anteversion angles are accounted for in fig 18, where the average value of regression for Antev 1 for boys and girls are also marked. Children with relative inward neutral rotation have an anatomical anteversion angle above the average and children with relative outward neutral rotation have an anatomical anteversion angle below the average.

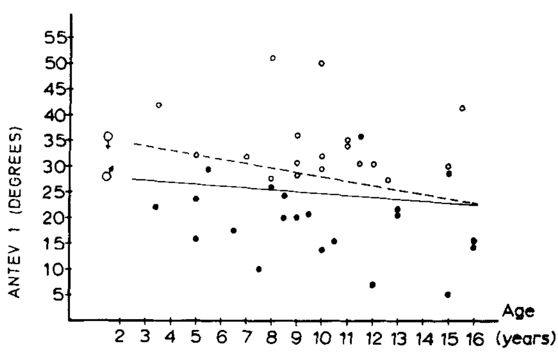

Fig. 18. The anatomical anteversion (ANTEV 1) of individuals with an inward neutral rotation (○) or outward (●) > 1 SD from the mean value of the age group are compared. The regression line for ANTEV 1 relative to age in girls and boys divides the two groups in the diagram.

If correlation is also made for the age factor the relation between the neutral rotation of the femur (Θ), the angle of anatomical anteversion and age can be described as:

ANTEV 1	$\Theta = 13.2 - 0.94\ \text{age} - 0.20\ \text{ANTEV 1}$
	$r = 0.78; F = 91.21; p < 0.005$
ANTEV 2	$\Theta = 12.9 - 0.87\ \text{age} - 0.18\ \text{ANTEV 2}$
	$r = 0.77; F = 88.12; p < 0.005$

Angles of inclination

Regression analysis demonstrates that both CD 1 and CD 2 diminish somewhat with age (*), CD 1 from 137° at 3 years of age to 131° at 16 years of age and CD 2 from 135° to 131°. No significant difference between boys and girls was found. The equations of regression are given in table 6.

The biological variation for CD 1 is 5.8° and for CD 2 6.0°.

Discussion

Methods for determining the angles of anteversion and inclination depend on precise anatomical definitions. The longitudinal axis of the femur should be defined as the ideal axis of the femur to avoid unreliability of measurement due to bending of the femur in the sagittal plane. In comparable measurements we have found a somewhat greater variation of anteversion angle if the short proximal axis of the femur is used instead of the ideal axis and also a higher numerical value of the angle because of the mentioned bending.

As Norman (1969) we have found that the central axis of the femoral neck passes in front of the longitudinal axis of the femur. The anteversion defined by Norman (ANTEV 2) thus gives higher values than ANTEV 1 (fig. 12). In clinical practice measuring according to Norman's definition is easy and the method of choice. The regression found ANTEV 1 = 0.84 ANTEV 2 implies that the values achieved well reflect the anteversion of the femoral neck i.e. ANTEV 1.

The major drawback in earlier studies is the lack of a well defined plane of reference in the distal femur to which the angles of the femoral neck axis can be related. Previous authors have determined the femoral condylar tangent either by palpation of the medial and lateral joint spaces (König & Schult 1973) or defined the tangent as perpendicular to the longitudinal axis of the lower leg where the knee joint as a rule has been kept bent 90° (Dunlap et al. 1953, Ryder & Crane 1953, Billing 1954, Rippstein 1955, Magilligan 1956, Budin & Chandler 1957, Shands & Steele 1958, Gibson 1967). The palpation of the tibia is an unreliable indicator of the direction of the femoral condylar tangent. With the knee flexed 90° the collateral ligaments often permit an angulation of the lower leg in 10° valgus or varus without any contemporary rotation of the femur (Brattström 1962). We have therefore used the method described by Norman (1969) where the direction of the femoral condylar tangent is determined by fluoroscopy when determining the distal plane of reference. The anatomical anteversion is a measure of the rotational position of the femoral neck and head in relation to the tangential plane of the femoral condyles (fig. 12). This measure can be used when calculating malrotations in femoral fractures (chapter V).

The functional anteversion is a compound measure of the anatomical anteversion and of the neutral position of the femur in rotation. This angle can together with the anatomical anteversion give information on imbalance in rotation of the hip joint in neuromuscular disorders such as cerebral palsy, myelomeningocele and polio. The existing difference between anatomical and functional anteversion has not been payed attention to by earlier authors.

The radiographically determined normal values (Rogers 1934, Dunlap et al. 1953, Billing 1954, Shands & Steele 1958, Fabry et al. 1973) demonstrate a marked decrease of the anteversion with increasing age, in close agreement with the variation in the functional anteversion in our material. As earlier authors have not taken into account that the condylar reference plane rotates inward with increasing age, their results therefore mainly describe a functional anteversion. Fabry et al. (1973) has reported a S.D. for anteversion in his normal material which closely corresponds to our S.D. for F ANTEV 1. Lanz has measured the angle of anteversion on femur preparations irrespective of sex. On the whole this author used the same points of reference as in our calculation of ANTEV 1. ANTEV 1 for the whole material has the same relation to age as reported by v. Lanz with a decrease of the angle of anteversion by 10° from 4 to 16 years of age. We have found that girls,however,seem to have higher anatomical anteversion than boys at a given age. This difference was also reported by Cyvin (1977).

Crane (1959) observed that children with pronounced toeing in and toeing out had a high and a low anteversion angle respectively. This is in line with our data. Crane, however, drew the conclusions that the extreme anatomical anteversion angles were caused by the fact that these children prefer sitting like frogs or tailors respectively. In extreme cases this may be the explanation. Similar conditions exist in cerebral palsy (Samilson 1975). However, when the anteversion angle is within ± 2 SD of the normal, presence of toeing in and toeing out might be caused by the above mentioned functional adjustment.

The trivariate linear relation of regression between neutral position of the femur in rotation, anatomical anteversion and age of the individual summarizes the normal anatomical and functional development of the torsion or version of the femur and neutral rotation during growth. Beals (1969) and Fabry et al. (1973) amongst others have shown that the angle of anteversion in children with cerebral palsy and congenital dislocation of the hip is higher than in normal children. Other authors (Alvik 1950, Morscher 1967) have proposed that a high anteversion angle is connected with a higher incidence for coxarthrosis. The above mentioned trivariate linear relation may be useful in further studies of these conditions.

We have measured the inclination using the ideal axis of the femur. Strasser (1917), v. Lanz & Wachsmuth (1938) and Shands & Steele (1958) have determined this angle using the proximal part of the femoral diaphysis (OD in fig 12). Determination using the ideal axis gives somewhat larger angles but the difference is very small as observed by Billing (1954). Our measurements indicate that the inclination decreases somewhat with age coinciding with earlier radiological investigations. (Heinrich et al. 1968, Zippel 1971, Hamacher 1974). The average values of CD 1 and SD in this study are almost identical with Zippel's results (1971). However, we could not find any significant difference between boys and girls. In adulthood our and Zippel's values are consistent with the values given by Backman (1957), who made measurements on femur preparations from adults.

Conclusions

This radiographic study of anteversion and inclination of the femoral neck in normal children has demonstrated that:

1. The anatomical anteversion of the femoral neck decreases slightly with age at least in girls, while the functional anteversion decreases considerably in both sexes because of the fact that the neutral position of the femur in rotation changes from relative outward rotation to relative inward rotation with increasing age.
2. Both anatomical and functional anteversion have a wide biological variation: ± 2 SD is about $15° - 20°$.
3. High anatomical anteversion is compensated for by relative inward rotation and low anatomical anteversion by relative outward rotation of the neutral position of the femur.
4. The inclination of the femoral neck decreases slightly with increasing age.
5. Measurement of anteversion according to Norman accurately reflects the angle between the femoral neck and the condylar plane.

Table 5. Results of radiological determination of angles of the right and left hip in 10 normal children (degrees).

	ANTEV 1		ANTEV 2		CD 1		CD 2		Θ	
	Dx	Sin	Dx	Sin	Dx	Sin	Dx	Sin	Dx	Sin
1	25	26	26	29	137	138	141	140	+4	+4
2	29	29	36	37	135	135	133	137	–5	–2
3	31	36	36	45	139	140	149	142	–4	–4
4	28	25	34	28	123	129	122	133	+2	+2
5	38	35	36	36	132	136	135	137	–2	–2
6	20	23	27	29	137	139	138	140	–6	–5
7	30	32	30	29	145	145	146	148	–4	–4
8	29	19	39	28	128	128	130	131	–5	–2
9	51	54	50	55	145	146	150	148	0	0
10	53	50	56	60	137	135	136	132	–5	–2

Table 6. Linear regressions between angles (degrees) defined and age (years) in 123 normal children.

ANTEV 1 = 30.5 – 0.48 age $r = -0.21$ $F = 5.43$ $p < 0.05$ SD = ± 8.6°

Girls: ANTEV 1 = 36.5 – 0.87 age $r = -0.32$ $F = 5.81$ $p < 0.05$ SD = ± 9.6°

Boys: ANTEV 1 = 28.2 – 0.38 age $r = -0.18$ $F = 3.39$ not sign   SD = ± 7.9°

ANTEV 2 = 32.3 – 0.17 age $r = -0.07$ $F = 0.56$ not sign   SD = ± 9.2°

Girls: ANTEV 2 = 38.6 – 0.54 age $r = -0.20$ $F = 2.10$ not sign   SD = ± 9.4°

Boys: ANTEV 2 = 30.3 – 0.14 age $r = -0.06$ $F = 0.26$ not sign   SD = ± 8.8°

F ANTEV 1 = 37.7 – 1.31 age $r = -0.56$ $F = 54.46$ $p < 0.005$ SD = ± 7.4°

F ANTEV 2 = 39.5 – 1.01 age $r = -0.43$ $F = 26.94$ $p < 0.005$ SD = ± 8.1°

CD 1 = 138.5 – 0.45 age $r = -0.27$ $F = 9.80$ $p < 0.05$ SD = ± 6.1°

CD 2 = 136.2 – 0.35 age $r = -0.20$ $F = 5.30$ $p < 0.05$ SD = ± 6.3°

Θ = 7.2 – 0.85 age $r = -0.69$ $F = 108.79$ $p < 0.005$ SD = ± 3.4°

Table 7. Results of radiological measurements of the right hip in 123 normal children, concerning anteversion (ANTEV 1 and ANTEV 2), inclination (CD 1 and CD 2) and neutral rotation of the femoral condyle (Θ). Inward rotation (Θ<0). Outward rotation (Θ>0). Angles (degrees), age (years). F = female.

No.	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
1	3,5	24	25	137	135	6
2 F	3,5	36	40	143	141	4
3	3,5	42	41	140	140	–3
4	3,5	21	28	127	125	4
5	3,5	22	28	139	138	11
6	3,5	22	27	130	128	5
7	3,5	23	25	132	129	7
8	3,5	39	37	142	142	3
9	4,0	30	40	134	128	3
10 F	4,0	40	38	137	138	2
11	4,5	27	32	140	137	4
12 F	5,0	32	35	134	136	–8
13	5,0	16	16	147	147	7
14	5,0	24	30	142	138	7
15 F	5,0	32	35	135	134	6
16 F	5,0	23	25	130	129	4
17	5,0	40	44	136	131	5
18	5,5	32	36	135	133	3
19	5,5	29	32	147	144	9
20	6,0	25	22	135	134	–1
21 F	6,0	26	31	137	136	0
22 F	6,0	32	34	139	138	2
23 F	6,0	37	36	144	144	3
24 F	6,0	30	27	152	151	4
25	6,0	26	27	137	136	4
26	6,0	34	42	133	126	2
27	6,0	19	32	148	145	3
28	6,0	23	29	133	132	2
29	6,5	30	28	132	132	0
30	6,5	18	20	136	135	8
31	6,5	29	27	145	144	4

No.	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
32	6,5	23	28	137	135	1
33	6,5	25	30	139	138	0
34	7,0	35	40	134	131	–2
35	7,0	32	35	129	127	–3
36	7,0	39	36	140	139	–2
37	7,5	10	9	136	137	5
38 F	7,5	26	35	129	126	3
39	7,5	20	22	137	135	0
40	8,0	26	32	135	134	4
41 F	8,0	32	40	142	140	0
42 F	8,0	25	31	131	129	2
43	8,0	19	23	140	139	–2
44 F	8,0	52	54	136	135	–4
45 F	8,0	27	32	120	118	–6
46	8,0	23	26	130	129	0
47	8,0	20	24	134	133	4
48	8,5	28	28	133	133	0
49	8,5	25	22	141	141	5
50	9,0	36	45	131	129	–10
51	9,0	20	22	134	133	4
52 F	9,0	28	49	118	114	–4
53	9,0	27	34	138	136	0
54 F	9,0	28	32	135	134	–2
55 F	9,0	31	39	121	120	–7
56	9,5	21	20	134	133	4
57	10,0	16	26	139	136	2
58	10,0	10	15	126	128	2
59 F	10,0	18	26	130	128	–3
60 F	10,0	50	55	134	129	–5
61	10,0	14	18	128	128	4
62	10,0	23	30	124	124	1
63 F	10,0	32	39	127	125	–5
64 F	10,0	20	28	127	126	–3
65 F	10,0	29	36	130	129	–6
66	10,5	28	36	132	130	–3
67 F	10,5	41	46	134	132	–3

No.	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
68	10,5	16	22	135	133	6
69 F	11,0	35	40	138	138	–8
70 F	11,0	22	38	128	126	1
71	11,0	24	26	131	131	–1
72 F	11,0	21	27	131	129	–3
73 F	11,0	16	22	131	128	–1
74 F	11,0	14	18	132	131	–8
75 F	11,0	34	44	129	127	–8
76 F	11,5	21	25	138	138	–3
77 F	11,5	32	40	133	131	–5
78	11,5	37	48	134	132	3
79	11,5	31	35	128	126	–6
80 F	12,0	7	12	127	127	1
81	12,0	31	38	135	135	–7
82	12,0	31	32	132	132	–2
83 F	12,0	12	19	129	129	0
84	12,0	27	37	132	131	–3
85	12,5	14	18	125	125	–4
86	12,5	18	21	135	134	–1
87 F	12,5	19	25	128	128	–5
88 F	12,5	27	29	126	126	–8
89 F	13,0	8	13	128	127	–4
90 F	13,0	28	36	130	129	–6
91	13,0	21	22	130	130	0
92	13,0	31	36	153	154	–1
93	13,0	14	18	130	131	–1
94	13,0	22	29	136	135	0
95	13,5	31	32	138	140	–5
96 F	14,0	27	34	144	143	–3
97 F	14,0	18	18	139	139	–6
98	14,0	11	14	127	127	–7
99 F	14,0	18	25	150	149	–3
100 F	14,0	29	34	127	127	–5
101	14,0	36	45	135	134	–8
102	14,0	31	31	134	134	–6
103	14,0	21	33	132	131	–5
104 F	14,5	27	39	143	141	–4

No.	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
105 F	14,5	18	24	137	137	–7
106 F	14,5	16	26	140	137	–3
107 F	14,5	43	45	129	130	–6
108	14,5	31	35	138	136	–5
109	15,0	6	8	126	127	0
110	15,0	11	16	118	118	–3
111 F	15,0	30	41	134	131	–7
112	15,0	30	38	135	132	–9
113	15,0	17	25	131	130	–7
114 F	15,0	30	33	131	132	–2
115 F	15,5	42	45	125	126	–10
116 F	15,5	23	36	130	129	–7
117	15,5	29	35	135	134	–9
118 F	16,0	28	31	138	137	–8
119	16,0	20	21	128	129	–5
120 F	16,0	32	37	130	127	–7
121 F	16,0	14	20	131	129	–2
122 F	16,0	16	23	133	133	–2
123	16,0	32	43	133	131	–5

Chapter IV

A FOLLOW-UP STUDY OF CHILDREN WITH CONGENITAL DISLOCATION OF THE HIP TREATED WITH VON ROSEN SPLINT IN THE NEONATAL PERIOD

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Introduction

It is possible to diagnose congenital dislocation of the hip (CDH) in the neonatal period and the chance of successful therapy increases if the treatment is started immediately (von Rosen 1956, Palmén 1961, Barlow 1962, Fredensborg 1975).

Increased anteversion of the femoral neck has been reported by several authors to be part of the anatomical derangement in CDH (Badgley 1943, Edgren & Laurent 1956, Shands & Steele 1958, Fabry et al. 1973).

Increased anteversion of the femoral neck has also been proposed to be a factor predisposing to osteoarthrosis of the hip joint (Alvik 1960, Morscher 1967, Müller 1971).

Alvik (1960) recommended operation with derotation osteotomy at the proximal end of the femur in children with increased anteversion of the femoral neck as a single sign of dysplasia.

Fredensborg (1975) reported on 111 children with CDH treated with von Rosen splint for 3 months. He evaluated the results obtained by measuring the centre-edge angle (CE-angle – Wiberg 1939) and the spherical index (Fredensborg 1975) and classified all except 2 children as normal.

Cyvin (1977) on the other hand reported on increased angles of anteversion of the femoral neck when re-examining 129 children with CDH who had been treated with the Frejka pillow in the neonatal period (Frejka 1941).

The purpose of this follow-up investigation was to study the anteversion and inclination of the femoral neck in children at the age of 6 – 9 years treated with the von Rosen splint during the neonatal period because of unstable hips (CDH).

The angles of anteversion (ANTEV 1 and ANTEV 2) (fig. 19) and inclination of the femoral neck (CD 1) have been measured by the technique defined in chapter I and II. The standard error of this method has been determined to be 3° when measuring angles of anteversion and 2° when measuring inclination. With a standard error of 3° when measuring anteversion the SD of difference in anteversion between normal symmetrical hips is SD = $\sqrt{3^2 + 3^2} \approx 4.25°$ and 2 SD $\approx$ 8.5°. Additionally the centre-edge angle (CE-angle – Wiberg 1939) was measured as well as the spherical index introduced by Fredensborg (1975).

The roentgenograms were also evaluated by an independent radiologist.

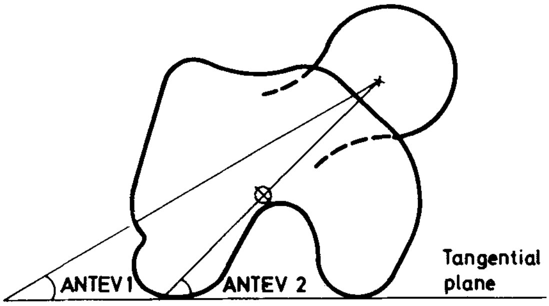


Fig. 19. Axial view of the right femur seen in the direction of the long ideal axis with the 2 anteversion angles ANTEV 1 and ANTEV 2.

Material

Between 1968 and 1970 there were 19.259 live births in the two departments of obstetrics in Gothenburg. 482 children (326 girls and 156 boys) with suspected unstable hips were referred to the Department of Orthopaedic Surgery within the first 10 days of life. 125 children demonstrated on clinical examination by the orthopaedic surgeons unstable hips (Ortolani 1937, Palmén 1961, Barlow 1962). Twenty-eight of these 125 children were selected (22 girls and 6 boys) for this study. Only children where the clinical diagnosis of hip instability was well documented were included (Hansson & Romanus 1975). No distinction was made between dislocatable and dislocated hip joints.

Primary clinical assessment

Eleven girls with unstable hips had unilateral and 11 had bilateral hip instability when first examined (table 8). Four of the 6 boys with unstable hips had unilateral and 2 had bilateral hip instability when first examined (table 8).

Table 8. Unstable hips at primary clinical assessment

	Left hip	Right hip	Bilateral	Total
Girls	5	6	11	22
Boys	2	2	2	6
Total	7	8	13	28

Choice and length of abduction treatment

All children had abduction treatment with the von Rosen splint, 4 cases less than 6 weeks, 15 cases between 6 – 9 weeks and 9 cases more than 9 weeks (table 12). Primary abduction treatment with the von Rosen splint was followed by a period of abduction treatment with Frejka pillow in all cases except 3. Total abduction time varied between 9 – 29 weeks (table 12).

Statistics

Standard statistical methods were used, Fischer's test for pair-wise comparisons and Student's t-test. The statistical significance (p) was tested at the 0.05 level.

Results

The results obtained are presented in table 12. (page 40).

Conventional radiographic evaluation: In 7 children (8 hips) the findings were considered as pathological (shallow acetabulum, short femoral neck and/or horizontal epiphyseal plate) and 5 children (9 hips) were judged as having a valgus deformity (table 12).

CE-angles were all $\geq 15^\circ$ except for one child (13°) and the spherical index was > 0.36 in all children (table 12).

Measurements of anteversion (ANTEV 1 and ANTEV 2) and inclination (CD 1)

a. Children with unilateral hip instability (n = 15)

No difference between unstable and stable hips was found regarding angles of ANTEV 1, ANTEV 2 and CD 1 (table 9).

Table 9. Mean value and SD of anteversion and inclination (degrees) in children with unilateral hip instability (n = 15).

Angle	Unstable hip	Stable hip	Difference unstable – stable hip	p
ANTEV 1	31 ± 6.8	28 ± 5.3	2.9 ± 7.8	>0.05
ANTEV 2	38 ± 8.4	33 ± 11.9	4.4 ± 10.6	>0.05
CD 1	135 ± 5.0	135 ± 5.9	0.3 ± 5.7	>0.05

b. Children with bilateral hip instability (n = 13)

No difference between right and left hip was found in children with bilateral hip instability regarding the angle of ANTEV 1, ANTEV 2 and CD 1 (table 10).

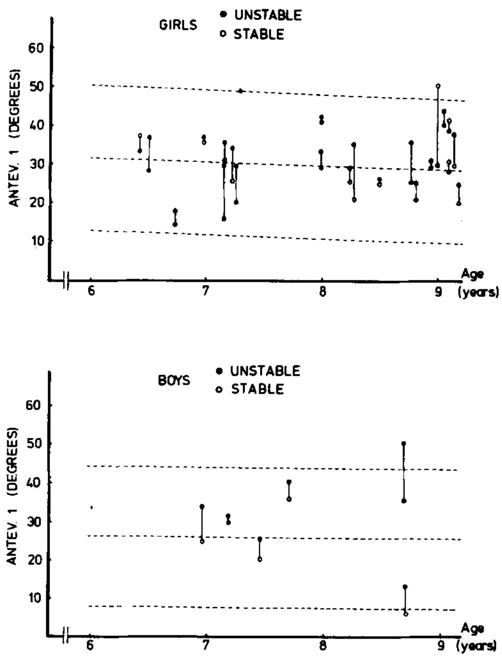
Table 10. Mean value and SD of anteversion and inclination (degrees) in children with bilateral hip instability (n = 13)

Angle	$\frac{dx + sin}{2}$	dx – sin	p
ANTEV 1	31 ± 8.0	3.0 ± 8.0	>0.05
ANTEV 2	37 ± 9.1	2.9 ± 8.2	>0.05
CD 1	135 ± 6.4	–1 ± 3.8	>0.05

When comparing children with unilateral and bilateral hip instability regarding the angles ANTEV 1, ANTEV 2 and CD 1, no significant difference was found.
There was no correlation between anteversion of the femoral neck (ANTEV 1) and length of abduction treatment.

Comparison of unstable hips and hips in normal children

1. Anteversion measured as ANTEV 1 and ANTEV 2 was within the limit of ± 2 SD for the reference material consisting of 123 hips (chapter III) except in 1 unstable hip measured as ANTEV 1 and in 3 hips measured as ANTEV 2 (figures 20 – 21). The inclination was within the ± 2 SD in 39 of 41 unstable hips (fig. 22).



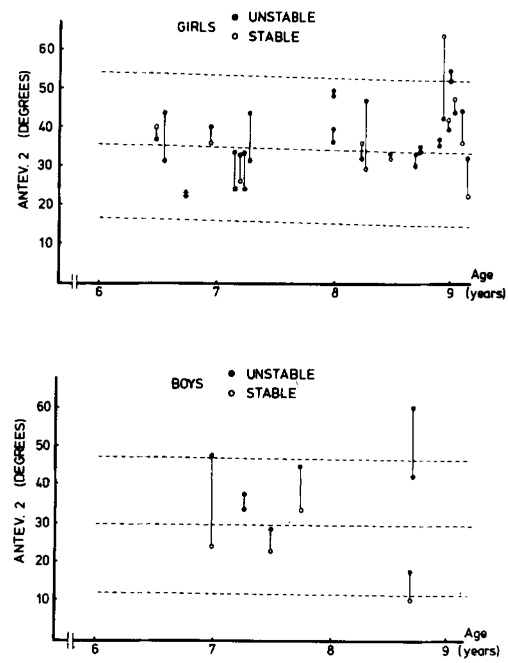


Fig. 20 (left) and Fig. 21 (right). The anteversion values (ANTEV 1 and ANTEV 2) in right and left hips in 28 children with unstable hips at birth. Girls and boys are represented in different diagrams. The anteversion was measured at the age of 6 – 9 years and compared with the anteversion of 123 normal children in the reference material (70 boys and 53 girls) represented by the regression mean and ± 2 SD limits.

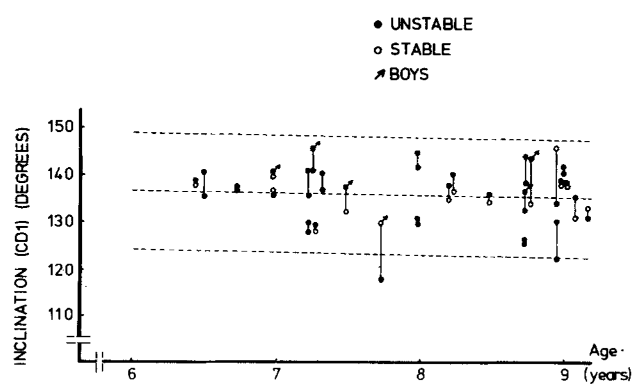


Fig. 22. The inclination values (CD 1) in right and left hips in 28 children with unstable hips at birth. Girls and boys are represented together. The regression mean and ± 2 SD limits for the reference material of 123 normal children are included for comparison.

2. 12 girls and 27 boys in the reference material (chapter III) were of the same age as the children with unstable hips (5.5 – 9.5 years) (table 7).

When comparing the anteversion and the inclination (ANTEV 1, ANTEV 2) in 22 girls with unstable hips with 12 girls with normal hips of the same age, no statistical difference was found. The same result was found when comparing inclination (CD 1). Nor was there a difference between 6 boys with unstable hips and 27 boys with normal hips of the same age (table 11).

Table 11. Angles of anteversion and inclination (degrees) in 28 children with unstable hips and 39 children with normal hips

Angle	Girls		Boys	
	Unstable n = 22	Normal n = 12	Unstable n = 6	Normal n = 27
ANTEV 1	31 ± 6.3	31 ± 7.4	31 ± 10.7	26 ± 7.0
ANTEV 2	38 ± 7.4	37 ± 7.8	38 ± 13.0	29 ± 8.1
CD 1	135 ± 5.0	134 ± 10.4	136 ± 9.9	136 ± 4.7

Discussion

There have been several reports of failures when treating children with unstable hips during the neonatal period with different kinds of splints (Hiertonn & James 1968, Fellánder et al. 1970, Walker 1971, Williamson 1972, Bjerkreim 1974, Cyvin 1977). Several reports have also been presented on iatrogenic effects of abduction treatment in children with CDH (Little et al. 1960, Dooley 1964, Salter et al. 1969, Gage & Winter 1972, Gore 1974). The opinions therefore vary about the type of abduction treatment that should be used. Salter et al. (1969) postulated that the adverse effects seen by abduction treatment depend on trauma to the blood vessels of the femoral head. He stressed the importance of not forcing the femoral head into the acetabulum and recommended the use of Frejka pillow postulating: "The hips are not rigidly immobilized yet maintained in a stable position. This type of splint is particularly useful for the newborn infants." According to Hiertonn & James (1968) it is necessary to choose a more rigid fixation of the hip joints and they recommend the use of the von Rosen splint.

This investigation has shown normal anteversion and inclination in children with unstable hips treated with the von Rosen splint during the neonatal period and these results are to be compared with the reports on increased anteversion in children treated with the Frejka pillow during the neonatal period (Bjerkreim 1974, Cyvin 1977). Eriksson & James (1970) also found a tendency to increased angles of anteversion in children treated with unspecified splint for unstable hips during the neonatal period. However, the number of patients in their study was too small for statistical evaluation. The anteversion measured by Cyvin, Eriksson & James was the angle between the femoral neck and the frontal plane, i.e. a functional anteversion. This functional anteversion was also studied by Asplund & Henriksson (chapter III) who demonstrated that, when the anteversion is above average there is usually an inward rotation of the tangential plane to the dorsal part of the femoral condyles, i.e. when the anteversion is high the anatomical anteversion is greater than the functional anteversion. This means that the children with reported increased anteversion in Cyvin's study might have a still higher anteversion if measured relative to the femoral condyles.

The results of our investigation support the idea that it is necessary to choose a more rigid form of immobilization of the hip joints to obtain normal angles of anteversion. When comparing our experiences with those of Cyvin, it must be pointed out that he included children with neurological disorders and there have been earlier reports on increased anteversion without dislocation of the hip joints in children with cerebral paresis (Beals 1969, Fabry et al. 1973).

There is no evidence of asymmetrical anteversion in healthy children [Norman 1978, Asplund & Henriksson (chapter III)]. Cyvin (1977) reported on asymmetrical development of anteversion of the femoral neck in 28 % of the children with unstable hips. Seven out of 28 children in this study (4 with bilateral hip instability and 3 with unilateral hip instability) had a difference in the angles of anteversion (ANTEV 1 and ANTEV 2) between right and left hip of 9° or more indicating asymmetrical development. In 2 out of 3 children with unilateral hip instability the anteversion was higher on the unstable side.

When interpreting the AP-films of the pelvis there was an impression of valgity in 5 children (9 hips). The inclination calculated was, however, within normal limits (135° – 146°).

This study has shown that in children with CDH the anteversion and inclination are within normal limits. However, the conventional radiological evaluation demonstrated abnormalities, such as horizontal tilting of the epiphyseal plate (fig. 23) and shortening of the femoral neck. These changes will be the subject for further studies.

Fig. 23. X-ray of the right and left hip in a child (patient no. 20 female, 7 years) treated with von Rosen splint in the neonatal period because of unstable right hip. At the examination a marked epiphyseal tilting was found on the right side with a short femoral neck. Left hip normal.

Conclusions

In studying 28 children (22 girls and 6 boys) with unstable hips treated with the von Rosen splint during the neonatal period, the following results were obtained:

1. In children with CDH there were no differences between stable and unstable hips with regard to anteversion and inclination.
2. The measured angles of unstable hips did not differ from those of healthy children of the same age.
3. The length of abduction treatment did not influence the angle of anteversion of the femoral neck.
4. Minor disturbances in development of the hip joints were seen.

Table 12. Results of radiological measurements in a follow-up study of CDH (22 girls and 6 boys). F = female. M = male. U = unstable side. Visual impressions from roentgenograms of the hips: N = normal. V = valgity. P = disturbed anatomy. The anteversion was measured according to 2 definitions (ANTEV 1 and ANTEV 2). Inclination (CD 1). Angles in degrees.

No.	Sex	Clinical assessm.		Treatment v. R.	F	Age at re-examin.	X-ray visual impression		CE-angle		Spherical index		ANTEV 1		ANTEV 2		CD 1	
		DX	SIN	weeks		years	DX	SIN	DX	SIN	DX	SIN	DX	SIN	DX	SIN	DX	SIN
1	F	U	–	7	4	9	N	N	25	28	0.40	0.45	25	20	33	23	130	133
2	F	U	–	12	–	9	V	N	25	27	0.43	0.43	37	30	47	36	135	130
3	F	U	U	6	6	9	V	V	23	23	0.45	0.43	40	43	53	55	140	141
4	F	U	–	10	10	9	N	N	24	26	0.40	0.43	38	41	44	47	137	137
5	F	U	–	12	–	9	N	N	27	25	0.44	0.44	29	31	40	42	138	138
6	F	U	–	6	6	8	N	N	33	34	0.40	0.37	30	50	42	63	134	145
7	F	U	U	9	4	8	N	N	23	23	0.44	0.46	28	31	36	36	122	129
8	F	U	U	9	8	8	V	V	35	35	0.44	0.44	26	21	34	35	138	143
9	F	U	U	8	18	8	N	N	28	35	0.46	0.47	36	25	34	30	126	125
10	M	–	U	6	6	8	P	P	19	17	0.44	0.39	4	14	10	17	133	143
11	M	U	U	6	6	8	N	N	30	28	0.40	0.39	39	49	42	60	132	136
12	F	–	U	13	–	8	N	P	20	13	0.45	0.42	26	26	32	33	134	136
13	F	–	U	12	–	8	N	N	30	32	0.40	0.44	21	35	29	47	136	139
14	F	–	U	12	7	8	N	N	27	39	0.38	0.41	26	29	36	32	134	137
15	F	U	U	6	7	8	N	N	26	24	0.38	0.41	33	29	40	36	129	129
16	F	U	U	12	17	8	N	N	27	28	0.42	0.42	42	42	49	49	143	141
17	M	U	–	6	7	7	P	N	20	23	0.42	0.41	39	35	45	34	117	129
18	M	U	–	12	4	7	N	P	27	18	0.40	0.37	25	20	29	23	137	132
19	F	U	U	6	7	7	N	N	25	25	0.41	0.42	29	20	34	24	129	127
20	F	U	–	3	7	7	P	N	19	24	0.40	0.39	34	26	33	26	128	127
21	F	U	U	3	11	7	P	N	17	21	0.38	0.40	31	31	44	31	140	136
22	M	U	U	12	8	7	V	V	26	22	0.37	0.38	29	30	38	34	146	141
23	F	U	U	6	3	7	N	N	36	36	0.40	0.40	37	16	34	24	135	141
24	M	–	U	7	5	7	V	V	29	33	0.42	0.40	25	34	24	49	138	140
25	F	–	U	6	6	7	N	N	19	19	0.44	0.43	36	37	36	40	136	135
26	F	U	U	1	10	6	N	N	26	29	0.44	0.43	14	17	23	22	137	137
27	F	U	U	6	7	6	P	N	19	25	0.41	0.41	37	28	44	31	136	140
28	F	–	U	2	11	6	N	N	38	40	0.42	0.43	33	36	40	37	137	137

Chapter V

A FOLLOW-UP STUDY OF CHILDREN WITH FEMORAL FRACTURES

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Introduction

Femoral shaft fractures in children have a natural tendency to heal and conservative treatment with traction is therefore the usual mode of therapy. Some spontaneous correction of angular deformity occurs during the healing process (Vontobel et al. 1961, Weber 1969), but not of malrotation. It has been claimed that these malrotations may play an important part in the development of arthrosis of the hip and knee (Müller 1967). It has also been pointed out that clinical symptoms occur when the torsion exceeds 20° (Nicod 1967). Torsion alters the anteversion in the hip and Müller considers that anteversion of more than 30° and retroversion of the neck of the femur by more than 5° causes arthrosis of the hip. In order to avoid this, corrective osteotomy has been recommended (Vontobel et al. 1961, van Joost & Gastkemper 1972, Zenker 1972). For determination of the degree of torsion in the fracture both clinical (Kootstra 1973, van Joost & Gastkemper 1972) and radiological methods have been used. The radiological methods are based on measurement of the difference in anteversion between the healthy and the fractured side, usually by means of the methods proposed by Dunlap et al. (1953) and Rippstein (1955). Measurements performed in this way assume that both the knee-joints and the femur are symmetrically positioned when the lower legs are symmetrically positioned, conditions which are difficult to achieve during clinical measurement. The error of measurement in clinical practice is therefore difficult to evaluate. The above mentioned authors, as well as Hamacher (1974), have estimated the error of measurement in clinical practice to be 5° – 10°. As pointed out by Norman (1969), knowledge of the orientation of the knee-joint is necessary for reliable measurements of the angle of anteversion. With a measuring error of 5° with the Rippstein method a difference of 5° between the fractured and non-fractured side as proposed by Benum et al. (1979) does not necessarily indicate a torsion of the same degree.

With the Rippstein method differences of 10° – 15° between right and left side can appear when measuring the anteversion of normal hips. Ruby et al. (1979) reported such differences when using the Ryder-Crane method, which is a similar biplanar method.

The aim of this study is to assess the torsion in healed femoral shaft fractures using a method in which the methodological error is known (chapter I and II). The dislocation of the fractures, especially the torsion, has been compared with the childrens' clinical symptoms and signs.

Determination of the torsion presupposes a knowledge of the original anatomy. Since this is difficult to obtain from ordinary roentgenograms it is natural to compare with the contralateral side. In normal children there is no evidence of asymmetry between right and left hip (Norman 1978, and chapter III). Thus we define the torsion as the difference in anteversion between the non-fractured and the fractured sides (fig. 24). Since the femoral shaft has been fractured, the long, ideal shaft axis from the knee to the proximal femur (Billing 1954) has not been used. The anteversion was therefore determined relative to the proximal short straight axis of the femur.

The anteversion was measured according to Norman (1969) and is defined as the direction angle of the capital centre relative to the tangential plane of the femoral condyles, as seen in the direction of the short axis (fig. 24).

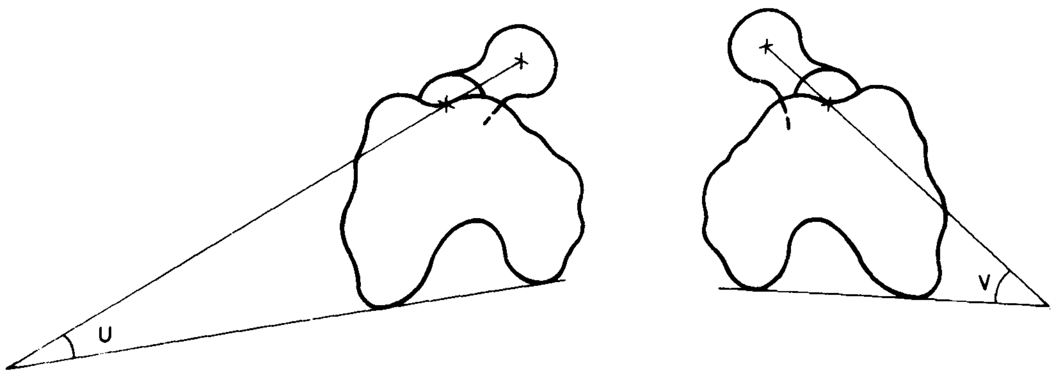

Fig. 24. The fractured (right) and non-fractured (left) femur in the axial projection. The line through the centre of femoral head and axis of the shaft of the femur forms an anteversion angle u and v, respectively, with the condylar plane. Torsion: v – u.

The radiological examination was performed as described in chapter II, with the patient placed supine with the pelvis horizontal and the lower leg hanging freely on the side to be investigated. The tangential plane of the dorsal parts of the condyles of the knee was determined on both sides by fluoroscopy and read off on the scale of the x-ray apparatus. The measurement errors in model experiments for this method of determining the angle of anteversion relative to the short proximal axis are 3.5° and are thus negligibly greater than when the ideal axis is used (Blomberg & Henriksson, chapter I). The SD for difference between symmetrical right and left hip is $\sqrt{3.5^2 + 3.5^2} \approx 5°$ 2 SD $\approx 10°$.

Material

The follow-up investigation comprises 28 children with consecutive unilateral femoral shaft fractures (14 boys and 14 girls). Their ages ranged between 5 and 16 years, the mean age being 9.5 years. The interval between the occurrence of the fracture and the investigation varied between 2 months and 4 years. Of the 28 fractures 24 were treated with traction. Twenty of these 24 fractures were situated in the central part of the shaft, 2 in the proximal part and 2 in the distal part. The remaining 4 fractures were treated by osteosynthesis according to the AO method. Three of these fractures were situated in the central part of the shaft and one in the distal part.

Results

Radiological measurement of the angle of anteversion

In 21 of the 24 fractures treated with traction the anteversion was reduced on the fractured side, (fig. 25) i.e. indicating outward torsion of the distal fragment of the femur. However, in only 6 cases the outward torsion of the distal fragment was greater than 2 SD for the methodological error.

None of the 4 fractures with increased anteversion on the fracture side, i.e. indicating inward torsion, exhibited a greater difference than 5° in anteversion.

The 4 fractures fixed by osteosynthesis all had smaller torsion than 5°. Since the surgical procedure allowed restitution of symmetrical anatomy, and thus essentially the same anteversion bilaterally, the measurements in these 4 cases may be regarded as a control of the accuracy of measurement, i.e. original symmetry between right and left.

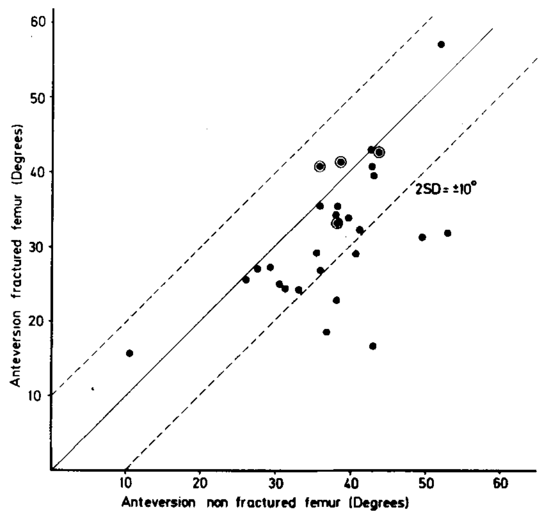

Fig. 25. The degree of torsion in 28 femoral fractures. Each point represents the anteversion in one patient for the femur on the fractured and non-fractured side. ◉ denotes AO synthesis of four femoral fractures. The limit for variation in the error of measurement is indicated in the diagram with 2 SD = ± 10°.

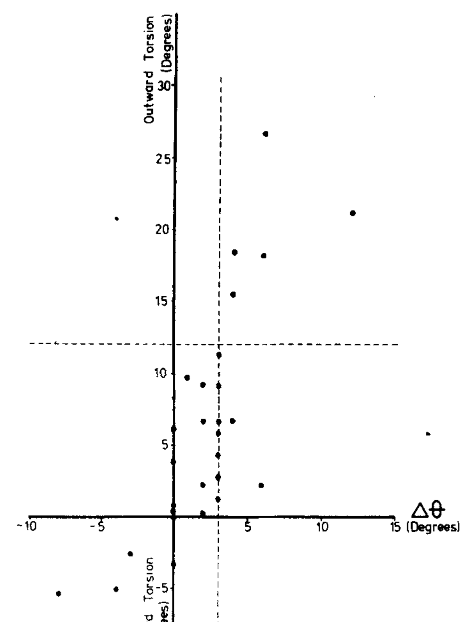

Fig. 26. The relationship between the fracture torsion and the difference in inclination from horizontal of the condylar planes on the fractured and non-fractured sides, ΔΘ, is illustrated. ΔΘ is usually positive owing to reduced anteversion on the fractured side. ΔΘ is ⩽ 0 if the fracture has caused increased anteversion on the fractured side. When ΔΘ ⩽ 3° the torsion was < 12°.

Table 13. Torsion for different positions and types of fracture (degrees). 28 femoral fractures altogether. Figures within brackets denote 4 fractures operated upon according to the AO method.

Type of fracture \ Torsion	< 5°	5° – 10°	10° – 15°	15° – 20°	> 20°	n
Proximal	2					2
Mid-diaphyseal						
Transversal	4 (3)	3		2	1	13
Oblique	4	4	1		1	10
Distal	(1)	1		1		3

Table 13 demonstrates the torsions classified by transverse and oblique fractures. The material is too small to allow conclusions about whether different fracture surfaces are associated with differences in the degree of torsion. No difference could be detected. Four of the 6 fractures with outward malrotation of > 10° had a moderate varus angulation. The two remaining fractures were oblique fractures without visible dislocation from the axis. In 10 cases of 12 without varus or valgus dislocation the torsion was < 10°. Valgus dislocation was uncommon in this material, 5 cases. In 3 of these 5 cases there was a tendency to slight inward torsion (fig. 27).

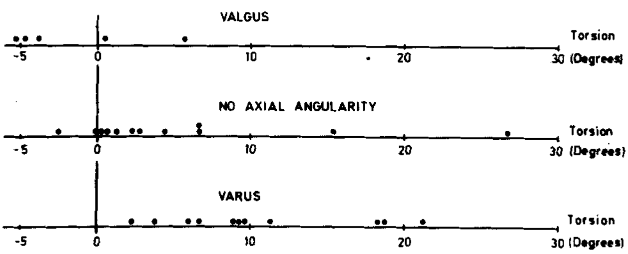

Fig. 27. Torsion for different axial dislocation (varus, valgus and non-axial dislocation). The axial dislocation has been assessed from the frontal projection of the femur when the fracture has healed.

Clinical investigation

No evidence of asymmetric gait could be found in any child. Clinical classification into small and large torsions was not possible. In children found radiologically to have small malrotations (< 10°), no evidence of a difference in the capacity for inward and outward torsion of the hips was found, but such a difference was found in some children with large torsions.

Four children had subjective symptoms. The study has not given any indications that the subjective symptoms can be explained by the torsion in the fracture, except in one case – a 16 year-old girl with a malrotation of 18°. The subjective symptoms four years after the fracture consisted of a feeling of tautness in the front of the thigh, clicking in the right ankle during gait and difficulty in running one year after the fracture occurred. The patient walks well without limping and can sit on her haunches and run. The other three children with subjective symptoms had torsion of < 10°. In two of these three cases the subjective symptoms could be explained by pain in the knees owing to concomitant patellar fractures. These two children also had difficulty in sitting on their haunches.

Discussion

Like Yano & Sawada (1975) we have found that conservative treatment of femoral fractures with traction in children usually causes outward torsion of the distal fragment. The total frequency of outward torsion is higher in our study than has previously been reported (Yano & Sawada 1975, Piroth & Bliesener 1977). Yano & Sawada, who used Rippstein's method of measurement, reported three cases of inward torsion of > 15° among 31 cases. Even allowing for a standard error of measurement of 5° with Rippstein's method, the occurrence of inward torsion must be regarded as proven. In one case they found an inward torsion of 20 – 25°. The frequency of large outward torsion (> 15°) in our study (20 %) is essentially consistent with the figure of 25 % found by the above authors, with 30° as the upper limit for outward torsion. However, outward torsion after traction may sometimes be as great as about 40° (Probst 1977).

The torsions after AO synthesis were small, as found in previous studies (Kootstra 1973).

No difference in torsion between transverse and oblique fractures was detected. The study suggests, however, that outward torsion is associated with moderate varus dislocation, at least in cases of large malrotations. This association has not previously been reported. Varus and valgus dislocations correct spontaneously less often than ad latus dislocations (Vontobel et al. 1961).

Since the femur, including the distal fragment, is curved in the lateral projection, an outward torsion of the distal fragment may give the impression of varus in the frontal projection. This may be one explanation why varus dislocation appears to be associated with large outward torsion.

No clear connection between subjective symptoms and gait disturbances owing to torsion has been found in this study. The incidence of subjective symptoms was strikingly low and was not related to torsion. In two of the four children with subjective symptoms the symptoms could be explained by concomitant patellar fractures. The torsion in these cases was slight. Only in one case were the symptoms considered to be due to the torsion. This patient had an outward torsion of 18° and experienced a feeling of tautness in the front of her thigh and moderate pain and clicking in her ankle. Symptoms of this type have been reported in connection with torsion (van Joost & Gastkemper 1972, Kootstra 1973).

Retroversion of > 5° is considered to cause coxarthrosis in adulthood (Müller 1967). In our study all outward malrotations were less than the anteversion on the contralateral side. This means that symmetry between the right and left knee during forward gait does not cause retroversion on the fracture side. The lower limit of torsion as an indication for corrective osteotomy varies. Zenker (1972) gives a limit of 30° and Vontobel et al. (1961) propose a figure of 15° for outward torsion. For inward malrotation the same authors propose 5 – 10°. At present we do not consider that there are clear indications for osteotomy in our material. The possibility of subjective symptoms occurring later must be borne in mind, however, since the duration of follow-up in this study is only a few years.

Since clinical assessment of torsions appears to be difficult, a simple method of estimating the angle of anteversion is desirable if subjective symptoms and gait disturbances occur. An association between anteversion and condylar tangent inclination has been demonstrated by Asplund & Henriksson (chapter III). High anteversion at a certain age is associated with relative inward rotation of the condyle of the knee and low anteversion with outward rotation. The results shown in fig. 26 are in line with this association and suggest a method of screening. The position of the condyle of the knee with the patient in the supine position with the pelvis horizontal can be determined by fluoroscopy. If there is an obvious difference between the inclinations of the condylar tangents, marked torsion in the fracture is usually present. Complete radiological measurement of the angle of anteversion should be carried out. If, on the other hand, the inclinations of the condyles of the knees are found by fluoroscopy to be essentially symmetric, torsion is unlikely to be present and further radiological investigation can be avoided.

Conclusions

Torsion in fractures of the femoral shaft in children treated by traction have been evaluated by radiological measurement of anteversion. The clinical and subjective symptoms have then been compared with the torsion.

1. Outward torsion of the distal fragment is more common than inward torsion.
2. In cases with outward torsion a concomitant moderate varus angulation was often found.
3. A method of screening is proposed for determining whether concomitant torsion is present in the fracture in cases with subjective symptoms and gait disturbances.

GENERAL DISCUSSION

A general computer-based method for determination of anatomical angles from roentgenograms was developed. This method is especially designed for determination of anteversion and inclination of the femoral neck. In this investigation a MIMER III apparatus was used but measurements can be performed with similar devices. In principle the measurement set-up is identical to that described by Norman (1969). The x-ray exposures are performed with the child in a constant supine position and the lower leg hanging freely. Three films are exposed for each leg – a frontal and a lateral view of the hip and a third view of the knee. The main difference from Norman's method is the use of a computer in the processing of the measured data from the films. By the three films the orientation of the femur is defined relative to a coordinate-system. From coordinates on the films of the axes and points of the femur the angles are calculated by mini-computer. The computer program (ANTEV in FORTRAN) is based on the general principles for central projection. In contrast to all other previously described methods the present computerized method does not presuppose an exactly defined position of the patient.

The first comparison between different principal methods for the determination of anteversion with regard to comparative accuracy and reproducibility as well as the radiation dose to the gonads has recently been presented by Ruby et al. (1979).

They made experiments in models and evaluated the results in clinical measurements. Three methods were compared. The fluoroscopic (Rogers 1934), the biplanar (Ryder & Crane 1953) and the axial (Dunn 1952). In clinical use the accuracy of measurement, expressed as the standard error (SD) was found to be within ± 5° for all three methods. They recommended the biplanar method because it was also easy to use in children with spasticity and this method was found to give the least radiation to the gonads. Another similar biplanar method was introduced by Rippstein (1955).

The Rippstein and the Ryder–Crane methods are performed in essentially the same way. The only difference is the abduction for the second projection (Rippstein 20°, Ryder–Crane 30°) Two films are exposed.

1. AP-projection of the hips in neutral position.
2. AP-projection of the neutrally rotated hips in a position of 90° flexion and 20° or 30° of abduction (γ°).

In the two films the projection CD' of the true inclination CD and the projection AV' of the true anteversion AV are constructed and measured (fig. 28). The true angle of anteversion is then calculated from the formula:

$$\tan(AV) = \tan(AV)' \cdot \frac{\cos(CD' - 90^\circ - \gamma)}{\cos(CD' - 90^\circ)}$$

Rippstein used a conversion table based upon this formula.

For a correct understanding of the values achieved in clinical use the standard error of the measuring method must be considered. The errors in clinical practice must exceed the experimental and theoretical limit.

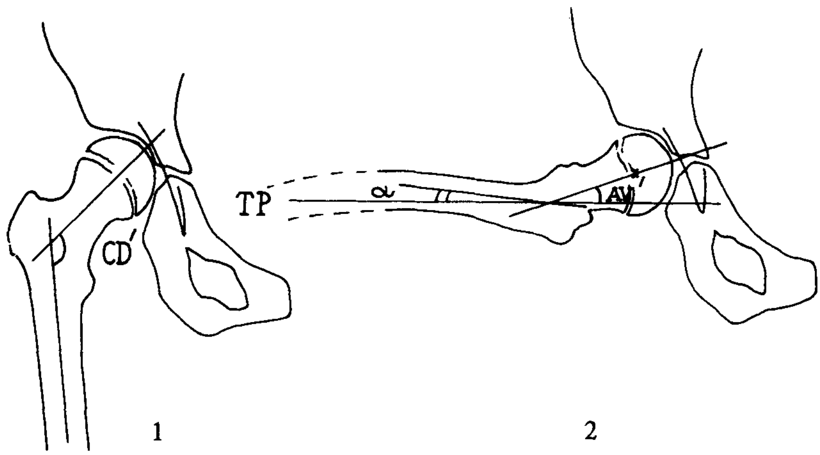

Fig. 28. 1. Frontal projection of the right hip. 2. Projection of the right hip after flexion and abduction. The projected angle of the inclination (CD'). The projected anteversion (AV'). Transverse plane (TP). The angle between the proximal shaft of the femur and the transverse plane (α).

Various factors contribute to the final error of the method:

A. Construction and measurement of angles on the films.

B. Orientation of the patient e.g.

  1. *Asymmetric positioning.*
  2. *Inexact abduction of the legs.*
  3. *Determination of the plane of reference at the knees.*

C. Instability of the x-ray apparatus.

The influence of errors in A and B upon the accuracy of measurement of the biplanar methods can be estimated theoretically.

Theoretical estimation of errors

Construction and measurement of angles on the films

On the assumption that the patient is symmetrically positioned according to the definition for the biplanar methods above, a theoretical calculation of errors can be performed in the following way:

By applying the Gaussian formula for propagation of errors

$$|\delta AV|^2 = \sum_{i=1}^{3} \left(\frac{\partial AV}{\partial V_i}\right)^2 (\delta V_i)^2$$

$V_1 = AV'$, $V_2 = CD'$, $V_3 = \gamma$ (abduction) to the formula for AV above, partial errors from these variables

$$\frac{\partial AV}{\partial AV'} \cdot \delta AV' \quad \frac{\partial AV}{\partial CD'} \cdot \delta CD' \;,\; \frac{\partial AV}{\partial \gamma} \cdot \delta\gamma$$

and the total error δAV can be calculated from errors in the 3 variables $\delta AV'$, $\delta CD'$ and $\delta\gamma$ respectively.

In the calculations an error of $1°$ ($\delta AV' = \delta CD' = \delta\gamma = 1°$) has been assumed for the 3 variables. Five measurements according to the Rippstein method performed and illustrated with roentgenograms by Cyvin (1977) were used by the present author for the calculations representing high, medium and low anteversion AV (table 14).

Table 14. Results (degrees) of 5 measurements with the Rippstein method ($\delta AV' = \delta CD' = \delta\gamma = 1°$ assumed). Calculated partial errors $\frac{\partial AV}{\partial AV'}$; $\frac{\partial AV}{\partial CD'}$; $\frac{\partial AV}{\partial \gamma}$ and the total error δAV are given in the table.

AV	AV′	CD′	$\frac{\partial AV}{\partial AV'} \cdot 1$	$\frac{\partial AV}{\partial CD'} \cdot 1$	$\frac{\partial AV}{\partial \gamma} \cdot 1$	δAV
67	43	168	0.72	1.11	0.57	1.44
63	48	158	0.82	0.55	0.44	1.67
38	28	148	1.17	0.40	0.38	1.30
25	20	136	1.20	0.21	0.19	1.23
17	13	141	1.31	0.18	0.17	1.33

An error in the variables AV′, CD′ and γ of $1°$ gives a theoretical error $\delta AV \leqslant 1.5° - 2°$ in the anteversion AV. The sensitivity is greatest to an error in AV′. An error in AV′ of $1°$ gives an error of about $1°$, $\left(\frac{\partial AV}{\partial AV'} \cdot 1°\right)$ in all cases.

The sensitivity to CD′ and abduction is smaller than for AV′. The sensitivity to these variables is most marked in high anteversion where an error of $1°$ gives an error of $0.5° - 1°$ in the calculated anteversion AV. If the error assumed in the three variables is larger the results in partial and total errors in AV are enlarged correspondingly, i.e. an error of $3°$ in all the 3 variables makes the values in the table 3 times larger.

When the anteversion is high unreliable results have been found by Elsasser & Walker (1973), who hold that the formula for AV is not precise for high anteversions. As a result of the theoretical considerations above this opinion can be modified. The formula is correct, but can be sensitive to the variables measured.

The computerized method for determination of angles presented in chapter I is a similar biplanar method. The rotation of the x-ray tube for the lateral exposure of the hip corresponds to an abduction $\gamma = 90°$. Although the computerized method uses coordinates instead of angles on the films, the sensitivity of the calculated anteversion and inclination to errors in construction and measurement on the films as found theoretically in chapter I are comparable to the sensitivity of the biplanar methods discussed.

In order to relate the results obtained by theoretical calculations to experimental and clinical results for the biplanar methods, it is necessary first to estimate realistic values of errors in the measured variables AV′ and CD′ and secondly to take into account other sources of errors not accounted for in the formula for AV.

Angles on the films can be measured approximately with an accuracy of 0.5° – 1°. When lines and axes are drawn to depict the angles on the films from bone further inaccuracy is added. Quite different values of CD′ can be achieved if the marking of the femoral shaft in the first projection is eccentric. When CD′ is large as in case 1 (table 14) an eccentric marking yields an anteversion AV that differs several degrees from the anteversion AV calculated from the true central axis. A change of CD′ in this case of 1° gives an error of about 0.5° in the anteversion AV.

The results calculated here theoretically seem consistent with the experimental results obtained in bone models by Ruby et al. with a standard error of 2.7°. This standard error is of the same order in the computerized method (chapter I). However, an important difference between the methods is that the computerized one is independent of errors in orientation of the patient. Such errors are inherent in the biplanar method and will therefore be discussed in the following.

Errors in orientation

Asymmetric positioning

In clinical practice inadequate position of the legs renders errors in the anteversion AV calculated (Gross & Haike 1970). As intended by the definition of the biplanar methods the femoral shafts must be symmetrically placed and parallel to the transverse plane in the second projection (fig. 28). Otherwise, an error in AV′ will arise. This error is directly reflected with the same magnitude in the calculated anteversion AV. The condition of parallelism implies that the angle (α) between the proximal shaft and the transverse plane is equal on both sides.

When measuring torsion in femoral shaft fractures the conditions of parallelism can be difficult to fulfill if there is an apparent deformity of the fractured femur. This difficulty can be avoided if the anteversion is defined relative to the short proximal axis of the femur, which constitutes one of the sides of the angle α (fig. 28). The short axis was used when studying torsion with the computerized method (chapter V). When using the biplanar methods and measuring according to this definition the short axis should be parallel to the transverse plane, i.e. $\alpha = 0$ on both sides.

Inexact abduction

Gross & Haike (1970) discussed the errors of incorrect abduction in their experimental work. However, they did not study the sensitivity to errors in abduction for different levels of anteversion. The results in table 14 demonstrate that in high anteversion an error of the abduction (γ) of 1° gives an error of about 0.5° in the anteversion AV. In clinical practice the error of (γ) is probably not less than 3° – 5°, perhaps larger, which means that the control of abduction is of importance.

Determination of the plane of reference at the knee

The prerequisite in the use of the Rippstein or the Ryder–Crane methods is that there is no rotation of the femoral condyles when the position of the legs is shifted between the two exposures. This assumption has not been tested in the methodological studies. A possible rotation between the positions is a further source of error.

This kind of error is eliminated when using the method described by Norman (1965) as well as the present method in which the femur is kept in a constant position. As advocated by Norman (1969), all measurements of anteversion must be performed relative to a well-defined plane of reference. Such a well-defined plane is the tangential plane to the dorsal parts of the femoral condyles and parallel to the long femoral axis. The inclination of this tangential plane can be determined by fluoroscopy (Norman 1969). The computerized method in this study includes determination of the inclination of the condyles by fluoroscopy. According to the results in chapter I the plane of reference can be determined with an accuracy of about ± 0.5° – 1°. Measurement relative to well-defined planes of reference at the knee has contributed to a better understanding of the variation of anteversion during childhood (chapter III).

The sources of error discussed, including the instability of the x-ray apparatus, add to the final result given by the Gaussian formula for propagation of errors. A standard error of at least 5° therefore seems reasonable when using a biplanar method clinically which is in accordance with the values found by Ruby et al.

Interpretation of clinical measurements

The evaluation of a change in anteversion is usually based on a comparison with the contralateral side assuming an original symmetry in normal individuals. With a standard error of 5° the SD of differences in anteversion between normal right and left hips is SD = $\sqrt{5^2 + 5^2} \approx 7°$ and 2 SD $\approx$ 14°. Such differences were found by Ruby et al. when they measured normal hips with the biplanar method. The largest difference was 16°. No statistically significant asymmetry was found between normal right and left hips which is in accordance with our results (chapter III). In the follow-up study of CDH (chapter IV) the possibilities of symmetrical or asymmetrical development of anteversion have been discussed.

Torsion can be measured in femoral fractures, the torsion being defined as the difference in anteversion between the nonfractured and the fractured sides (chapter V).

Benum et al. (1979) proposed that a difference of 5° in anteversion between the hips could indicate a torsion in the previously fractured femur. The theoretical calculations and the experiments presented by Ruby et al. demonstrate that a difference of 5° with the biplanar methods is too small to state that torsion exists.

Torsion after previously traction treatment of femoral shaft fractures has also been studied by Piroth & Bliesener (1977). These authors also used the Rippstein method. A difference of up to 10° was regarded as within normal. Outward torsion of the distal fragment was the rule in their investigation. This is in agreement with the results presented in chapter V.

The inconsistent interpretations of the results in clinical measurements are probably one explanation for the relatively large number of methods published in this field of orthopedic radiology. New methods for measurement of anteversion are successively proposed in order to combine precision and simplicity.

Chevrot (1976) has proposed two frontal projections of the hip with the x-ray tube angulated in cranial and caudal direction along the femur which is kept in a constant position. Computer programs of the trigonometric formula for this method have made it possible to choose the two angulations arbitrarily (Vanhoutte & Raeside 1978). Unfortunately, as expressed by the authors, the results are often significantly poorer in clinical practice than in experiments. One explanation for this difference is that the computer program used does not correct for positional errors of the femur including the plane of reference at the knee. The standard error (SD) of the computerized method presented in this study is ± 3° when measuring anteversion relative to the long ideal axis of the femur (Billing 1954) and negligibly larger when the short proximal femur is used. The error of method for the inclination is ± 2°. It has been possible to reduce the error of method when determining angles radiographically by using the computer program (ANTEV), which in principle makes the determinations independent of the positioning of the patient.

Karl Friedrich Gauss

SUMMARY

The object of this investigation has been:

to elaborate a method for accurate determination of anatomical angles from roentgenograms using a computerized technique and

to apply this method when measuring the anteversion and inclination of the femoral neck in children.

First the limits of accuracy of measurement in this type of measurements, i.e. accuracy of measurement when determining angles from roentgenograms without any introduced indicator was investigated. A theoretical analysis of the general principles for determination of angles from roentgenograms has been performed. By the use of computer technique a practical method for determination of anatomical angles from roentgenograms has been evaluated and established. No exactly defined position of the object to be measured is required. In this study especially the anteversion and inclination of the femoral neck have been investigated, but the method is general and is directly applicable for determination of other anatomical angles in the body. In the present investigation a Mimer III apparatus (Siemens-Elema) was used, but the method can be performed with similar devices.

In order to measure the angles of the hip, the child is placed on the table lying supine with the actual lower leg hanging freely over the edge of the table. Three films are exposed:

1. A frontal view of the hip
2. A lateral " " " "
3. A lateral view of the knee after translation of the x-ray tube and the film

From the coordinates on the films of the anatomical landmarks and axes of the femur different defined angles can be calculated simultaneously. The calculations have been performed using a minicomputer with the computer program ANTEV in FORTRAN.

When measuring anteversion the accuracy is ± 3° (SD) and for inclination ± 2° (SD). The angles have been defined relative to the long ideal axis of the femur.

All measurements of anteversion must be performed relative to a well defined plane of reference at the knee. Two such planes have been studied.

1. The frontal plane i.e. the horizontal plane in supine position.
2. The tangential plane to the dorsal parts of the femoral condyles parallel to the long axis of the femur.

The inclination of the tangential plane to the femoral condyles has been determined by fluroscopy. In fluoroscopy it is possible to determine the tangential plane to the femoral condyles with an accuracy of about ± 0.5° – 1°.

The measurement of anteversion relative to a well defined plane of reference has contributed to a better understanding of the age-dependent change of anteversion during childhood.

In young normal children there is a relative outward rotation of the femoral condyles of the neutrally rotated femur. In adolescense this rotation is shifted to an inward rotation. This means that the anteversion towards the frontal plane, i.e. the functional anteversion diminishes with growing age. The anatomical anteversion, i.e. the angle of the femoral neck towards the tangent-

ial plane of the femoral condyles, does not diminish with age to such a degree as has been reported in previous studies.

Only in girls does the anatomical anteversion, defined as the angle between the axis of the femoral neck and the tangential plane to the femoral condyles, diminish significantly during childhood.

Another observation of biomechanical interest is the tendency to compensate for high anatomical anteversion at a given age with a relative inward rotation of the femoral condyles, and the opposite when the anteversion is low.

A well defined group of children with congenital dislocation of the hips (CDH), treated with a von Rosen splint in the neonatal period, was investigated at the age of 6 – 9 years. The anteversion and inclination in the hips of these children as a group appeared to be within normal limits. These results are at variance with reports after Frejka treatment. Follow-up studies after such treatment have revealed remaining high anteversion in a number of children.

Torsion in healed femoral shaft fractures in children treated with traction was also measured. Outward torsion was the rule in the present series. The maximum outward torsion did not exceed 30°. A screening method has been proposed in order to judge if torsion is present or not. If the inclinations of the femoral condyles in fluoroscopy are mainly symmetric further radiological investigations can be avoided as a torsion deformity is unlikely to be present in the fracture. If the inclinations of the femoral condyles are asymmetric and differ more than 3°, a torsion may be present and further radiological investigation must be performed in order to determine the degree of torsion.

In the closing general discussion the principal differences between conventional biplanar methods and the present computerized method were studied. The sources of errors in biplanar methods, type Rippstein, were analyzed theoretically. A major restriction when using these methods is that the patient to be measured must be placed in a well defined position relative to the axes of projections. These conditions are difficult to fulfill in clinical practice. Such conditions are not required with the present computerized method which enables more precise determination of anatomical angles.

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