THE USE OF STEREOPHOTOGRAMMETRY TO MEASURE ACETABULAR AND FEMORAL ANTEVERSION

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Stereoradiography with a base shift of the source of illumination was used to produce pairs of radiographs to be measured by stereophotogrammetric techniques. The direction of shift was parallel with the longitudinal axis of the body, so that each radiograph in the stereopair could be used for other clinical purposes. A base shift of 10 centimetres with a distance of 100 centimetres between the focus and the film gave acceptable values of stereoscopic parallax. The radiographs were measured using a Hilger and Watts medical stereometer. This method was checked with test specimens, namely an osteotomised pelvis in which one acetabulum could be rotated and an osteotomised femur in which the whole upper portion could be rotated against the shaft. Measurements made on the acetabulum and its radiographs showed a correlation coefficient of 0.9838 over the range 0 to 30 degrees of anteversion, with a mean error ±2.54 degrees and a standard deviation of ±1.52 degrees (n = 21). For the femoral neck, over the range from 10 degrees of retroversion to 80 degrees of anteversion, the correlation coefficient was 0.9979, the mean error ±2.46 and the standard deviation ±1.48 degrees (n = 30).

A technique is presented which enables a concurrent estimate to be made of the four factors which determine the structural stability of the hip: the acetabular shape, the angle of inclination of the roof, and the degree of forward rotation (anteversion) of both the acetabulum and the femoral neck. These angles must be concordant if there is to be true congruity between the two components.

In the management of congenital dislocation and subluxation of the hip the objective is a congruous eccentric and stable reduction which can be maintained throughout growth without vascular insufficiency while weight-bearing. Failure to recognise and correct one or more of the four fundamental features is likely to result in discordance between the components of the joint which may lead to instability or eccentric movement and ultimately to mechanical failure.

When the relative positions of three-dimensional structures are unknown, a single radiograph will not show the spatial arrangement. A stereophotogrammetric technique, however, using no more than two standard radiographs, provides a three-dimensional prospect of the joint from which structural abnormalities may be recognised qualitatively and quantitatively.

DEFINITIONS AND PRINCIPLES

Stereoscopy. The principles of x-ray stereoscopy are well known and were demonstrated in the early days of radiography. Two radiographs are taken of an object from slightly different directions and are viewed with a mirror stereoscope system which enables the object to be seen in three dimensions. Simple stereoscopic examination of anteroposterior radiographs of the pelvic region gives a clear three-dimensional picture, which permits qualitative but not quantitative assessment.

Photogrammetry. When corresponding points can be identified in a pair of radiographs, their relative positions in space can be assigned from simple geometrical calculations and expressed quantitatively. However, simple x-ray photogrammetry is confined to subjects in whom metal markers have been placed in the tissues.

Stereophotogrammetry. This combines stereoscopic observation with measurement. It is a non-invasive technique which permits both qualitative and quantitative assessment. Stereoscopic pairs of radiographs are viewed in special stereoscopes with built-in measuring techniques.

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facilities based on the principle of the "floating mark", as follows.

A three-dimensional stereoscopic image (the "optical model") can only be formed if corresponding features in the two radiographs are automatically (and usually subconsciously) identified with one another. Thus the ability to see a stereoscopic image means that the areas which are seen in three dimensions have been recognised separately in the two radiographs. Their positions can therefore be measured. If a point of light (or any other form of marker) is injected into each radiographic image and the two points of light overlay corresponding features, then only one light marker will be seen on stereoscopic viewing; this is called the floating mark because it appears to hang in space at the same height as the feature it marks. By adjusting the horizontal separation between the two components of the floating mark or by moving the radiographs in a horizontal direction, the mark moves up and down through the optical model.

The distance through which an adjustment is made in order to bring the floating mark into register with features at different distances is the stereoscopic parallax. A record is made of the parallaxes between, on the one hand, features in the plane of the x-ray table-top and, on the other, those within the patient (or test specimen) above the table-top; and the left radiograph coordinates in the x and y directions (parallel to the table-top).

Thus in stereophotogrammetry the matching feature pairs are identified by stereoscopic inspection, marked by a stereoscopic floating mark brought into register with the point of interest, and measured simultaneously. These measurements are entered into standard calculations from which the three-dimensional coordinates can be reconstructed (Hallert 1970). Although stereoscopy gives an impression of the relative three-dimensional positions of features, the optical model which is formed by fusing the two members of the stereopair may be distorted if the viewing system does not exactly reproduce the original projective system. Although this is unlikely (Bellman 1953; Latham 1966), distortion of the optical model is not important in stereophotogrammetry, since stereoscopy is used only to identify corresponding points. The actual three-dimensional coordinates are derived from calculation, not visual impression.

METHODS

Technique. Radiographic estimation of the angles of inclination of the acetabulum and the femoral neck requires that the pelvis is always in a standard and reproducible position. McKibbin (1970) when studying cadaveric specimens emphasised that the supine position was unsatisfactory since variations in the size of the buttocks and even slight lateral tilting would modify the calculation. He recommended that the pelvis be prone with the pubis and anterior superior spines in the same horizontal plane, in apposition to the top of the x-ray table. The position of the femora must also be standardised. This is done by bringing the knees together and flexing the legs until they are at right angles to the table-top. The femoral condyles then lie against the table-top and adjacent to each other.

The radiographs are taken on a horizontal Bucky table with the pelvis in the prone position. The vertical x-ray beam is centred to the midpoint of the second sacral vertebra (the level of the anterior superior iliac spine) and the first radiograph exposed with a distance of one metre between the focus and the film. For the second radiograph the x-ray tube is moved 10 centimetres cephalad, maintaining the position of the pelvis, the vertical direction of the beam and the focus-to-film distance (Fig. 1). To enable orientation of the radiographs and to prevent rotation, a sheet of cardboard containing staples is placed on the table-top, causing this plane to be marked on the radiographs. To keep the radiation dose low while maintaining high definition, rare-earth image-intensifying screens are used and a beam of more than 70 kilovolts.

Examination of radiographs. For qualitative examination of the stereopair radiographs both the Hilger and Watts medical stereoscope (Fig. 2) and a modified Wheatstone stereoscope were used. The Wheatstone stereoscope arrangement utilised two semi-reflecting mirrors and two standard viewing boxes facing each other one to two metres apart, as described elsewhere (Franc, Boyde and Wientroub, in preparation). For quantitative examination the medical stereoscope was used with the radiographs aligned with each other to avoid rotation; the metal staples on the table-top defining one plane. The radiographs must also be carefully aligned on the stereoscope so that the shift axis is parallel with the interocular axis of the observer, to ensure that there is no difference in parallax between any of the staples. The plane of the cardboard containing the staples is also used as a zero reference plane for the Z (vertical) direction to define distances within the patient (or specimen) lying on the table.

Reproducibility of parallax measurement was ±0.1 millimetre, and of the x and y coordinates ±0.2 millimetre. Greater precision could be obtained with a better design of instrument, but this is not, in fact, required for the present purposes. A simple BASIC programme was used for routine calculation.

RESULTS OF EXPERIMENTAL STUDY

The validity of this method was checked using cadaveric specimens. An osteotomised pelvis in which one acetabulum could be rotated was radiographed: measurements of the anteversion of the acetabulum were made over the range 0 to 30 degrees. An osteotomised femur was prepared so that the whole upper portion could be rotated against the shaft: measurement of the
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Ray diagram explaining the relationship of the x-ray tube, table and film for x-ray stereophotogrammetry. $S$ is the distance through which the x-ray tube (or in this case, the table) is moved between exposing the two radiographs. The height $Z_1$ is derived from the measurement of the incremental parallax $P$ by the formula $Z_1 = (G \times P)/(H+P)$.

The Hilger and Watts medical stereoscope with radiographs mounted for measurement. Two light sources ($A$, $A$) inject dots of light through semisilvered mirrors ($B$, $B$) to form the floating mark. Parallaxes are measured by altering the separation of the two plattens ($C$, $C$) with the screw $D$. 

\[ S = H \]
\[ G = F \]
\[ S = \text{Base shift} \]
\[ F = \text{Focus to film} \]
\[ G = \text{Focus to table} \]
\[ F_1 = \text{Focus to feature} \]
\[ Z_1 = \text{Table to feature} \]
\[ H = \text{Fixed increment of parallax for table plane} \]
\[ H-S = \text{Measured parallax for feature in table plane} \]
\[ P = \text{Measured parallax for feature at } Z_1 \]
rotation of the femoral neck was made over the range from 10 degrees of retroversion to 80 degrees of anteversion.

The angles of acetabular rotation measured directly on the osteotomised pelvis and those obtained by calculation made from x-ray photogrammetric measurements are compared in Figure 3. The correlation coefficient was 0.9838, the mean error was +2.54 degrees (range −0.52 to +4.94 degrees) and standard deviation ±1.52 degrees (n=21). Further measurements were performed to check the reproducibility and reliability of the method. An acetabulum with an anteversion of 13.5 degrees on direct measurement was recorded on three occasions in each of five different stereopair radiographs; the range of calculated angles was 11.27 to 13.35 degrees. The results of measurements made on the osteotomised femur and its radiographs are given in Figure 4. The correlation coefficient was 0.9979, the mean error +2.46 degrees (range +1.31 to +5.09 degrees) and standard deviation ±1.48 degrees (n=30).

**DISCUSSION**

We believe that a stereophotogrammetric method has advantages over the alternatives which are available. The difficulty of estimating acetabular anteversion in the living has discouraged investigation of this important feature of the pathological anatomy of congenitally disordered hips. In our earlier studies (Chrispin, Harris and Lloyd-Roberts 1978), using a single radiograph with the patient in the prone position, we were able to obtain useful qualitative information in children aged less than three years, but results were less reliable in older children. It became increasingly difficult to identify the skeletal landmarks necessary to estimate anteversion in those very children for whom this information was likely to be of particular practical value. Quantitative calculation also became less reliable with increasing age for this required that we assumed the acetabulum to be approximately spherical, whereas in neglected or imperfectly treated patients secondary changes develop so that this assumption becomes untenable.

We also studied the potential of computerised axial tomography. Although this provided valuable information in that both skeletal and cartilaginous components could be seen, thus allowing direct and accurate measurement of acetabular anteversion, there were certain disadvantages. Only one thin slice of the acetabulum is visible at one time whereas stereoscopy enables us to see the entire acetabulum and the proximal femur as one image from which to calculate angles. Furthermore, axial tomography is not always readily available, is expensive and exposes the patient to a greatly increased dose of radiation. Computerised axial tomography may, however, be superior to stereoscopy as a method of estimating acetabular depth because the cartilaginous margins are resolved in the CAT scan image. The depth of the acetabulum may be an important factor. Recent investigations suggest that the relative immunity of the African to congenital dislocation may be determined by this increase in the depth of the acetabulum (Skirving and Scadden 1979).

In the present method, anteversion of the femoral neck is measured concurrently with that of the acetabulum. Separate exposures are unnecessary and the radiation dosage is correspondingly reduced. Furthermore, the instability index of McKibbin (1970) which relates femoral to acetabular anteversion may be readily calculated from the stereoscopic image. Lastly, the acetabular angle of Hilgenreiner and the CE (centre of head to edge of acetabulum) angle of Wiberg may be
measured by the stereoscopic method.

The good correlation between measurements made directly on the osteological specimens and the calculations made from measurements of the stereopair radiographs, and also our first clinical experience, show that the method is accurate enough for clinical use. When operation is indicated we may be able, thereby, to assess beforehand the extent and site of anatomical imperfections so that the appropriate corrections may be made. It is, of course, essential that any such correction be preceded by congruous reduction which implies adequate soft-tissue release and acetabular clearance. Lastly, we must recognise that in the very young the hip has the potential to develop satisfactorily, overcoming moderate anatomical imperfections, once exposed to the normal biological stimulus of walking, providing that relative concordance has been achieved. Our observations may therefore apply predominantly to those neglected or imperfectly treated patients over the age of two years.

REFERENCES