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Planar anteversion of the acetabular cup as determined from plain anteroposterior radiographs

Riten Pradhan

From Frimley Park Hospital, Camberley, England

In total hip replacement, orientation of the cup is critical to the stability of the prosthesis. A new method to determine the angle of planar anteversion is described. A simple mathematical formula uses the measurements taken from anteroposterior radiographs to calculate the planar anteversion without reference to tables or charts.

An experimental study in vitro has shown the efficacy of the formula in giving results which are within a clinically acceptable range.

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In total hip replacement (THR), correct orientation of the acetabular cup is essential for the stability of the prosthesis. Malposition predisposes to dislocation.[1,2]

Planar anteversion is the angle of the plane passing through the opening of the cup in relation to the parasagittal plane of the trunk[1] (Fig. 1). Anterior tilt of this plane represents anteversion and posterior tilt is retroversion. During THR, alignment guides are used to orientate the cup in three dimensions. The exact position of a cup after operation is difficult to determine and various techniques have been described to measure anteversion from plain radiographs.

The circumferential wire marker near the edge of the cup is projected as an ellipse when seen at an angle. The methods described for assessment of anteversion therefore involve the complex mathematical and trigonometrical laws of an ellipse. McLaren[3] described anteversion as the function of a quotient of the maximum and minimum diameters of the ellipse. He prepared a reference table of quotients for each degree of anteversion.

Ghelman[4] used fluoroscopy, changing the direction of the X-ray tube from cephalad to caudad and noting the angle of the tube from the sagittal plane when the two halves of the ellipse overlapped, that is when the X-rays were tangential to the opening of the cup. He defined this as the angle of version. Schneider et al[5] used a similar technique, but took multiple pictures until the wire circle was seen tangentially. These methods involve repeated irradiation with increased effort, time and money.

Visser and Konings[6] described a complex trigonometrical formula using a system of Cartesian co-ordinates on the projected ellipse. They did not record the efficacy of their method.

In routine postoperative films, the ellipse is partly obscured by the head of the femoral component and therefore has to be completed to apply these formulae. Accurate drawing of this ellipse is a demanding process; any minor variation is a source of inaccuracy in further calculations. Lewinnek et al[2] used draughtsman's French curves to complete the ellipse, but variation in the size of the cups and changes in curvature with different degrees of anteversion introduce error.

Ackland, Bourne and Uhthoff[7] described a method using mathematical formulae to calculate the minor axis of the ellipse to avoid "unacceptable subjective human error" while completing the obscured part. They considered that it was too tedious to calculate from the formula in each case and used a computer program for further estimation. They prepared a table from which to read degrees of anteversion. The formula used in the computer program was not given. Hassan et al[8] described a complex mathematical formula to judge planar anteversion and studied its intraobserver reliability.

All the above methods are based on the complex mathematical laws of an ellipse. A new method is described, based on the elementary geometry of a circle and a triangle, to derive a simple formula which can be used to determine planar anteversion using a pocket calculator.

Method and Results

In routine postoperative radiographs of the pelvis, divergence of the X-rays can lead to an error in calculating the angle of anteversion by up to 5°. To avoid this an AP film is taken with the beam centred over the hip.

A point M is marked 1/5th of the distance along the maximum diameter (D) of the projected ellipse of the wire

R. Pradhan, MS Orth, FRCS, Specialist Orthopaedic Registrar
Department of Orthopaedics, Royal Surrey County Hospital, Egerton Road, Guildford GU2 5XX, UK.

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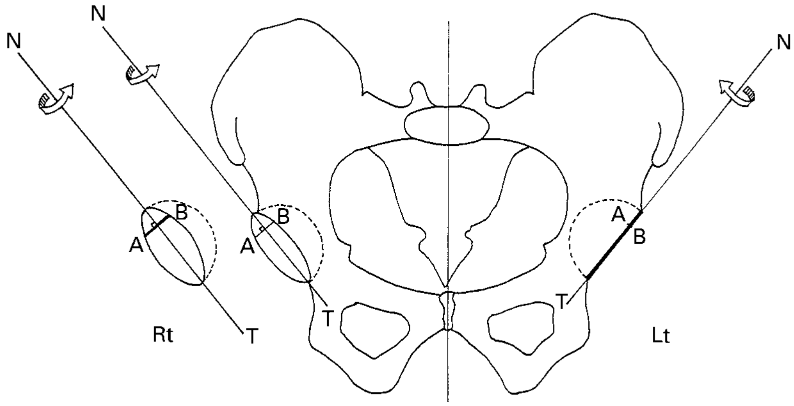

Fig. 1

The plane of the opening of a cup rotates around an artificial axis, NT, which is projected on the radiograph as the major axis, of the ellipse of the wire marker. On the left side the plane of the opening of the cup is tangential to the AP X-ray beam, i.e., planar anteversion is zero. On the right half of pelvis, as the cup rotates around the axis NT, the angle of planar anteversion increases and is seen as a broader ellipse on the radiograph.

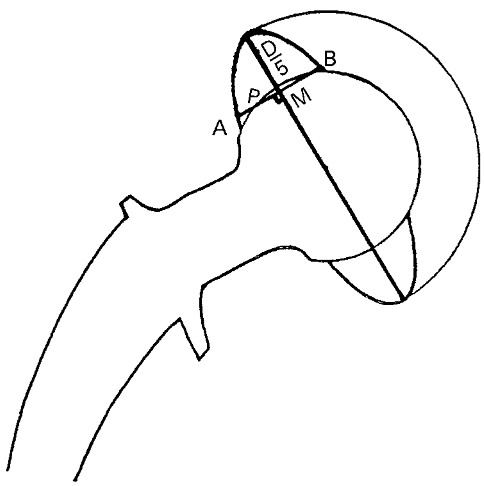

Fig. 2a

Fig. 2b

Drawing (a) and radiograph (b) of the cup. The point M is marked at one-fifth of the long diameter. The perpendicular distance (p) from the arc is measured. Any wear of the plastic cup will expose the arc of the ellipse unequally.

marker (Fig. 2). The perpendicular distance (p) is measured from point M to the arc.

The formula is thus:

$$\text{planar anteversion} = \text{arc of sin}\left(\frac{p}{0.4D}\right)$$

The method is as follows. With a scientific calculator in degree mode, perform the division p ÷ 0.4D. This gives the value of sin Θ (where Θ is the angle of planar anteversion). In order to find the value of Θ, keeping this answer on the screen, shift the mode. The key $\sin^{-1}$ shows the angle.

This formula was derived as follows. The narrow arc of the wire marker seen on the radiograph indicates less version; the broader arc means more version, but this has never before been quantified.

Consider a circle representing the opening of the cup, of radius r, diameter D and centre C (Fig. 3). M is a point D/5 distant from the circle. AB is a perpendicular cord passing through M and touching the circle at A and B. A right-angled triangle (CMB) may be described of which sides CB (the hypotenuse) = r, MC = 3/5r, and MB = L.

According to the theorem of Pythagoras

$$r^2 = L^2 + (3r/5)^2$$

$$\therefore L^2 = r^2 - (3r/5)^2$$

$$= r^2 - \left(\frac{9}{25}\right) r^2$$

$$\therefore L^2 = \frac{16}{25} r^2$$

$$\therefore L = \frac{4}{5} r$$

$$= 0.8\, r$$

$$= 0.4\, D \left(\text{since } r = \frac{D}{2}\right)$$

When this circle rotates around a diametrical axis D, perpendicular to the cord AB, the circle will appear elliptical on the frontal view and the length of AB will vary. As the circle rotates further the ellipse will narrow. When this circle rotates through 90° the points A and B will overlap.

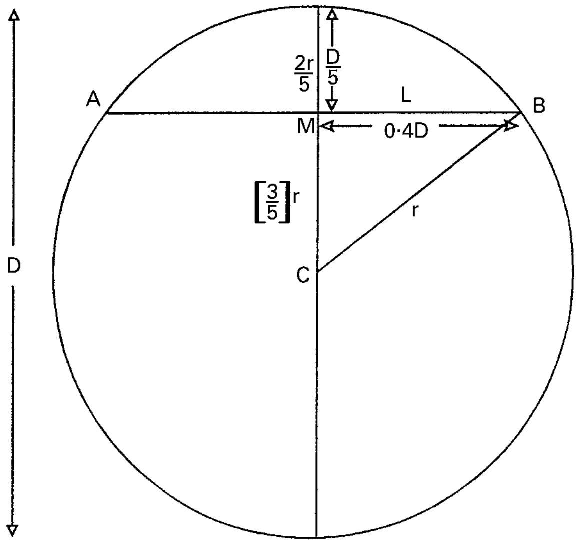

Fig. 3

The circle represents the opening of the cup: points A and B lie on the circle and the cord AB passes through point M, perpendicular to the diameter.

$$\sin(\Theta) = \text{opposite side (AP)} \div \text{hypotenuse (AM)}$$

The numerator is equal to the measured distance between point A (or B) on the arc from a point 1/5th of the distance along the diameter. Using the calculator in degree mode, the value of sin (Θ) is obtained; the value of Θ in degrees can be found easily by shifting the mode to $\sin^{-1}$. Hence, the formula for the angle of planar version is:

$$\text{arc of sin}\left(\frac{p}{0.4\,D}\right)$$

Although intricate completion of the ellipse is not required, in some cases the end of the arc has to be extrapolated (Table I). The method can be used in metal-backed cups with a circular edge as shown in Figure 6.

A simple device using a 360° angle measure with a concentric rotating sliding pointer was fixed coaxially with a rod (Fig. 7). At the other end of the rod the acetabular prosthesis was mounted using its diameter as the axis. Two different sizes of cup with wire rims were used. Each cup was mounted in the acetabulum of a bony pelvis. The pelvis was set in the anatomical position with the anterior superior iliac spines and the pubic

On further rotation the two points will again separate (Fig. 4). At a rotation of 180° length AB would be maximal in frontal view.

When this rotation is viewed along the axis of rotation (NT in Fig. 1) points A and B will follow a circular course, with its centre, M and radius L (Figs 4 and 5). Points A and B on the smaller circle (centre M) with radius 0.4D, when viewed from the front, will be seen to be separated by a distance equal to the sum of perpendiculars (p) from the axial plane, that is, 2p (Fig. 5). In the right-angled triangle MAP, the angle Θ formed at the centre is the same as the rotation of the larger circle, which is the same as the angle of planar anteversion.

Table I. The extent of overlap of the distance D/5 by the metallic head

External diameter of acetabular cup (mm)*	Head size (mm) 28	32
40	3	4.6
42	2.4	4
44	2	3.4
46	1.2	2.8
48	0.6	2.2
50	-	1.6
52	-	1
54	-	0.4

* magnification is not considered. The ring size is taken to be 2 mm less than the cup size

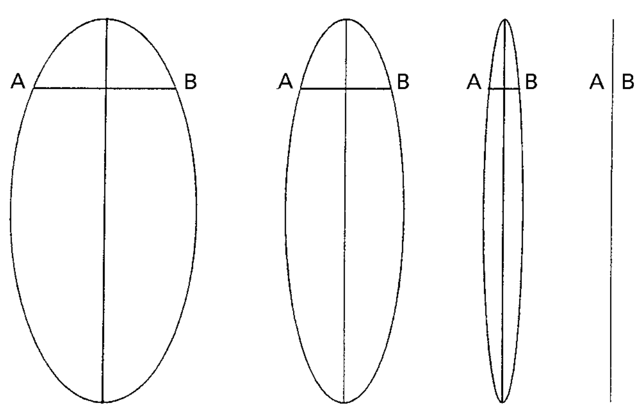

Fig. 4

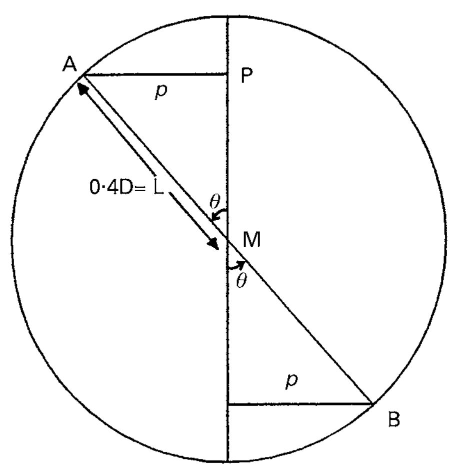

Fig. 5

Figure 4 – Frontal view as the circle rotates around the diametric axis; the cord AB varies according to version. Figure 5 – The lesser circle inscribed by points A and B when rotation is viewed along the axis. The points A and B also lie on the larger circle and the segment AB therefore represents the opening of the cup. The angle subtended at the centre of this circle by segment AB is the angle of planar version.

Fig. 6

Radiograph showing that half the ellipse seen in a metal-backed circular edged cup is enough to calculate planar version.

symphysis in the same horizontal plane using a spirit level.

Femoral heads of two sizes, 28 and 32 mm, were used, located in appropriately sized sockets. Radiographs were taken in seven different angles of version ranging from retroversion to anteversion. The angle of vertical tilt was changed between cup sizes and measured directly with a set square and protractor. AP radiographs with the X-ray beam accurately centred over the hip were taken on a bucky film with a tube-to-film distance of 100 cm which is common in clinical use. Measurements were taken from each radiograph with a plastic scale marked in millimetres. Using a pocket calculator, in degree mode, calculations were made and the angle of planar version was judged by three neutral observers with a degree of precision and accuracy, well within clinical acceptability. The measurements calculated are given in Table II.

The formula described does not differentiate anteversion from retroversion. Keeping the X-ray beam centred over the hip, radiographs were taken with the plane of assembled pelvis and mounted cup tilted 10° towards the opposite side. The angle of the anteverted cup widened, whereas that of the retroverted cup narrowed. Therefore a second radiograph with the pelvis tilted to the opposite side should differentiate anteversion from retroversion.

Discussion

Measurement of three-dimensional version on two-dimensional radiographs has obvious limitations and is bound to have some degree of inaccuracy. This is in part due to manual measurement with an ordinary scale; when the ellipse is broader the apex of the ellipse is difficult to pinpoint. These pitfalls are, however, common to the previously described methods using radiographs. The methods of Ackland et al[7] and by Hassan et al,[8] which are based on

Fig. 7

The pointer is set at zero when the AP beam shows that the opening of the cup is tangential; the ring of the wire marker is seen as a line. As the cup rotates (anteverts or retroverts) the pointer records the rotation. The ellipse on the radiographic film correspondingly widens.

Table II. Readings of anteversion recorded by the observers using the new formula $\sin^{-1}\left(\frac{p}{0.4D}\right)$

Film code	Actual angle (degrees)	Calculated angle of anteversion (degrees)							
		Observer 3			Observer 1		Observer 2		
I AV	10	9.47	9.47	9.47	10.27	10.27	10.14	9.48	9.48
II AV	19	18.93	18.93	18.93	19.4	20.3	20.32	20.32	19.63
III AV	32	30.51	32.84	31.28	32	29.9	29.89	31.28	31.28
IV RV	20	19.55	18.87	18.87	19.3	19.4	19.55	20.93	19.55
B1	8	8.05	8.05	8.63	9.2	8.8	9.13	9.13	9.71
B2	17	16.86	16.26	16.26	16.25	16.50	17.91	17.91	17.91
B3	24	21.72	21.72	22.33	22.60	22.66	25.25	23.38	20.92

the laws of an ellipse, also require the observer to measure the long diameter of the ellipse and its perpendicular distance from the arc. Further calculations in the former method are done by computer and the anteversion is found using a reference table. In contrast, Hassan et al[8] have used an intricate mathematical formula and a reference table. The reliability of the new formula for radiological calculations of acetabular cup planar version was confirmed during the in vitro study.

The method described has the advantage of ease of application in clinical practice and has proved to be reliable under most conditions.

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