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A new geometrical method (BMCRI Method) for measuring cup anteversion after total hip replacement

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Abstract
Back ground: In total hip replacement the cup placement is critical. Orientation is determined by anteversion and abduction. We have devised a simple geometrical method to calculate anteversion using simple instruments which does not require complicated conversion tables, scientific calculators, trigonometric tables and special x ray equipment.
Objectives: The aim of study is to evaluate the new method in terms of reliability and validity in comparison with other commonly used radiological methods against CT evaluation.
Methodology: In 30 hips of 25 consecutive patients, 13 females and 12 males who underwent primary total hip replacement in our institution, the component version in our method was calculated and compared with CT evaluation of angles. The intra and inter observer reliability were assessed.
Results: Average CT measurement was 23.28 for anteversion.We found our method had good correlation with CT calculation with average variability of +/_ 3.9138^0 in planar anteversionand CT methods had excellent intra and inter observer reliability (C.I. = 0.884 to 0.947&0.866 to 0.963).
Conclusion: Our method is accurate in comparison with CT (P value>0.05), which does not need any reference tables, conversion tables, scientific calculators, multiple radiation exposures and not time consuming.

Keywords: Cup anteversion, abduction, reliability, validity, BMCRI method

1. Introduction
In total hip replacement the cup orientation is critical as inaccurate placement can cause dislocations in long term [1, 2]. The orientation of the cup is described in terms of abduction and anteversion, the three forms of which was defined by D.W MURRAY [2] in 1934 as anatomical, radiological and surgical anteversion and abduction. Anatomical anteversion is the angle between transverse axes to acetabular axis on transverse plane. Radiological (planar) anteversion is the angle between acetabular axis and coronal plane. Surgical anteversion is angle between longitudinal axis of pt and acetabular axis projected on sagittal plane.
Planar anteversion is the angle made by the face of the cup to the parasagittal plane of the body in a plane perpendicular to the cup opening plane [2] (Fig 1). There are many methods proposed to calculate anteversion from plain AP radiograph.

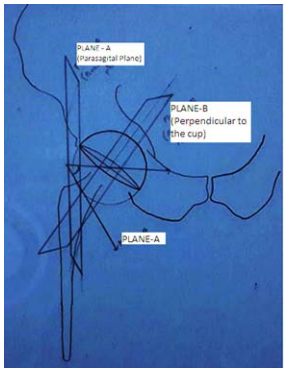


Fig 1: Planar angle of anteversion

In the plain radiograph the edge of the cup is projected as ellipse. Using the principles of construction of ellipse many authors have proposed different methods for the calculation of anteversion.

McLAREN [3] defined anteversionas quotient of function of maximum and minimum diameters of ellipse and prepared a reference table of quotients for each degree of anteversion.

Visser and Konings [4] described a complex trigonometric formula using Cartesian coordinates projected on the ellipse.

Auckland, Utthoff and Bourne [5] described a method using mathematical formula to calculate the minor axis of the ellipse.

GHELMAN [6] used fluoroscopy by changing the x ray tube from caudad to cephalad direction until the rays are tangential to cup edges and notingthe angle made to the sagittal plane.

LEWINNEK [7] used the mathematical formula (Fig 20) using major and minor axis, sine inverse calculation.

WIDMER [8] used a formula using minor axis and total length (Fig 21), sine inverse calculation.

LIAW [9] used beta angle, sine inverse for the calculation anteversion (Fig 22)

HASSAN [10] used a complex formula(Fig 23) involving sine inverse formula RITHUN used a formula (Fig 6) using sine inverse formula (Fig 24)

All these methods use complex trigonometric formula; inter conversion tables and scientific calculator for calculating inverse sine formula. We have devised a method which can directly measure the anteversion angle using simple geometric instruments like divider, compass and protractor.

Methodology

We studied 30 hips in 25 patients with 12 males and 13 females in the age-group of 24 to 73 years that were evaluated for anteversion and abduction by assessing from both plain radiographs and CT measurement.

Indications were avascular necrosis in 20 hips, rheumatoid arthritis in 6 hips, secondary arthritis due to fracture neck of femur in 2 hips; post traumatic in 1 hip and GCT proximal femur in 1 hip.

We excluded patients with fixed pelvic obliquity, revision THR, gross pelvic asymmetry and those contraindicated for radiation exposures.

Fig 1: AP X-ray of the pelvis in neutral plane

The x-ray beams were focused perpendicular to body from a distance of 110cm. The pelvic tilt is corrected by making anterior pelvic plane parallel to the ground. Anterior pelvic plane is formed by three points. The three points are two ASIS and Pubic symphysis which should be on the same level to form the anterior plane and this plane should be parallel to the ground. This is ensured by placing a hard cardboard over these three points and adjust the pelvis tilt to make the anterior plane parallel to the ground

Fig 3: A-P x-ray centered on Pubic symphysis

Fig 4: A-P x-ray centered on Prosthetic head

Two plain AP radiographs, one focusing on pubic symphysis and another focusing on prosthetic head were taken between 3 to 10 days after surgery.

Steps of tracing the cup on the tracing paper.

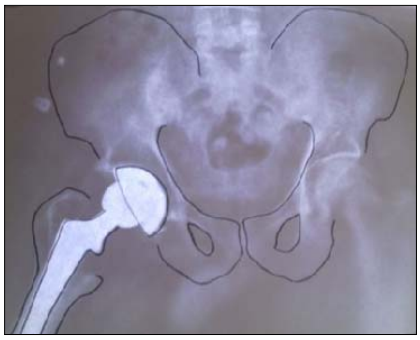


Fig 5: Superimposed image on trace paper centering on pubic symphysis

Fig 6

Fig 7

Fig 6: Superimposed image on trace paper centering on prosthetic head
Fig 7: Tracing the ellipseformed by the mouth of the cup

The edge of cup is imposed on the plain film in the form of hemi ellipse

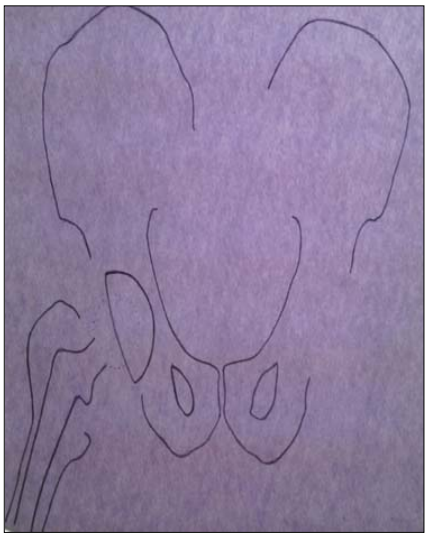


Fig 8: Tracing the cup dome

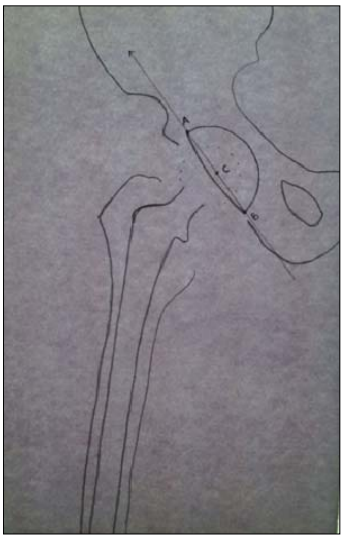


Fig 9: Major Axis (A-B) drawn From the edge of the ellipse

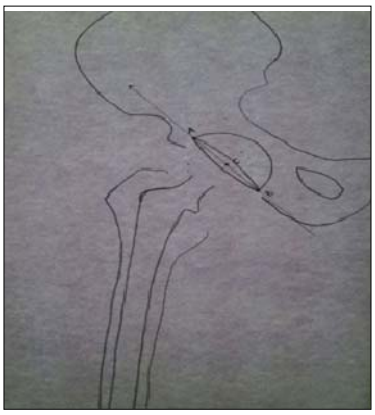


Fig 10: Completing the ellipse

The ellipse is completed using pencil/sketch pen after placing the trace paper over the X-ray image. The photocopies of constructed ellipse were obtained for further geometrical constructions.

All the patients were subjected to CT scan of pelvis within 10 days post operatively. We used 64 channel MDCT systems with high resolution. The protocol was approved by ethical committee and informed written consent was taken from all patients.

Radiological method of calculation of anteversion

Task 1: to ensure the cup is anteverted and not retroverted

The AP radiographs obtained by focusing on pubic symphysis and prosthetic head were taken and ellipse was completed. The size of the ellipse was compared. If the size increases

from pubic symphysis focused to prosthetic head focused means it is in anteversion and retroversion if it decreases.

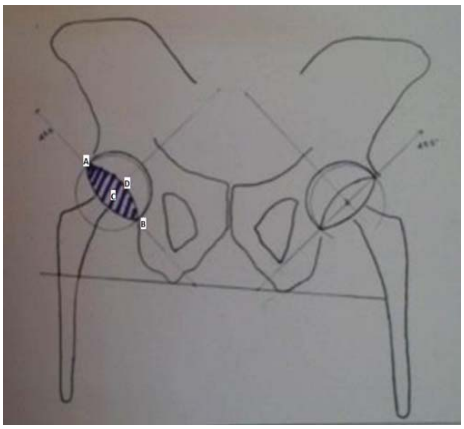


Fig 11: The size of the ellipse formed in 'PUBIC symphysis centered X-RAY'

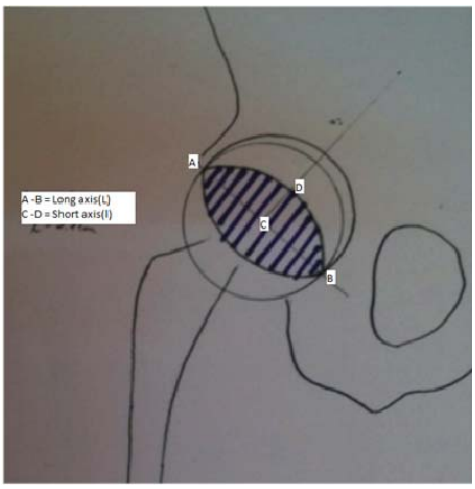


Fig 12: The increased size of the ellipse (increased short axis) formed on the 'prosthetic head centered X-RAY' indicating cup anteverted

TASK 2: To determine anteversion by new geometrical method. (Our method…hence forth called "BMCRI method") FIRST STEP: The photocopy of AP pelvis x ray with reconstructed ellipse is taken. The inter tuberosity line (L-L') is constructed which represents the transverse plane of the body. (fig.13) SECOND STEP: The imaginary axis of rotation of cup is drawn by connecting the two edges of the ellipse. This represents the 'Major Axis' (A-B) around which the face of cup rotates to produce anteversion.

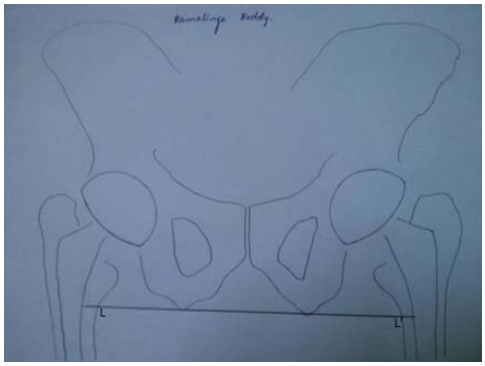


Fig 13: L-L' line = Intertuberosity line

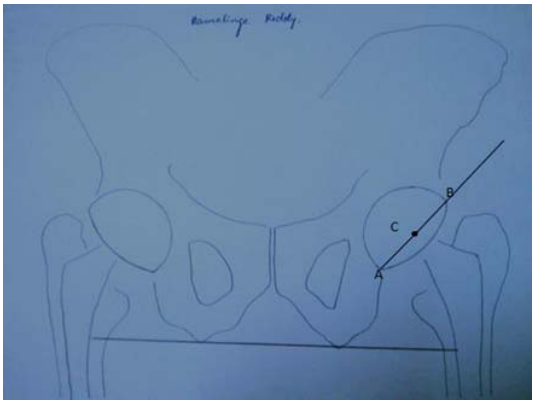


Fig 14: A-B = Major Axis

Third Step: The line connecting the two edges of the cup forms the 'major axis' of ellipse. The exact centre of the line is taken as 'C'. (Fig. 15)

Fourth Step: Then the other part of ellipse is drawn. With 'C' as centre, half the diameter (half the Major Axis) is taken as radius andan interpolated circle (in RED) is completed such that it just touches the edges of ellipse. (Fig 15)

Fifth Step: From the centre a perpendicular line is towards the edge of the ellipse to complete 'half of the minor axis'(C-D). (Fig 16, Fig 17)

Sixth Step: Draw another line E-F parallel to the major axis tangentially just at the edge of the ellipse where it touches the minor axis (C-D). (Fig18)

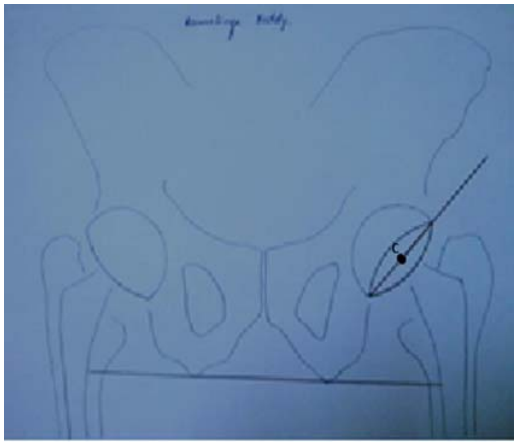


Fig 15: C= center of the Major Axis and the ellipse completed by drawing the other half

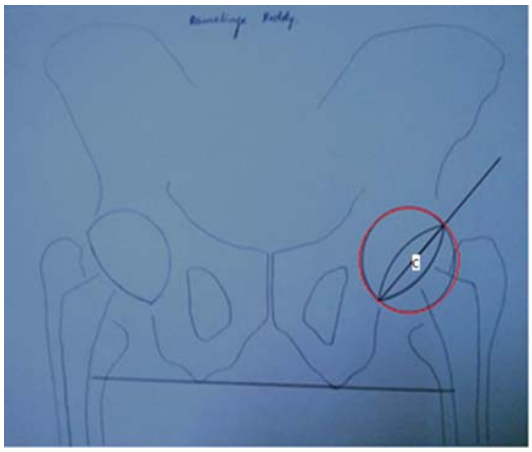


Fig 16: Interpolated circle drawn from the centre C

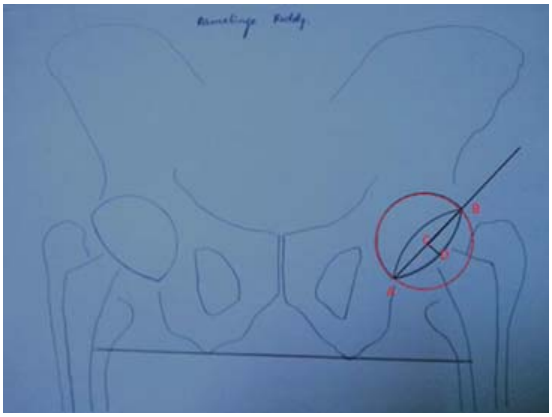


Fig 17: Half of the Minor axis C-D drawn

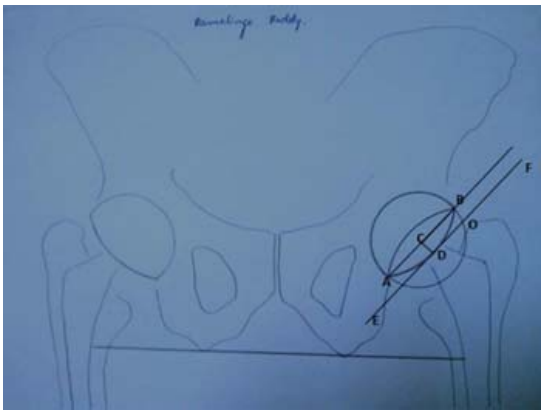


Fig 18: E-F =Tangential line to ellipse parallel to major axis, O= Point of intersection of EF to the interpolated circle

Seventh Step: The line E-F cuts the circle at 'O'. Connect C to O. The angle between the line CO and the major axis (C-B) gives the planar ANTEVERSION ANGLE (a=α).

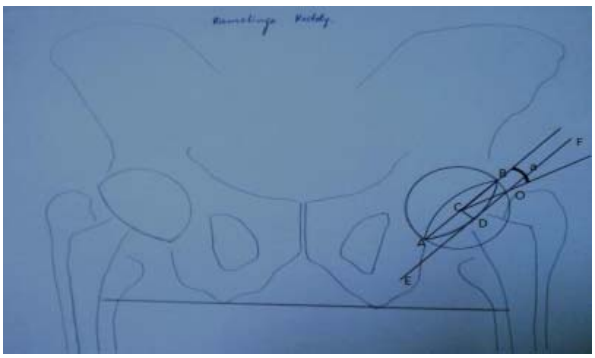


Fig 19: Anteversion, a = α

TASK 3: Assessing the anteversion by other radiological methods namely LEWINNEK,
Widmer, Hassan, Liaw and Rithen Pradhan Method.
Hard copy of each superimposed image was collected and stored. Three surgeons were involved in the calculation of anteversion in all five methods for all patients. The detailed methodology of measurement was explained to all 3 surgeons and doubts were clarified.

1. Lewinnek Method [8]: Formula For Version = ARC sine (D1/D2),

D1: minor axis **D2:** major axis

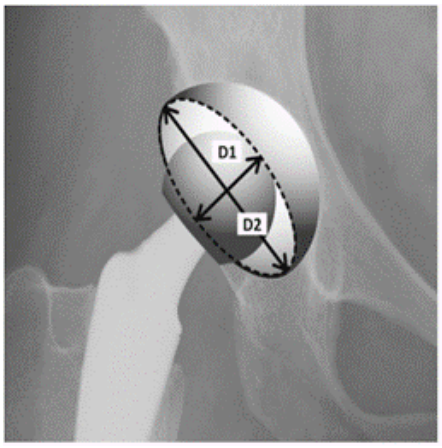


Fig 20: Lewinnek method

2. Widmer Method [7]: Foermula For Version =AR Csine (short axis/ total length (TL))=48.05 multiplied with (S/TL)-0.3 if 0.2<S/TL<0.6. Where S is short axis,TL is the entire distance of the projected cross section of acetabular component along short axis. This method shows linear correlation in the range of S/TL.

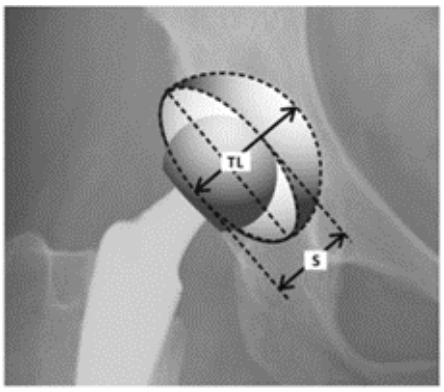


Fig 21: WIDMER radiological method of calculation of anteversion

3. Hassan Method [9]: Formula For Version = ARC sin {(h/D)/√ ([m/D]-[m2/D2])}. D is the long axis, m is the distance along D not obscured by head, and h is the length of perpendicular dropped from endpoint of distance m to acetabular rim.

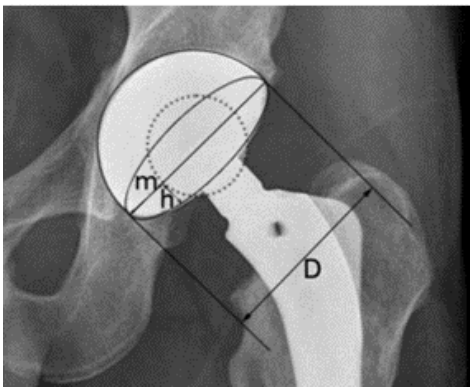


Fig 22: HASSAN radiological method of calculation of anteversion

4. Liaw Method [10]: Formula For Version = inverse sine tan (beta), where the angle β is obtained by connecting top point of ellipse to the end of long axis.

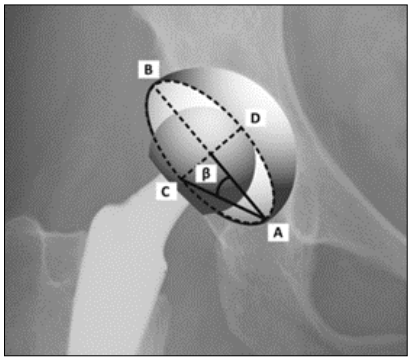


Fig 23: LIAW radiological method of calculation of anteversion

5. Riten Pradan Method [11]: Formula For Version= Arc sin (P/ 0.4D), where P is the length of perpendicular dropped from 1/5th of long axis to acetabular rim and D is the long axis.

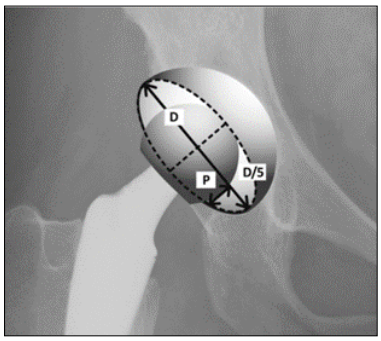
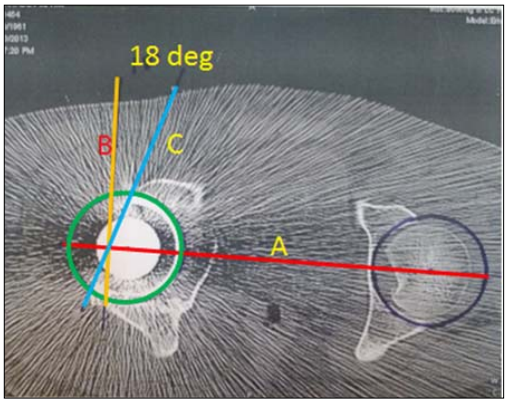


Fig 24: RITHEN radiological method of calculation of anteversion

6. Measurement of version on ct scan

We used the axial section of CT containing the largest diameter of the acetabular component. A circle was completed touching the edges of the acetabular component / acetabular rim on both the hips. Centres of both circles were identified and a line A was drawn connecting them. The second Line B was drawn perpendicular to the first line passing through the centre. The third Line C was drawn touching the anterior posterior edges of the cup. Now the anteversion is measured as the angle subtended between line B and C.



CT method for measurement of anteversion.

Fig 25: CT method for measurement of anteveersion

Results

The intra and inter observer reliability were found to be high. The results for intra observer reliability were calculated by absolute agreement from the readings of the same examiner.

Intra Observer Reliability

Table 1: Intra observer reliability in our study

Icc (Intraclass Corelation Coefficient)	95% Confidence Interval
Ct – 0.948	0.901 To 0.964
Lewinnek – 0.920	0.854 To 0.960
Widmer – 0.916	0.859 To 0.942
Liaw – 0.954	0.884 To 0.970
Hassan – 0.904	0.832 To 0.950
Riten – 0.920	0.878 To 0.946
New Geometrical Method- 0.903	0.844 To 0.956

Inter Observer Reliability

Table 2: Inter observer reliability

Icc (intraclass corelation coefficient)	95% confidence interval
Ct – 0.984	0.958 to 0.990
Lewinnek – 0.938	0.898 to 0.966
Widmer - 0.942	0.902 to 0.976
Liaw – 0.962	0.914 to 0.962
Hassan – 0.908	0.884 to 0.946
Riten – 0.914	0.872 to 0.952
New geometrical method- 0.953	0.868 to 0.964

Measurement of validity

Validity of different methods

Mean and standard deviation (SD) measurements of each method were compared with the mean of CT measurement using Pearson's correlation coefficient and paired *t*-tests

Table 3: Validity of different radiological methods in our study.

Method	Anteversion		As compared to C.T. Scan	
	Mean	S.D.	'p' value As per paired *t*-tests	Pearson's correlation coefficient
C.T. Scan	23.27	11.93		
Lewinnek	21.65	10.9	0.5899 Not Significant	0.9372
Widmer	31.47	11.7	0.0107 Significant	0.8622
Liaw	21.07	11.04	0.468 Not Significant	0.9193
Hassan	22.4	11.34	0.7757 Not Significant	0.8674
Rithun	22.76	12.12	0.8715 Not Significant	0.8444
New geometrical method	22.63	10.69	0.8306 Not Significant	0.9318

The radiological measurements of all five methods showed good positive correlations with the CT measurements. The measurements in new method used in this study were similar to the CT measurements (no statistically significant difference) ($p > 0.05$, paired *t*-test).

Discussion

Based on the theory of 'the Geometry of ellipse', the measurement of anteversion of the acetabular cup after THR was done by the methodology on mathematical principles. The opening of the face of the cup is a 'circle' when it is viewed perpendicular to its centre. When acircle with AB& CD as its diameters, is rotated around the AB diameter as axis (Major axis), the 'circle face' of the cup start becoming 'ellipse'. On every degree of rotation around the major axis, the circle slowly takes the shape of an ellipse. In simple terms the diameter AB becomes major axis and CD becomes the minor axis of the forming ellipse.

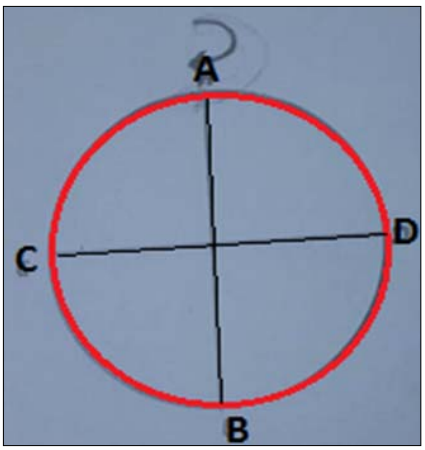


Fig 26: Full 'circle face' of the cup

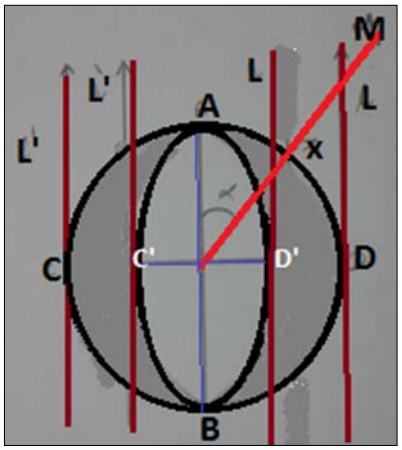


Fig 27: Anteverting cup (forming 'ellipse'), X= variable point on the circle

The lines L and L' are tangents to the circle parallel to the AB diameter (Major axis). When the circle is rotated around the axis of AB, the CD diameter (Minor axis) decreases proportionately to the degree of rotation (C'-D'). The tangents approach closer to each other and to the diameter ABas per the theory of ellipse. These three lines coincide when the face of the cup subtends 0^0 to the coronal plane (i.e., the line perpendicular to the face of the cup is 0^0 to coronal plane or anteversion is 0^0.) then there is no anteversion in the cup (fig 28).

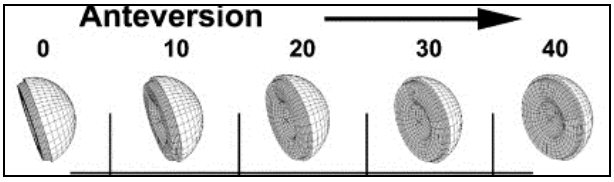


Fig 28: The change of forming ellipse i.e., anteversion proportionate to changing rotation

For every degree of rotation around the major axis the tangent line 'L' cuts the original circle at various points 'X' over the circle. As the tangential line moves on the point 'X' over the circle towards the major diameter (major axis), the area of the circle proportionately decreases (forming ellipse) according to the theory of geometry of ellipse.

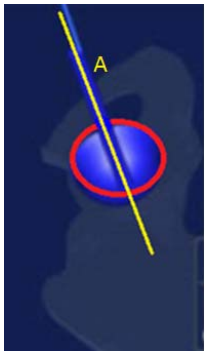


Fig 29: Circle face (Sagittal face) of cup with its axis'A' being perpendicular

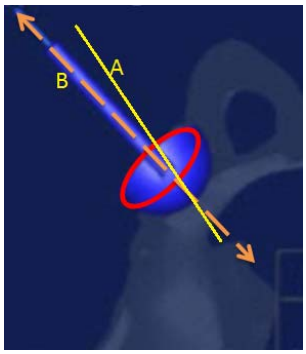


Fig 30: Coronal face becomes ellipse (anteversion)- axis changes from A to B

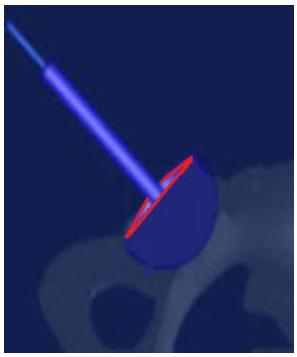


Fig 31: (0^0Anteversion)

The axis of the cup dropped to the centre of circle subtends an angle when the circle changes to ellipse. This angle is anteversion (planar).

This three dimensional change (angle) which takes place can be changed to a two dimensional model by connecting center point to x where the tangent cuts original circle. The angle α

between line M and AB is the planar anteversion.

Assessment of reliability

Reliability is defined as consistency of measurements, calculated by absolute agreement. It is calculated in terms of intra and interobserver reliability.

To calculate intra observer reliability one surgeon (JV) measured the anteversion in all five methods for all patients two times within a period of four weeks. On the second time the CT and x-ray were distributed to the surgeon (JV) in a random manner.

To calculate the inter observer reliability all 30 hips were evaluated by three surgeons (KSM), (GK), (JV) for all the five methods and the CT method and the results were produced in single statement by absolute agreement. All the measurements were made without any knowledge of clinical information or other surgeons readings.

The ICC and 95% confidence interval were calculated for intra and inter observer reliability. We used two way random effects (intra class correlation model and absolute agreement) to calculate ICC.

An ICC of 1 means perfect reliability and 0 is not at all reliable. ICC values of 0.00 to 0.20 is slight; 0.21to 0.40 is fair; 0.41 to 0.60 is moderate; 0.61 to 0.80 is substantial; >0.81 is perfect reliability.

Measurement of validity

Validity is defined as proximity to reference standard. The validity was calculated by taking mean of anteversion of each method from all the three surgeons and was compared to mean of CT method of measurement of anteversion readings of all three surgeons. We used paired t-test and PEARSON correlation coefficient with statistical significance set at $p<0.05$.

Pearson correlation coefficient is characterised as 'r':- 0.00 to 0.20 =poor; 0.21 to 0.40 = fair; 0.41 to 0.60 = moderate; 0.61 to 0.80= good and 0.81 to 1.00 is excellent.

Statistical Tools

The information collected regarding all the selected cases were recorded in a Master Chart. Data analysis was done with the help of computer using Epidemiological Information Package (EPI 2010) developed by Centre for Disease Control, Atlanta.

Range, Frequencies, Percentages, Means, Standard Deviations, Chi Square, 't' value and 'p' values were calculated using this software. Paired 't' test was used to test the significance of difference between quantitative variables. The 'p' value less than 0.05 is taken to denote significant relationship.

Correlation coefficient was calculated using Excel Software. Ifthe value of 'r' between two variables is more than $\pm$ 0.5., then those two variables are taken to be correlated.

Conclusion

- Our new method (BMCRI method) is simple, very close to CT scan readings (High validity) and reliable (High reliability).
- In terms of validity our method is better than LEWINNEK method.

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