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An experimental study to evaluate a new radiographic method for measuring femoral anteversion

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Abstract

Introduction: The measurement of femoral anteversion has been a subject of interest and debate. Femoral anteversion is defined as the angle formed by the bicondylar plane and a plane passing through the center of the neck and femoral head. The angle of anteversion in humans exhibit a wide range (-25° to 40°) with the mean varying from 8° to 25°. Many methods for measuring femoral anteversion have been proposed each with its own merits and demerits. Our aim was to evaluate the validity of the Parallax method for measuring femoral anteversion and compare the results with Direct measurement and Biplane radiography - the method of Ogata *et al.*

Materials and Methods: This is a Prospective study conducted at our institute with a total of 50 dried femur specimens obtained from the department of anatomy. Bones with obvious deformities in the proximal portion were excluded from the study. The anteversion angle was calculated by three methods:

1. Direct measurement – taken as the reference value against which the values of the other two methods can be compared.
2. Parallax method
3. Biplane radiography – the method of Kosuke Ogata *et al.*

Results: Considering direct measurement of anteversion by the Kingsley-Olmsted method as the most accurate method, the mean anteversion was found to be 11.235°, Range: -12° to 37°. 5(10%) femurs were retroverted. 3(6%) were in neutral version. 32(64%) were in the range 1° to 20° of anteversion. 10(20%) femurs showed anteversion more than 20°.

Conclusion: The parallax method is comparable to biplanar radiography in terms of safety, availability, cost and accuracy. The patient can lie with the hips extended and in neutral rotation and the radiographs can be taken. Therefore the “Parallax Method” seems to be a viable alternative to the biplanar method especially in complicated and difficult situations.

Keywords: Femoral anteversion, parallax method, biplanar method

Introduction

The measurement of femoral anteversion has been a subject of interest and debate in the orthopaedic literature dating back at least to the middle of 19th century. Femoral anteversion is defined as the angle formed by the bicondylar plane and a plane passing through the center of the neck and femoral head. The angle of anteversion in humans exhibit a wide range (-25° to 40°) with the mean varying from 8° to 25° [1]. It varies from one person to another and even from side to side in the same person [2]. The geometry of femur and the definition of femoral anteversion was described in detail by billing in 1954 [3], The long axis of the femur is the line defined by two points (figure-01) - the center of the knee (the centroid of the distal femoral metaphysis on a cross section through the femoral condyles), K and the center of the base of the femoral neck (the centroid of the femoral diaphysis on a cross section through the base of the femoral neck), O. The axis of the femoral neck is the line defined by two points-the center of the femoral head, H and the center of the base of the femoral neck, O. The plane of anteversion is the plane that contains both the long axis of the femur and the axis of the femoral neck. The condylar axis is the line that is parallel to the posterior aspects of the femoral condyles and passes through the center of the knee, K. The condylar plane contains both the long axis of the femur and the condylar axis. The angle of anteversion is the angle in the transverse plane between the plane of anteversion and the condylar plane. Many methods for measuring femoral anteversion have been proposed each with its own merits and demerits.

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Though 3-D reconstruction computed tomography has been shown to be the most accurate method⁴, it exposes the patient to a large amount of radiation when compared to other radiographic methods. Moreover 3-D reconstruction CT and MRI are expensive & available only in few cities in India. A single x-ray yields a two-dimensional picture of the femur and therefore we cannot measure the angle of anteversion as it lies in a plane perpendicular to that of the x-rays. We need an x-ray in another plane in order to get a 3-dimensional picture. and using trigonometric functions it is theoretically possible to measure anteversion accurately^[5]. Bearing this in mind, a new method using radiographic parallax – “The Parallax Method” - to measure femoral anteversion, based on a sound theoretical background^[6]. Our aim was to evaluate the validity of the Parallax method for measuring femoral anteversion and compare the results with Direct measurement and Biplane radiography - the method of Ogata *et al.*^[7]

Materials and Methods

This is a Prospective study conducted at our institute with a total of 50 dried femur specimens obtained from the department of anatomy. Institutional Ethical board approval obtained. Bones with obvious deformities in the proximal portion were excluded from the study. Immature bones were also excluded (Figure 02). The anteversion angle was calculated by three methods:

1. Direct measurement – taken as the reference value against which the values of the other two methods can be compared.
2. Parallax method
3. Biplane radiography – the method of Kosuke Ogata *et al.*^[7]

Direct Measurement (Kingsley Olmsted Method)^[1]

The femur was placed on a flat surface such that both the posterior condyles were in contact with the table, so that the surface of the table can be taken as the horizontal reference plane. Then the antero-posterior diameter at the most proximal and distal parts of the neck were measured using Vernier calipers and the center points were marked. A 2mm ‘k’ wire was then fixed with plasters parallel to the two points so that it represents the axis of the neck. Then the angle of inclination of the ‘k’ wire was measured using a transparent protractor with its base placed exactly at the level of the edge of the table (Figure 03 & Figure 04). For femurs showing retroversion, two 1” thick cards were placed, one below the greater trochanter and other below the condyles so that both the condyles rested on the flat surface and the same procedure was repeated. All bones were measured and labeled.

Parallax Method

Principle: This method is based on the distortion of the x-ray of femur when it is radiographed at an angle. The anteversion can then be calculated by using trigonometric functions. As in any other radiographic method, two views are needed in this method also

- a) Antero-posterior view (Figure 05)
- b) An oblique view at an angle α without changing the position of the femur (Figure 06).

If the relative positions of the base of the femoral neck and the center of the femoral head in three-dimensional space are known then the slope of the line joining these two points can be calculated using trigonometric functions- which is the

angle of anteversion. In case of neutral version, since both base of the neck and center of the head lie in the same horizontal plane, the images in both the views will be of almost same dimensions. In case of positive version or anteversion the center of the head lies at a higher level than the base of the neck and hence the oblique view will appear to be elongated compared to the AP view. Similarly, a retroverted femur will look shorter in the oblique view.

Anteversion angle is calculated as follows

Below is a three-dimensional representation of the procedure (Figure 07). In the figure the X axis is the horizontal line, the Y axis is the vertical line and the Z axis is a line perpendicular to both X and Y axis, projecting vertically out of the plane of the paper. The femur is placed horizontally in the XZ plane represented by the grey outline. A Point O on the YZ plane is taken as the base of the neck and a point H on the XY plane is taken as the center of the head. Therefore, OH represents the axis of the neck. The angle of anteversion is represented by θ , the angle between the XZ (horizontal) plane and the plane of OH. First the projection of the axis of the neck in the Antero-posterior view is drawn by dropping vertical lines from O and H to the Z and X axis respectively.

In the AP projection the base of the neck is point A and the center of the head is point B. Similarly, the projection of the axis of the neck in the oblique view is drawn by drawing lines parallel to the XY plane at an angle α from O and H meeting the XZ plane at C and D respectively. Now in the oblique projection C is the base of the neck and D is the center of the head and CD is the axis of the femoral neck in the oblique projection. A line is drawn from O perpendicular to HB intersecting line HB at E. On simplifying to two-dimensions: (Figure 08)

Calculations

$$\tan\theta = HE/OE \text{ -----Eq (1)}$$

Unknown values: HE and OE

Known values: AC, BD, AB and α

From the figure 08, OE is parallel and equal to AB, therefore

$$OE = AB \text{ -----Eq (2)}$$

HE=HB-BE, in the figure BE is parallel and equal to OA

$$HE = HB - OA \text{ -----Eq (3)}$$

In triangle AOC, angle AOC = α . Therefore,

$$\tan \alpha = AC/OA \text{ (or) } OA = AC/\tan\alpha \text{ -----Eq (4)}$$

Similarly, in triangle BDH, angle BDH = α . Therefore,

$$\tan\alpha = BD/BH \text{ (or) } BH = BD/\tan\alpha \text{ -----Eq (5)}$$

Substituting Eq (4) and Eq (5) in Eq (3),

$$HE = (BD/\tan\alpha) - (AC/\tan\alpha) = (BD-AC)/\tan\alpha \text{ -----Eq (6)}$$

Substituting Eq (2) and Eq (6) in Eq (1),

$$\Rightarrow \tan\theta = (BD-AC)/(AB \times \tan\alpha) \text{ -----Eq (7)}$$

Arbitrarily assigning a value, 30° to $\alpha \Rightarrow \tan 30^\circ = 1/3^{1/2}$, substituting in Eq (7),

$$\Rightarrow \tan\theta = (BD-AC) / (AB \times \tan 30^\circ)$$

$$\Rightarrow \tan\theta = (BD-AC) \times 3^{1/2} / AB$$

$$\Rightarrow \tan\theta = (BD-AC) \times 1.732 / AB$$

(Since $3^{1/2} = 1.732$).

Procedure

A SYFM SC-1002 digital X-ray machine (Figure 09 & 10) with a digital angle meter and altimeter with grid focus light was used for taking x-rays. Two 'k' wires, each 3 cm in length were fixed at right angles to each other on the detector. They serve as reference lines for measuring the relative distances of various points in the radiographs (as their positions do not vary when the source is tilted).

1. AP View (Figure 11): The femur is kept in its anatomical position on the radiolucent x-ray table about 10 cms above the detector so as to simulate the natural position of femur. The source was then placed 125cms above the detector focusing over the lesser trochanter and the AP view is taken. The height of the source was set at maximum to minimize errors due to magnification.
2. 30 Degree Oblique View (Figure 11): Without changing the position of the femur and the detector, the X-ray tube alone is moved laterally and rotated by 30 degrees. After focusing on the lesser trochanter, the oblique radiograph is taken. Then the images are printed onto X-ray films without altering the size. The X-rays are placed side by side such that the horizontal 'K' wires are at the same level. And the following points are marked. (fig-12a, fig-12b):
 1. The base of the femoral neck in the antero-posterior view – point A (the point of intersection of the long axis of the shaft and the axis of the neck).
 2. The center of head of femur in the antero-posterior view – point B.
 3. The base of the femoral neck in the oblique view – point C. (The center point of the shaft at the same horizontal level as point A).
 4. The center of the head of femur in the oblique view – point D. (the center point of the head at the same horizontal level as point B).

The radiographs are then placed one over the other in the X-ray lobby such that both the reference 'k' wires are perfectly on top of their counterparts in the other X-ray and the following values are calculated: AB (the horizontal distance between points A and B), AC and BD. The anteversion was calculated using the formula:

Biplanar Radiography

The method of Kosuke Ogata *et al*⁴ was used. The AP view taken previously was used for this method also. A lateral view is taken by tilting the source and screen by 90°. The femur is left in the same position. The acute angles between the long axis of the shaft and the axis of the femoral neck are measured in the AP (α) and lateral views (β) (Figure-13). Anteversion is calculated using the formula: $\tan \theta = \tan \beta / \tan \alpha$

$$\tan \theta = (BD-AC) \times 1.732 / AB$$

Totally 150 X-rays were taken, 3 for each femur and anteversion by all 3 methods was noted for comparison. The anteversion angles found by direct measurement were taken as the reference values against which the biplanar method and

parallax method were compared. To calculate the inter-observer variation in the parallax method, the X-rays of each femur were analyzed by three persons, labeled as observer1, observer 2 and observer 3. The mean value was taken as the final value of the parallax method. To calculate the intra-observer variation in the parallax method the X-rays of each femur were analyzed three times with an interval of at least one day between measurements to avoid bias due to recall. To calculate the repeatability of the parallax method, the anteversion of one femur was measured 10 times, each time a new set of X-rays were taken.

Results

Considering direct measurement of anteversion by the Kingsley-Olmsted method as the most accurate method, the mean anteversion was found to be 11.235°, Range: -12° to 37°. 5(10%) femurs were retroverted. 3(6%) were in neutral version. 32(64%) were in the range 1° to 20° of anteversion. 10(20%) femurs showed anteversion more than 20° (Table 01).

Direct Measurement vs Biplanar Method

Statistical analysis was done using StatistiXL (2007) 1.8 (Trial version) Add-in software for Microsoft excel. Paired t-test was used to compare direct and biplanar method. The null hypothesis was that no significant difference exists between the two methods within 95% confidence interval (Table 02). The mean anteversion by direct measurement was 11.235° and by biplanar method was 11.598° and the mean error was 1.448° and 1.388° respectively. Results showed that no significant difference exists between the two methods ($p = 0.253$).

Direct Measurement Vs Parallax Method

Paired t-test was used. The mean anteversion measured by the parallax method was 11.417° (Table 03) and the mean error was 1.409°. Results showed that no significant difference exists between the two methods:

($p = 0.253$).

Biplanar Vs Parallax Method

Paired t-test was used. No statistically significant difference was found between the two methods ($p=0.253$). The mean anteversion (Table 04) measured by the biplanar method was 11.598° and by the parallax method was 11.417° and the mean error was 1.388° and 1.409° respectively.

Intra-Observer Reliability

The Pearson correlation coefficient (R) was used to test the intra-observer reliability. The value of R ranges between -1 to +1. Statistical analysis shows strong correlation between all three observations (Table 05). Correlation coefficient for the 1st and 2nd, 2nd and 3rd, 1st and 3rd measurements was 0.999 indicating strong correlation between all three measurements. The mean error in the 1st measurement was 1.432°, in the 2nd measurement was 1.452° and in the 3rd measurement was 1.436°.

Inter-Observer Reliability

The Pearson correlation coefficient was used to test the inter-observer reliability. Analysis showed strong correlation between all three observers ($R=0.998$). Correlation between observer 1 and 3 was slightly more than correlation of observer 2 with 1 and 3 ($R = 0.996$) (Table 06).

Repeatability

Femur-22 with anteversion of 10^0 was used for testing repeatability. The mean of the 10 measurements was 11.8^0 , the standard error was 0.175^0 and the range was 1.6^0 (10.5^0 to 12.1^0). Therefore, the error is minimal, around $\pm 1^0$.

Relationship between Biplanar Radiography and Parallax Method

By simple logistic regression an equation was formed to get an approximate estimate of the anteversion values as measured by biplanar radiography from the parallax method: An approximate estimate of the anteversion values as measured by Kingsley-Olmsted method from the results of parallax method can be obtained using the following formula:

$$\text{Direct Measurement} = -0.428^0 + 1.022 \times (\text{Parallax})$$

$$\text{Biplanar Radiography} = 0.428 + 0.978 \times (\text{Parallax})$$

Discussion

Even though CT and MRI have been shown to be the most accurate methods, Anteversion is still routinely measured by radiography as it is easily available and inexpensive. The clinical method described by Ruwe *et al.* [8] is a simple and easy method which can be done as a bedside procedure, but it is prone to errors as the measurement is based on subjective inference of maximal prominence of the greater trochanter which may vary from person to person. Also, errors may be introduced by the amount of soft tissues over the greater trochanter and by deformities involving the greater trochanter. In a study by Richard B Souza *et al.* [9] the clinical method was shown to have good reliability and moderate correlation with MRI, only in persons with low BMI. In 1972 Staheli *et al.* [10] compared fluoroscopic and biplanar methods and concluded that biplanar method is superior to fluoroscopic method in both accuracy and reproducibility. Leonard Ruby *et al.* [11] compared fluoroscopy, Biplanar and axial radiography (Dunn) and concluded that biplanar radiography was more reproducible and superior to both axial radiography and fluoroscopy. Compared with other radiographic methods the method of Kosuke Ogata *et al.* is simpler and accurate enough for clinical use. In this study no significant difference was found between all three methods - Kingsley-Olmsted method, biplanar method and the parallax method. Also, the parallax method has been found to have high inter-observer, intra-observer reliability & repeatability. Considering direct measurements obtained by the Kingsley-Olmsted as the true value, the range of error in the biplanar and parallax method was found to be around -4^0 to $+5^0$ and -5^0 to $+4^0$ respectively which is accurate enough for clinical use. The random errors in this method may be due to the following reasons:

1. The x-rays are not parallel since the filament in the X-ray

is a point source. Therefore, the X-rays are divergent and some amount of magnification does occur despite increasing the distance of the source.

2. In the parallax method and the biplanar method the center of the head was used to plot the axis of the neck. But in the kingsley-olmsted method, the neck axis is defined by 2 points on the neck itself. Therefore, head must be exactly centered over the neck for the neck axis to pass through the center of the head. But in about 60% of the bones the head was offset either anteriorly or posteriorly. So, some amount of discrepancy between the true value and measured value is to be expected.
3. Random errors due to
 1. Positioning of the femur: For accurate measurement, the femur must be placed in its exact anatomical position. Abduction or adduction introduces small errors in the measurement of anteversion.
 2. Subjective errors in marking the center of the head or base of the neck.
4. Variation in the alignment of the axis of the neck and the long axis of the shaft [37]: The axis of the neck does not intersect the long axis of the shaft but it passes anteriorly, therefore small errors occur in the radiographic measurements as the base of the neck is marked as the point of intersection of the two axes.

But all these errors are common to both the methods and are well within the limits needed for clinical use. In the parallax method for a femur with normal anteversion $\sim 10^0$, an error of 1mm in the measurement of one of the points introduces an error of $\sim 0.5^0$ in the calculation of anteversion.

Advantages of Parallax Method over Biplanar Method

1. The main advantage in this method is that the position of the patient need not be changed as in CT or MRI. It may be particularly helpful in patients with bilateral hip pathology.
2. Plotting the points in this method is easier when compared to drawing the neck axis in the lateral view as the neck is obscured by the shadow of the greater trochanter, especially in coxa vara.
3. Calculation is dependent on finite points and distances and therefore the error is practically less when compared to measuring angles as in biplanar method.

Disadvantages of The Parallax Method

1. Slightly more time consuming than the biplanar method since direct graphs are there for readily calculating anteversion by biplanar radiography.
2. Requires accurate measuring device for positioning the X-ray source for the oblique view, not necessary in the biplanar method.

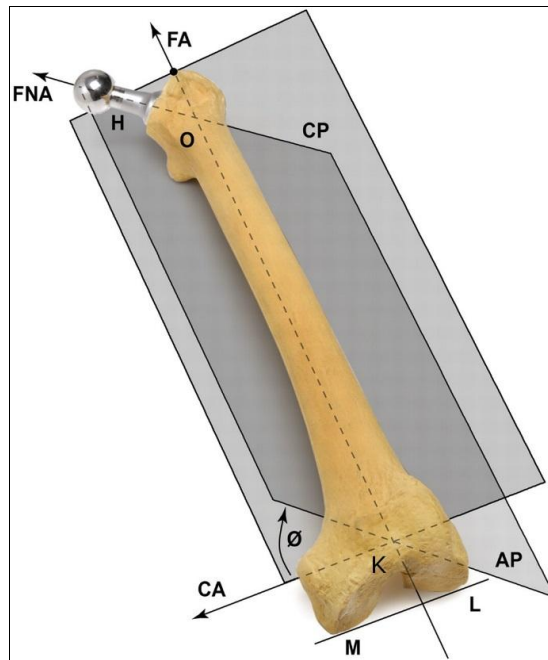


Fig 1: Ø-anteversion angle; CP-condylar plane; H-center of femoral head; O-base of femoral neck; K-center of the knee; AP-plane of anteversion; OK-long axis of femur; OH-axis of femoral neck; CA-condylar axis.



Fig 2: Specimens used for the study

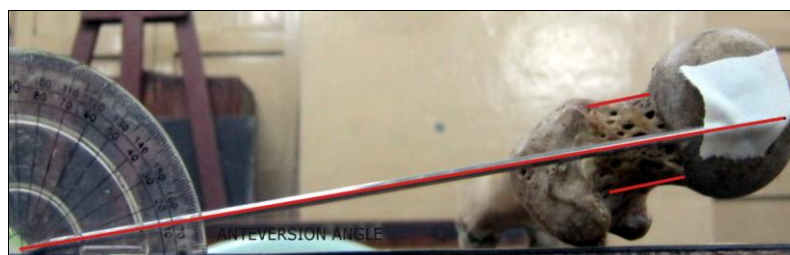
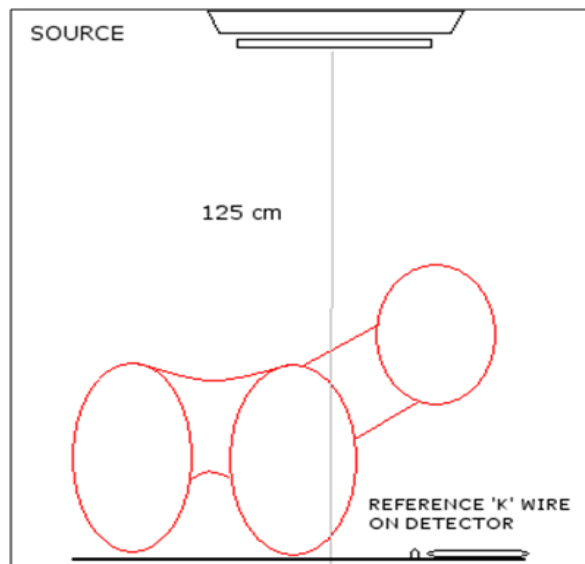
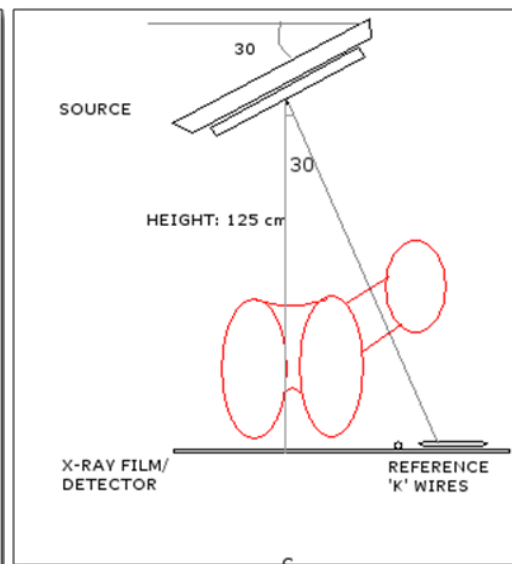
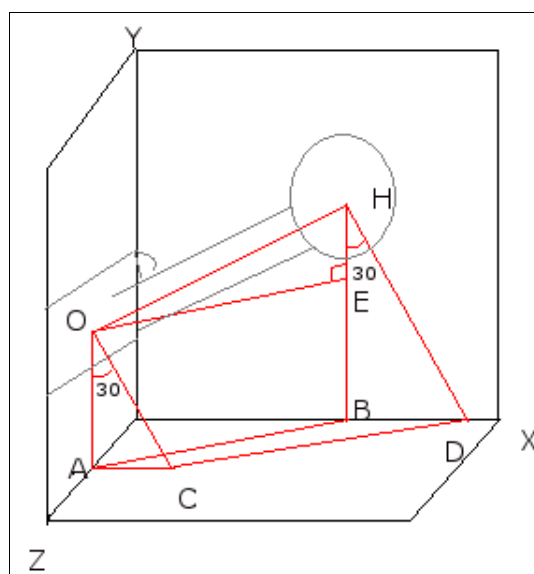
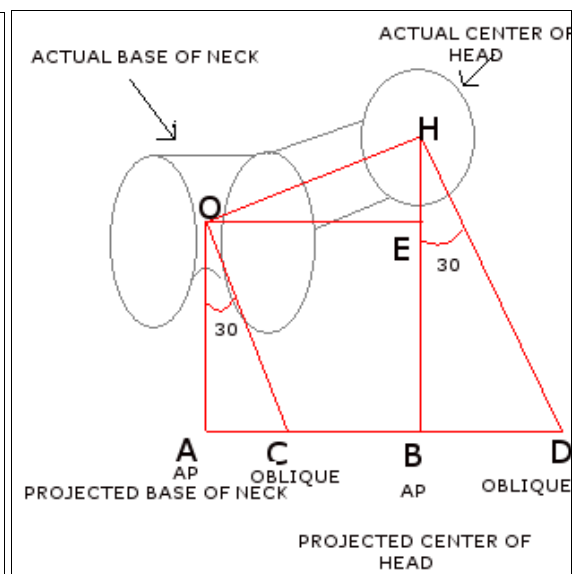
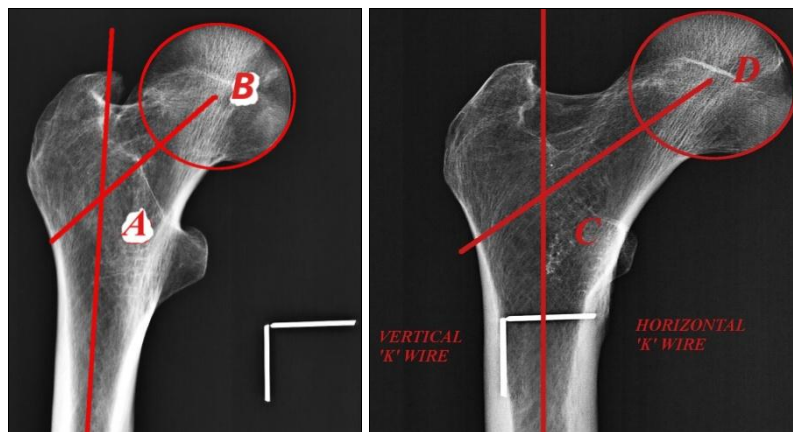
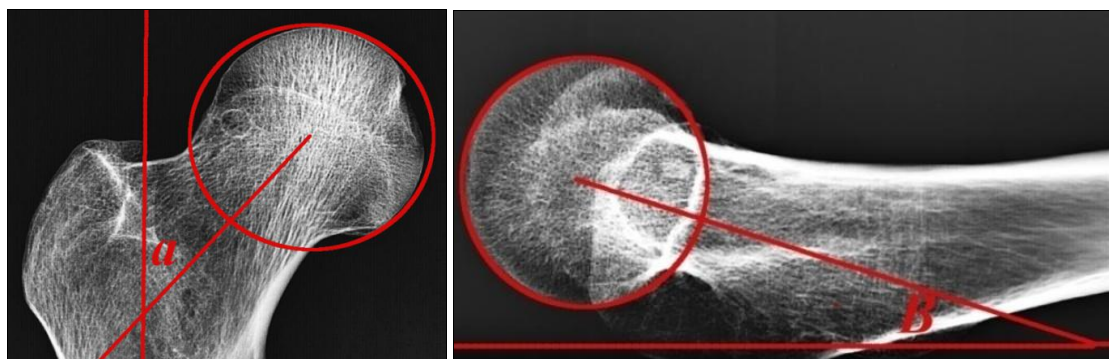


Fig 3: Measurement of Anteversion- Kingsley Olmsted Method



Fig 4: Vernier Caliper Used for Measuring Neck Diameter

**Fig 5:** Ap View**Fig 6:** Oblique View**Fig 7:****Fig 8:****Fig 9:** X-Ray Tube with Digital Angle Meter and Altimeter**Fig 10:** X-Ray Tube Tilted To 30 Degrees

**Fig 11:** Positioning for AP-View & Oblique View**Fig 12A:** AP view**Fig 12B:** Oblique view**Fig 13:** Neck-Shaft Angle in Ap View & Lat View**Table 1:** Descriptive Statistics of All Three Methods

Distribution of Anteversion	Direct Measurement	Biplanar Method	Parallax Method
N	50	50	50
Mean	11.235	11.598	11.417
Standard Deviation	10.240	9.812	9.967
Standard Error of Mean	1.448	1.388	1.409
Median	11	12.25	11.5
Maximum	37 ^o	35.3 ^o	36.3 ^o
Minimum	-12 ^o	-12.9 ^o	-12.4 ^o
Range	49 ^o	48.2 ^o	48.7 ^o

Table 2: Direct Measurement Vs Biplanar Method

Paired t-Test	Mean	Standard Deviation	Standard Error of mean	Lower 95% CL	Upper 95% CL	P
Direct	11.235	10.240	1.448	8.325	14.145	0.253
Biplanar	11.598	9.812	1.388	8.809	14.386	

(CL – Confidence limit)

Table 3: Direct Measurement Vs Parallax Method

Paired t-Test	Mean	Standard Deviation	Standard Error of mean	Lower 95% CL	Upper 95% CL	P
Direct	11.235	10.240	1.448	8.325	14.145	0.253
Parallax	11.417	9.967	1.409	8.584	14.249	

(CL – Confidence limit)

Table 4: Biplanar Method Vs Parallax Method

Paired t-Test	Mean	Standard Deviation	Standard Error of mean	Lower 95% CL	Upper 95% CL	P
Biplanar	11.598	9.812	1.388	8.809	14.386	0.253
Parallax	11.417	9.967	1.409	8.584	14.249	

(CL – Confidence limit)

Table 5: Statistical Analysis between all three observations

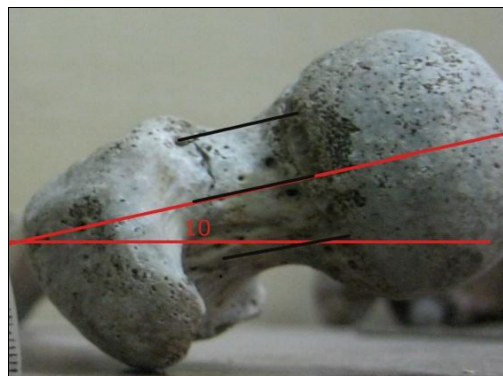
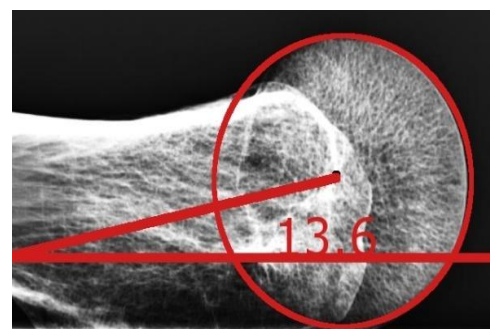
Correlation Matrix (R)	Observer – 1		
	1 st Measurement	2 nd Measurement	3 rd Measurement
1 st Measurement	1.000	0.999	0.999
2 nd Measurement	0.999	1.000	0.999
3 rd Measurement	0.999	0.999	1.000

Table 6: Statistical Analysis between all three observers

Correlation Matrix (R)			
	observer-1	observer-2	observer-3
observer-1	1.000	0.996	0.998
observer-2	0.996	1.000	0.996
observer-3	0.998	0.996	1.000

Case Illustration: Femur-22 (Normal Anteversion)

Kingsley-Olmsted Method

 $\Theta = 10^\circ$ **Biplanar Method**

$$\alpha = 45^\circ; \beta = 13.6^\circ$$

$$\tan \theta = \tan \beta / \tan \alpha$$

$$= \tan 13.6^\circ / \tan 45^\circ$$

$$= 0.242$$

$$\Theta = 13.6^\circ$$

Parallax Method

Ap View

Oblique View

Calculated Values:

1. AB=3.5cm
2. AC=6.2cm
3. BD=6.6cm

$$\tan\theta = (BD-AC) \cdot 1.732 / AB$$

$$= (6.6-6.2) \cdot 1.732 / 3.5$$

$$= 0.198$$

$$\text{Therefore } \theta = 11.1^\circ$$

Femur-22	Direct Measurement	Biplanar Method	Parallax Method
Anteversion Angle	10°	13.6°	11.1°

Conclusion

A method used in clinical practice has to be simple, easily available, safe, inexpensive, accurate, reliable, reproducible and ethical. Biplanar radiography^[12] is a widely accepted method which satisfies all the above criteria. Both are expensive and not easily accessible to everyone. For a demographic study requiring precise data MRI and CT may be the only option but are not practical for everyday use^[13]. Other methods like the trochanteric prominence test and ultrasonography, even though safe and simple are less accurate^[14]. The parallax method is comparable to biplanar radiography in terms of safety, availability, cost and accuracy. It is also reliable and reproducible with an error of within $\pm 2^\circ$ in most of the cases which is well within the requirements for clinical use^[15]. It also has an added advantage – the position of the patient need not be changed. The patient can lie with the hips extended and in neutral rotation and the radiographs can be taken. In addition, this method can be used for other purposes as well like planning for total hip replacement, derotational osteotomy, etc. Therefore the “Parallax Method” seems to be a viable alternative to the biplanar method especially in complicated and difficult situations where positioning of the patient for taking lateral radiographs of the hip may not be possible.

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