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Radiological comparison of acetabular anteversion on cross-table lateral roentgenograms and computed tomograms & functional outcomes in total hip arthroplasty

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Abstract
Introduction: Orientation and Alignment of prosthetic components are vitally important for the stability of total hip arthroplasty. Poor acetabular positioning is one of the many issues implicated with persistent pain due to impingement, dislocation, edge loading and liner fracture, which may be lead to patient dissatisfaction after total hip arthroplasty.
Material and methods: Post-operative radiological analysis of the version of acetabulum through X-ray images and CT images was performed. Pre & post-operative scoring according to Modified Harris Hip Score (HHS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Oxford Hip Score (OHS) was documented.
Results: A total of 55 patients were included in the study. The mean anteversion angle calculated on cross-table lateral radiograph by Woo and Morrey's method was 22.410 (Range 16-560), compared to CT Scans measured was 28.640 (Range 11.10-50.100).
Conclusion: Majority 69.09 % of patients had excellent functional outcomes in a range of 11.1-360 of anteversion compared to Lewinnek's safe zone. It suggests that there is flexibility in positioning the acetabular component than previously believed. If one has to err, it should be towards more anteversion. Infact to avoid dislocation, more anteversion is required to guard against unwarranted activities on part of the patient.

Keywords: Computed tomograms, total hip arthroplasty, Orientation and Alignment

Introduction
Total Hip Arthroplasty (THA) is one of the most common procedures performed in Orthopaedic Surgery and is considered to be one of the best medical innovations of our generation [1]. Arthroplasty depends upon ideal placement of both acetabular and femoral components. Accurate biomechanical reconstruction of the joint is essential to achieve function and longevity with acetabular positioning being a key factor, the consequences of malposition include instability, increased wear, impaired muscle function, reduced range of motion (ROM), impingement, bearing-related noise generation, poor functional outcomes,1 limb length discrepancy, and loosening and cup failure [2-4]. Dislocation is one of the most frequent complications after THA with an incidence of 0.6% to 11% in the early postoperative period; between 13% and 30% of dislocations reportedly are caused by implant malpositioning [5]. It is found that even in normal subjects there is a great variation in acetabular morphology. However, the range of normal acetabular & femoral variation may differ between races [6]. At age 13 to 14, the mostly ossified bones of the ilium, ischium, and pubis unite at the acetabulum, forming Y-shaped triradiate cartilage that proceeds to fusion by age 15 to 16. The other secondary centres unite and fuse between the ages of 20 and 22. The acetabular surface is orientated approximately 45 degrees caudally and 15 degrees anteriorly. The average anteversion of the native acetabulum measures 16 to 21 degrees with an average inclination of 48 degrees. Men tend to have less anteversion than females. Angular position includes the anteversion and inclination (abduction angle) of the cup. The most commonly quoted study is by Lewinnek *et al.* He found an increased dislocation rate in cups placed outside anteversion angles of 5°–25° and 30°–50° of inclination.

Inclination and anteversion can thus be operative, radiologic, or anatomic [7]. Operative and radiographic angles are the most relevant surgically in the lateral position of the patient. During surgery in the lateral position, operative anteversion is assessed by looking down, to project the insertion angle onto the sagittal plane, and measuring against the longitudinal axis. The most commonly used method for radiographic analysis is the one proposed by Woo and Morrey [8] namely the "angle formed by a line drawn tangential to the face of the acetabulum and a line perpendicular to the horizontal plane, as seen on a lateral view of the pelvis". In comparison, McCollum and Gray [9] suggested a position of 40° ± 10° abduction and 30° ± 10° flexion to prevent impingement and dislocation. Harris recommends a position of 30° abduction and 20° anteversion; however, the Harris angles are referenced using a mechanical guide and the trunk of the patient [10]. During the implantation process, surgeons use different techniques to judge the positioning of the acetabular component. The purpose of the present study was aimed at the morphometric evaluation of the acetabular version radiologically using well-defined parameters of acetabular positioning in primary total hip replacements on patient satisfaction and functional outcomes at a tertiary centre which will further help in planning, execution, and evaluation of total hip arthroplasty (THA). However, most of the studies have been done on western populations with limited follow-up period & to the best of our knowledge, only limited studies have been done in the Indian populations. The present study was undertaken to study the effects of acetabular component position well as acetabular position relative to bony anatomy on patient-reported functional outcomes and further to compare results whether accurately positioned acetabular component in Lewinnek's safe zone using freehand technique as wide variability has been reported in cup orientation, also how accurately operating surgeon can achieve desired anteversion using factors such as visual cues and side of the operating table. To determine whether acetabular component positioned assessed by cross table radiographs and anteroposterior radiographs and computed tomography could provide measure of acetabular version and compare their reliability and accuracy of methods.

Material and methods

This present study was conducted in tertiary care institution between the periods of 2017 to 2019, a total of 55 patients were included in the study. In this study, males were 58.2% compared to 41.8 % females. The mean age of study population was 49.65 years with range from 17-75 years. The most common indication for surgery in our study was idiopathic osteoarthritis in 43.64 % patients followed by post-surgical osteonecrosis of femoral head in 21.82%. The mean follow-up was 19.83 months.

Inclusion criteria

- All age group patients, who need THA for painful disabling hip were included in the study.

Exclusion criteria

- Revision surgery
- Patients with bony pathology of pelvis and femur
- Patients with contralateral hip pathology as evident clinically with gait abnormality and pain or restriction of movements.
- Patients with current or previous metabolic bone disease.
- Bilateral Total Hip Arthroplasty,
- Medical illness or known case of malignancy predisposed by radiation.

Post-operative radiological analysis of the version of acetabulum through X-ray images and CT images was performed. Pre & post-operative scoring according to Modified Harris Hip Score (HHS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Oxford Hip Score (OHS) was documented.

Radiographic Assessment: Radiographs were taken with a tube-to-film distance of 120 cm by a computed digital radiographic system (Philips Bucky Primary Diagnostic CS System 1000mA, November 2016 Hamburg, Germany).

Cross Table Lateral Radiographs

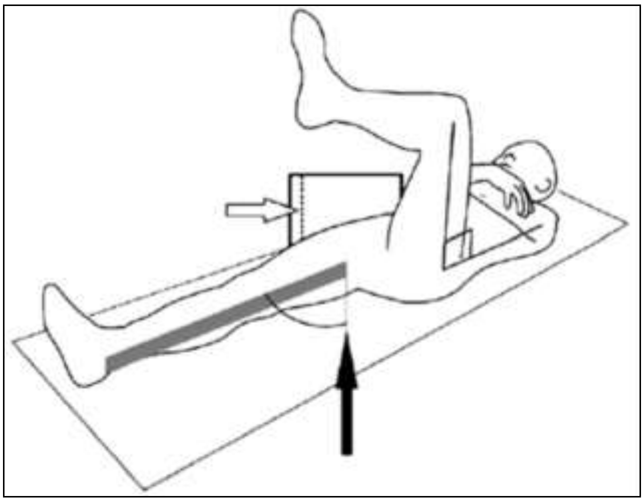

Fig 1: Cross Table Lateral Radiographs

The patient was placed in the supine position with the contralateral hip flexed to 90^0. If the patient could not flex the contralateral hip to 90^0, it was taken with the hip flexed as much as possible. The direction of the radiation beam was parallel to the examination table and at 45^0 to the long axis of the body (black arrow) as shown in Figure 1. An X-ray film was held perpendicular to the floor using a cassette holder, and a gravity line is shown using a metal chain (white arrow) as in Figure 1.

All CT scans included scanning by Antero-posterior tomogram as well as axial images of both acetabulum and femur. All angles were measured at CT work station (64 slice MDCT GE [General Electricals] Light Speed VCT XTE, April 2010, Wisconsin USA). The tomogram through the centre of the acetabulum was selected for measurement of the acetabular anteversion angle, which is defined as the ventral orientation of the acetabulum related to the sagittal plane. A measuring point was assigned at the anterior edge of the acetabulum and a second at the posterior edge. The line connecting these points were drawn, and the angle formed by this line and the plane sagittal to the pelvis determined as the acetabular anteversion angle.

Woo and Morrey's method.

This method uses cross-table lateral radiographs to measure the version of the component, this method needs no equations and distinguishes between anteversion and retroversion. The angle is directly measured between a line perpendicular to the table and a line tangential to the opening face of the acetabular component.

The imaging data of CT scans for each case was anonymized prior to interpretation and stored in an online database where patient identification was removed, and the interpreting radiologists were blinded to prior measurements. The protocol was approved by our institution's ethics committee and written informed consent was obtained from each patient.

Statiscal Analysis: Patient characteristics were summarized using means and standard deviations for continuous variables and frequencies and percentages for discrete variables. Pearson's coefficients were determined to quantify the correlations between radiographic assessments of acetabular version on cross-table lateral views. The comparison of normally distributed continuous variables between the groups was performed using Student's t-test. Nominal categorical data between the groups were compared using the Chi-square test or Fisher's exact test whichever was found appropriate. Non-normal distribution continuous variables were compared using Mann Whitney U test, Odds ratio and 95% confidence interval was also calculated. For all statistical tests, a p-value less than 0.05 was taken to indicate a significant difference.

Results

A total of 55 patients were included in the study. The mean age of study population was 49.65 years. Mean BMI in study population was 23.48 kg/m2. The most common indication for surgery in our study was idiopathic osteoarthritis in 24 (43.64 %) patients followed by post-surgical osteonecrosis of femoral head in 12 (21.82 %). In our study, the mean follow-up was 19.83 months. In this study, anteversion angles calculated on cross table lateral radiographs had mean anteversion angle of 22.41^0 (Range 16 – 56^0), with 19(34.54 %) patients lying in Lewinnek safe zone. Version angles as calculated on CT scan had mean angle of 28.64^0(Range 11.10 – 50.10^0); 17(30.90 %) patients were in Lewinnek's safe zone i.e. $5\text{-}25^0$. The mean anteversion angles on CT scan for normal non-operated side was 18.82^0 (Range $6.3\text{-}35.2^0$); 50 (90.9 %) patients were in Lewinnek's safe zone ($5\text{-}25^0$). In this study, only 17 (30.90%) the patients had anteversion in Lewinnek's safe zone i.e. $5\text{-}25^0$ on operated side whereas 70% patients had anteversion outside the Lewinnek's safe zone. On normal side 50(90.9 %) patients had anteversion in Lewinnek's safe zone. However, this correlation was non-significant. In present study, mean anteversion of native non-operated hip was 18.52^0 (Range $6.3\text{-}35.2^0$) in male population whereas in females mean anteversion angle was 22.43^0 (Range $11.4\text{-}29.5^0$). The correlation between anteversion angles measured on CT Scan and cross table lateral radiographs using Woo & Morrey's method was found to be significant (p value 0.02). 22 (40 %) patients had excellent Harris Hip score with anteversion angle in range of 24.1-360 as measured on CT scan whereas 9 (16.3%) patients had excellent outcomes in range of 12.1-240 of anteversion. 32 (58.18 %) patients reported excellent WOMAC Score in anteversion angle in range of $24.1\text{-}36^0$, whereas 15 (27.2 %) patients reported excellent outcomes in range between $12.1\text{-}24^0$ of anteversion. 28 (50.9 %) patients reported excellent Oxford Hip Score with anteversion angle in range of $24.1\text{-}36^0$, whereas 9(16.3 %) of the patients reported excellent outcomes in range between $12.1\text{-}24^0$. Patients with higher BMI in our study had trend towards decreased anteversion angles. However, there was no significant correlation between BMI of the patient and anteversion angle. Precision analysis was performed using intraclass correlation coefficients (ICCs) and spearman's rho. There was excellent intra-observer reliability for Woo and Morrey's cross table lateral radiographs (ICC = 0.658, p <0.0001) On CT Scan measurement spearman's rho coefficient was poor (0.00 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), good (0.61 to 0.80) or excellent (0.81 to 1.00). CT had a high intra- and interobserver reliability, supporting this as the ideal method for measuring acetabular anteversion. There was no significant correlation between anteversion angles calculated on CT scan, X-rays and complications. We had one patient with femoral stem loosening and DVT was seen in the other patient; however, there was no significant correlation (p-value 0.302 & p-value 0.140) respectively.

Discussion

Measuring the acetabular component position after total hip arthroplasty (THA) is commonly performed as part of the routine postoperative follow-up and as part of the assessment of the malfunctioning THA. Malposition of the acetabular component after THA has been associated with an increased risk of dislocation [11], polyethylene wear [12], early component loosening, and negative clinical effects including pain and decreased range of motion. The assessment of the acetabular component position is based on a combination of the inclination and anteversion angles. Pelvic computed tomography (CT) scans have been shown to be the most accurate assessment of the component position. All cases were of primary Total Hip Arthroplasty and the posterolateral approach was used in all cases as we are quite familiar with it. Lu *et al.* [13] used the posterolateral approach in their study. Goyal *et al.* [14] measured the outcome of their study using a modified Hardinge approach on 1010 patients, whereas Callanan *et al.* [15] used direct lateral, posterolateral and anterolateral approach. Barrack *et al.* [16] reported the anterolateral and posterolateral approach in their study. The mean BMI in our study population was 23.48 kg/m2. 13 (23.63 %) patients were in the overweight category as per WHO guidelines, 2 (3.63 %) patients were in the obesity category. In our study, the patients with higher BMI had decreased anteversion angles. Brodt *et al.* [17] from their study postulated that cup anteversion significantly correlated with BMI; this corresponded with a reduction of anteversion by 3.4 degrees in the morbidly obese group compared with the normal-weight group and they concluded that the precision of cup positioning declines with increasing obesity. Barrack *et al.* [16] concluded high BMI with increased odds of component malposition. Callanan *et al.* [15] demonstrated an increased risk of malpositioning for the minimally invasive surgical approach, low volume surgeons and obese patients. The mean angle measured on a cross-table lateral radiograph in our study was 22.41^0(Range $16\text{-}56^0$) with 19(34.54 %) patients in the Lewinnek safe zone. whereas the mean angle on CT scan was 28.64^0(Range $11.10\text{-}51.10^0$) with 17(30.90 %) patients were found in Lewinnek safe zone. Reikeras *et al.* [18] concluded that cross-table radiography provides acceptable information for clinical use. Reikeras *et al.* [19] studied that the range of acetabular component anteversion actually achieved by the use of a cup positioner by the freehand technique in many cases was not within the intended range of 10 to 30°. Nunley *et al.* [20] concluded that a standardized cross table radiograph remains useful for most of the cases in assessing the anteversion of the acetabular component. Arai *et al.* [21] compared Lewwinek's method with Woo Morrey's method and concluded that there was a difference of an average of 5.8^0 between angles measured on cross-table lateral radiographs and those measured on AP radiographs of the hip joint. A stiffer contralateral hip causes more pelvic tilting when taking a cross-table lateral radiograph, which affects the measurement of the anteversion angle. Saxler *et al.* [22] studied freehand positioning of the acetabular cup compared the results to the "safe" position as defined by Lewinnek *et al.* and concluded that a safe position as defined by Lewinnek *et al.* was only achieved in a minority of the cups that were implanted freehand. McArthur *et al.* [23] concluded that CT is the investigation of choice for measuring anteversion whereas properly positioned cross-table lateral radiographs yielded similar accurate results. Our study supports the notion that Lewinnek's safe zone is not a reliable predictor of stability and there is no absolute specific safe zone for acetabular component positioning. We also found that in the freehand placement of acetabular cups only a minority of the cups could be placed in Lewinnek's safe zone as seen in 17 (30.90 %) of the patients. In this study, 35 (63.63%) had excellent and 13 (23.63%) patients well whereas 6 (10.90%) patients had fair HHS at final follow-up. Anteversion angle in range of 24.1-36^0 as measured on CT was associated with excellent outcomes. Even in acetabular anteversion range of 36.1 – 60^0, 3 (5.45 %) patients had excellent HHS, whereas only 11 (20 %) patients lying in Lewinnek's safe zone had excellent functional outcomes. Goyal *et al.* 91 demonstrated significant improvement in HHS total score. The absolute position of the cup showed a very weak yet significant positive correlation in between cup anteversion and HHS pain (p=0.01), HHS function (p=0.001) and HHS total score (p=0.001). The mean anteversion was 21.8 ± 11.80 in their study compared to mean of 28.64^0(Range 11.10-50.10^0) in our study. The effect of the absolute and relative position of the acetabular component in total hip replacements on functional outcomes has not been studied in the literature. The ideal position of the acetabular component is still debated in the literature. Previous studies have not examined patient satisfaction as a primary outcome. Our study shows significant improvement in post-operative HHS in terms range of motion, pain relief as reported by patients. Our study also shows that the Lewinnek's "safe zone" does not have any direct effect on patient outcome score. In present study, 54 (98.1%) patients had excellent WOMAC Score post-operatively at latest follow-up. Goyal *et al.* reported WOMAC Scores in their study; WOMAC pain (p=0.02), WOMAC physical function (p=0.01) and WOMAC total (p=0.02) which was significant. The mean anteversion was 21.8 ± 11.80 in their study. In the present study, 43(78.1 %) patients had excellent OHS post-operatively compared to their pre-operative OHS which was statistically significant (p-value 0.038). Sculco *et al.* [24] reported better OHS outcomes in the range of anteversion angles of 25±5°. Grammatopoulos *et al.* [25] recently recommended an inclination of 45 degrees and an anteversion of 25 degrees based solely on the Oxford Hip Score. In our study, anteversion angles in range 30±6^0 had excellent outcomes which are fairly comparable to the study done by Sculco *et al.* and Grammatopoulos *et al.* In this study, anteversion angles measured on CT Scan and cross-table lateral radiographs indicated significant results in terms of measurement of angle (p = 0.02). The mean anteversion angle was 22.41^0 on cross-table lateral radiographs whereas the mean angle of 28.64^0 was reported on CT scan. Reikeras *et al.* [18] postulated that cross table radiography provides acceptable information for clinical use but has limited use for precise analysis of the acetabular cup version. McArthur *et al.* [23] demonstrated properly positioned, cross-table lateral radiograph-derived measurements are similarly accurate as CT measurements. Ghelman *et al.* [26] found that the accuracy of anteversion measurements on crosstable radiographs depends on radiographic technique and patient positioning whereas properly performed CT measurements are independent of patient position. In our study possibly the difference between the anteversion calculated using the cross table lateral method and CT scans were high because the measurement in the cross table lateral method is not performed in the coronal plane as it is done using CT. In our study, the anteversion was measured in relation to the horizontal plane, and we assumed that the patient positioning was in parallel plane. Pelvic tilting and rotation of pelvis possibly while performing cross table lateral where contralateral hip is flexed can lead to tilting of pelvis during imaging can possibly lead to a change in radiographic projection and distort the measurement. Moreover, measurement done on radiographs was manual using a goniometer which theoretically can contribute to error if any in measurement when compared to more precise measurements done in CT console. In our study, anteversion angles ranged from 11.10 – 50.10^0 with 17(30.90 %) patients in Lewinnek safe zone. Saxler *et al.* [22] concluded that safe position as defined by Lewinnek *et al.* was only achieved in a minority of the cups that were implanted freehand. Danoff *et al.* [27] advocated a sweet spot safe zone of 17.10 of anteversion. Abdel *et al.* [28] concluded that the historical target values for cup inclination and anteversion may be useful but should not be considered a safe zone given that the majority of these contemporary THAs that dislocated were within those target values. Cotong *et al.* [29] did a survey and concluded that strict usage of the Lewinnek "safe zone" cannot be justified. Goyal *et al.* [14] concluded that "safe zone" has no effect on patient-reported functional outcomes which are similar to our study as the majority of patients with excellent functional outcomes were within the range of 24.1-36^0 of anteversion which is outside the historic Lewinnek's safe zone Similarly, patients outside Lewinnek's safe zone too had excellent and good HHS, WOMAC and OHS. We too believe that ideal cup position varies from patient to patient. The reasons could be multifactorial; one possible reason could be native anteversion of the patient which varies in each individual. More studies are needed to further redefine the concept of safe zone or the range of safe zone needs to be more comprehensive or elaborate. Our study is the first to calculate acetabular anteversion in patients operated by posterolateral approach with freehand technique. There are limitations of this study. The first limitation was that we used goniometer to measure angles on radiographs instead of more precise computer softwares. We used free hand techniques on the basis of visual cues instead navigation controlled implantation of acetabular cup or mechanical alignment guides. There is a bias in the measurements of anteversion using radiographs which is inevitable when measuring a 3D object with a 2D projection. We also recognize that our conclusions regarding the effect of patient characteristics, specifically sex and BMI, are not definitive because they may indicate that our study was underpowered to establish such relationships. The patient's position during radiography influences the measurements. We largely eliminated the patient positioning variables (pelvic tilt and rotation) which produce error in clinical practice. These limitations must be taken into consideration when our results are applied in clinical practice. Our sample size was small. The study design was reviewed by our institutional review board, which restricted the case number because of the radiation hazard and cost of CT scans, further we did not perform multiple CT scans on the same patients because of concern for radiation exposure; thus, we have no repeatability data for the CT scans. Our study is one of the few studies done in the past which measures patient reported functional outcomes as a function of anteversion angle. A good understanding of anatomic, patient and implant related factors that affect the "optimal" cup position is mandatory. Creating a stable THA remains a balancing act among appropriate component positioning taking into account individual patient bony and muscular anatomy in both the static and dynamic state, soft tissue balance and tensioning, and appropriate aftercare and rehabilitative efforts. Due to the variety of study designs, surgical approaches, and patient populations identified, it is difficult to draw broad conclusions regarding a definitive target zone for cup positioning in THA. The target zone for cup placement is probably influenced by several other factors, so the ideal target zone for each patient may vary depending on these factors. Considering the advantages of plain radiography, including low cost, low radiation level, and convenience for clinical follow-up and assessment of prosthesis position we recommend the use of Morrey's method as they provide reproducible and accurate data compared with CT. We believe that the safe zone should be tailored to the surgical approach used. A properly positioned acetabular cup in isolation will not guarantee success. Intentionally we inserted the acetabular cup in more anteversion. It has been observed that 20-25 % of patients subject their hip to deep seating and even go for squatting against advice. To avoid dislocation, the anteversion was kept about 100 above the normal. If we had to err, it was towards more anteversion. This was coupled with myocapsuloplasty, as a result we had no dislocation in our patients. Further research is encouraged to investigate the ability of emerging technologies to assist surgeons in optimally positioning the acetabular components. Functional outcome measurements with improved resolution may be of great importance for clinical research in the future.

Conclusion

Majority 39(69.09 %) of patients had excellent functional outcomes in a range of 11.1 – 360 of anteversion compared to Lewinnek's safe zone. It suggests that there is flexibility in positioning the acetabular component than previously believed. If one has to err, it should be towards more anteversion. Infact to avoid dislocation, more anteversion is required to guard against unwarranted activities on part of the patient. Cross-table lateral radiographs can be used as a surrogate method for measuring the anteversion angle compared to CT scan as it avoids radiation exposure and lessens the cost.

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