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Assessing Posterior Femoral Neck Cortical Line for Stem Anteversion in Direct Anterior Hip Replacement: A Retrospective Analysis

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ABSTRACT

Background and Objective: Unlike the native femoral cortical line, consensus is lacking on osteotomy landmarks for stem placement. Templating alone often fails to achieve a proper femoral version, highlighting critical intraoperative neck height-cutting parameters. This study evaluated the reliability of using the posterior femoral neck cortical line on osteotomy surfaces as a reference landmark for correcting version angle during total hip arthroplasty via the direct anterior approach. **Materials and Methods:** Data from patients who underwent unilateral total hip arthroplasty (THA) via the direct anterior approach (DAA) by the same surgeon between March, 2015 and June, 2016 were analyzed. The 63 patients (29 females, 34 males; mean age 64.9±9.5 years) met the inclusion criteria. The CT scans and 3D reconstructions were used to measure anteversion at various lines. The study was approved by the RenMin Hospital Review Board, with informed consent obtained from all patients. **Results:** The indications for surgery were osteoarthritis (OA) and osteonecrosis (ON), which accounted for 43 and 20 cases, respectively. There were significant relationships between native femoral anteversion and posterior femoral cortical line anteversion ($r = 0.8831$, $p<0.001$; $r = 0.866$, $p<0.001$ and $r = 0.8436$, $p<0.001$ at 5, 10 and 15 mm cutting heights, respectively). **Conclusion:** There is a crucial need for the posterior cortical line to be universally adopted as a reference cutting surface to optimize stem positioning and achieve a satisfactory femoral version during DAA THA.

KEYWORDS

Total hip arthroplasty, direct anterior approach, stem anteversion, anatomical reference, osteotomy surface

INTRODUCTION

Osteophyte production, persistent progressive cartilage deterioration and synovial inflammation are the hallmarks of osteoarthritis (OA). It is commonly diagnosed in ambulatory primary care visits, affecting more than 21 million people and accounting for 47.5% of all arthritis-related hospitalizations annually in

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United States alone[1,2]. Patients with end-stage hip OA are often been offered a unilateral total hip arthroplasty (THA) as optimal treatment. Estimations have shown that 15 to 25% of patients being considered for THA ultimately require bilateral procedures and subsequently, in patients with bilateral hip disease, optimal function is not entirely regained until both hips have been replaced[3-5]. Traditionally, elective THA has been done either *via* direct lateral or posterior approach[6].

The high demand for minimally invasive surgery, various approaches have become more commonly utilized. Nowadays, approaches currently used for total hip arthroplasty are (i) Direct lateral, (ii) Anterolateral, (iii) Posterior and (iv) The direct anterior approach (DAA). Although, each surgical approach has expected qualities including preservation of the anatomy, quality of exposure, reproducibility and possibilities of extension, they also present some disadvantages[6]. Even though total hip replacement surgery (THR) has a high success rate when it comes to pain relief, quality of life and physical function, a certain percentage of patients still do not regain their normal gait one year or longer following surgery. This is probably due to the effect of the surgical approach on the function of those muscles in the vicinity of the hip joint[7].

Comparatively to other approaches, the DAA has features of direct anterior's sparing of the abductor musculature, true inter-nervous interval and kinematics restoration, hence low dislocation rates[6-8]. The direct anterior approach (DAA) is a minimally invasive surgical method used for total hip arthroplasty (THA), employing two common types of incisions. One method involves a traditional 8-10 cm long incision made laterally and distally to the anterior superior iliac spine, directed towards the fibular head. Another technique uses an oblique "bikini" incision of similar length, centered in the inguinal crease[9,10]. Both incisions are situated in areas supplied by specific nerves-the iliohypogastric/ilioinguinal nerve and the lateral femoral cutaneous nerve[9]. The DAA for THA not only aids in satisfactory functional recovery but also enhances overall quality of life. However, there have been reports of higher complication rates associated with early surgeons' experience with this new technique[11-13].

In direct anterior approach total hip arthroplasty (DAA-THA), femoral component is prepared and inserted while the patient lies supine with the leg fully extended. The lower part of the knee is typically shielded from the surgeon's sight[14,15]. Nevertheless, the procedure is quite challenging and most of the femoral complications might occur during this stage of the procedure[16]. Improper prosthesis placement might cause stem-bone bed mismatch and lead to peri-prosthesis fracture. A poorly exposed proximal femur often leads to a stem implanted in valgus, calcar fracture, or perforation simply due to wrong stem anteversion determined by the surgeon during the surgical procedure[17]. A few years ago, the American Association of Hip and Knee Surgeons Evidence-based Committee recommended elective THA in patients with a Body Mass Index (BMI)>40, especially via DAA[18]. Moreover, patients with a large abdominal panniculus, especially those with tissue presenting an overlap of the upper thigh, face extra challenges when using the DAA. This is because the overlapping tissue can create a moist environment, resulting in chronic skin irritation or fungal infection[18].

Medical literature suggests that preoperative computed tomography (CT) can help assess femoral anteversion[19], which is regarded to be the most accurate imaging method currently available so far[20]. A body of knowledge has proven a direct link between implant stability, optimal range of motion (ROM), impingement occurrence and the appropriate postoperative stem anteversion in THA. There are now a number of techniques available to forecast postoperative stem anteversion, but no accepted prognostic technique has yet been established[19]. Furthermore, opinions on the relationship between proper stem anteversion and the surfaces of the femoral neck landmark osteotomy that should be used as a guide for prosthetic placement are divided. There is still insufficient data to reach a consensus regarding the optimal stem anteversion strategy and consequently, which femoral neck cutting surface line is better than which on its own. Therefore, it is deduced from this study that the optimum optional cutting surface to use intraoperatively to modify stem location and version during DAA-THA is the posterior femoral cortical line. The CT scan data were used to mimic the femoral cutting surface during DAA-THA, while the mid cortical line[21], the transverse line (T-line)[22] and the posterior cortical line were calculated independently on different osteotomy surfaces. Furthermore, femoral anteversion angles were investigated individually using the aforesaid cortical lines. Therefore, this study aims to explore the characteristics of the femoral neckline and its optimal level for measuring femoral anteversion to predict postoperative stem anteversion.

MATERIALS AND METHODS

Inclusion and exclusion criteria: This paper presents a monocentric center retrospective study, approved by our Institutional Review Board and through which informed consent from all patients was obtained. All procedures were undertaken in accordance with the ethical standards established by the institutional and national committees on human experimentation and in accordance with the Declaration of Helsinki.

The inclusion criteria followed the PICOS (P-Participant, I-Intervention, C-Comparison, O-Outcomes and S-study design) principle. According to the PICOS principle, the explicit inclusion criteria were as follows: (a) Participant: Adult hips experiencing severe impairment of daily activity due to the osteoarthritis (OA) or avascular necrosis (AVN also known as osteonecrosis) of the femoral head and confirmed by CT scanning and 3D reconstruction, (b) Intervention: Underwent primary unilateral THA between March, 2015 and June, 2016, (c) Comparison: Examining the differences in femoral anteversion at various levels compared to postoperative stem anteversion, (d) Outcomes: Identifying the optimal level of femoral neck for predicting postoperative stem anteversion and (e) Study design: Retrospective study. The study exclusion criteria were (i) Body Mass Index (BMI) above 30, (ii) Evidence of femoral fractures, (iii) Congenital deformities of the hip such as developmental dysplasia of hip, congenital dislocation of hip and Legg-Calve-Perthes disease and (iv) Patients with bilateral hip joints deformities or those needed revisions surgery (secondary hip replacement surgery). These exclusions were assessed and confirmed by conventional radiographs.

Patients information: A retrospective analysis was conducted on 105 consecutive patients who underwent DAA-THA surgical procedures between March, 2015 and June, 2016 in Department of Orthopaedics of the affiliated Renmin Hospital of Wuhan University Medical School. After further screening, 42 patients were excluded from the study based on the exclusion criteria. After all, sixty-three consecutive patients (63 hips) including 34 males and 29 females, met the inclusion criteria and were enrolled for the study. At the time of surgery, the patient's mean age was 64.9±9.5 years (43-88) and the mean BMI was 22.9±3.3 kg/m^2 (17.2-29.6). All arthroplasties were performed by the same experienced orthopaedic surgeon (HL) through a direct anterior approach.

CT scanning: All patients received CT scans (Light Speed VCT, General Electric Company, America). The Materialize Interactive Medical Image Control System (MIMICS, Version 17, Leuven, Belgium) was used to reconstruct the pelvis and prosthesis after inputting the volumetric CT data. The CT scans ranged from double hip joints to bilateral knees, including the distal femoral condyles. The scan pixel was 0.782, current 140 mA and voltage 120 kV. The pre-and postoperative CT data were stored in Digital Imaging and Communication in Medicine (DICOM) format.

Surgery process:

- **Anesthesia and position (Step 1):** All the patients underwent DAA-THA due to osteoarthritis and osteonecrosis. They received general anesthesia and were maintained at a supine position on the operating table, the pelvis and bilateral lower limb in a neutral position

- **Approach and exposure (Step 2):** The direct anterior approach was employed for all patients. Initially, an incision was made 2 cm lateral and distal to the anterior superior iliac spine, extending longitudinally along the fibers of the tensor fascia lata muscle (TFL) as previously described[23]. Dissection involved incising the fascia and raising it off the TFL. A horizontal bone cut at the femoral neck was made approximately 10 mm superior to the lesser trochanter using a template design to ensure proximal stability of the sleeve component[24]. After locating the intermuscular plane and femoral neck, retractors were positioned to reveal the hip capsule
- **Pathological changes, resection (Step 3):** Under C-arm X-ray machine, the assessment was made as capsular visualization was necessary. After resection of femoral neck of 10 mm above the lesser trochanter, the bone stock was preserved to restore high offset, the press-fit metaphysical prosthesis was inserted after broaching. The acetabulum implant design was a single cup - head size of 28 to 32 mm. The combined anterversion was achieved without impingement and maintained a range of motion
- **Fixation or placement of prosthesis (Step 4):** After enlarging the acetabulum with progressively larger reamers, the acetabular cup was inserted, followed by placing the liner. As previously mentioned[25] a femur elevator hook was used to lift the proximal femur with the leg externally rotated. The correct positioning and orientation of the femoral component were determined using a canal finder, followed by rasping and insertion of the appropriately sized stem. The cup was irrigated and checked for debris before final reduction. Subsequently, final fluoroscopic images were captured to check for any fractures in the femur.
- **Reconstruction (Step 5):** Reconstruction was performed from raw data using 2 mm slices with 1 mm intervals. After impacting the head onto the stem, the reduction was performed with proper traction and internal rotation in a leg-raising manner. After tying together, the two capsular sutures in order to repair the capsule and the fascia overlying the TFL, the surgical site and soft tissue wound were cleansed. The subcutaneous and skin layers were closed

Overall, the overview process of the surgical procedure is depicted by the schematic layout diagram in (Fig. 1A-G). In this surgical approach, the femoral component broaching and insertion takes place while the patient lies supine with the leg fully extended (Fig. 2A).

Postoperative treatment and follow-up: All surgeries were performed by a single surgeon. On surgery day, a standard program of quick recovery was initiated and implemented by a multidisciplinary team. Patients did not do any weight bearing on the surgery day and was not even recommended for the first week post-operative. Subsequent weeks later, they started physiotherapy with partial weight bearing as soon as they were physically able to take part. Besides the physical therapy program, administration of antibiotics (intravenously during the first 24 hrs of surgery to prevent infections), non-steroidal anti-inflammatory drug (orally for 2 weeks as anti-analgesic) and inhibitor of clotting factor X (orally for 5 weeks to prevent deep venous thrombosis) were also included in the postoperative protocol.

Follow-up visits were scheduled at 1 and 3 months postoperatively, during which the patients were clinically and radiographically examined. The follow-up visits were done in outpatient clinic. The radiographic analysis was done with standard anteroposterior pelvic and lateral views.

Outcomes measure

Measurements of the native femoral anteversion: Femoral measurement was performed using the Radiant DICOM Viewer (version 4.6.9, 64-bit, Medixant Company, Poland). Each examination was performed by using a 2 mm slice thickness. Only the healthy side was studied, femoral shaft was connected to centre of the condylar fossa and centre of the trochanteric fossa. The native femoral anteversion was measured by the angle between femoral neck axis and posterior condylar axis (Fig. 2B).

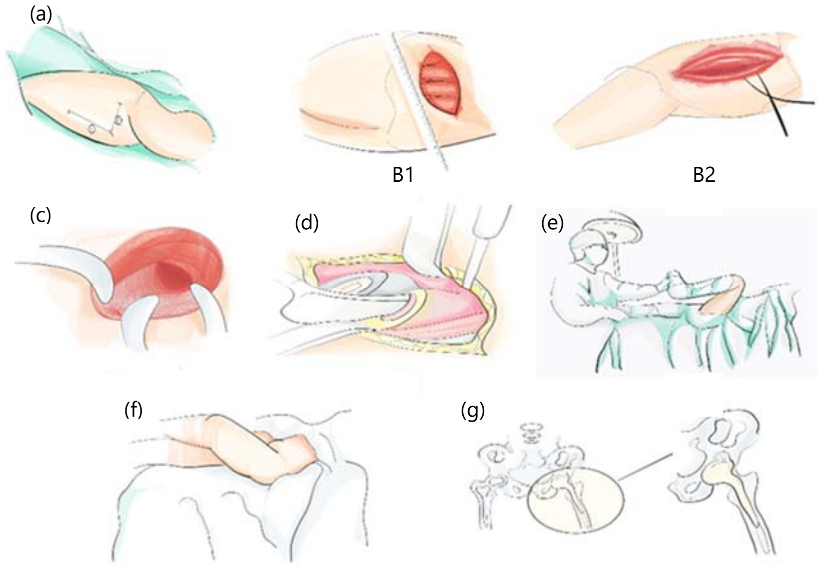

Fig. 1(a-g): Schematic layout diagram of DAA-THA, (a) Operative field seen before prepping and draping and demonstrating markings for the skin incision which is outlined in relation to the anterior superior iliac spine (ASIS) and the tensor fascia lata (TFL). Anatomical illustrations of, (B1) "bikini" surgical incision type and (B2) traditional longitudinal surgical incision type, (c) View of the exposed anterior capsule of the hip, while the anterior retractor is pulling aside the iliacus and rectus femoris muscles, (d) Femoral components placement and trialing, (e) Testing the range of motion after THA-DAA, (f) Flexion of the hip at 9°, external and internal rotation of the hip and (g) Total hip arthroplasty via direct anterior approach is performed

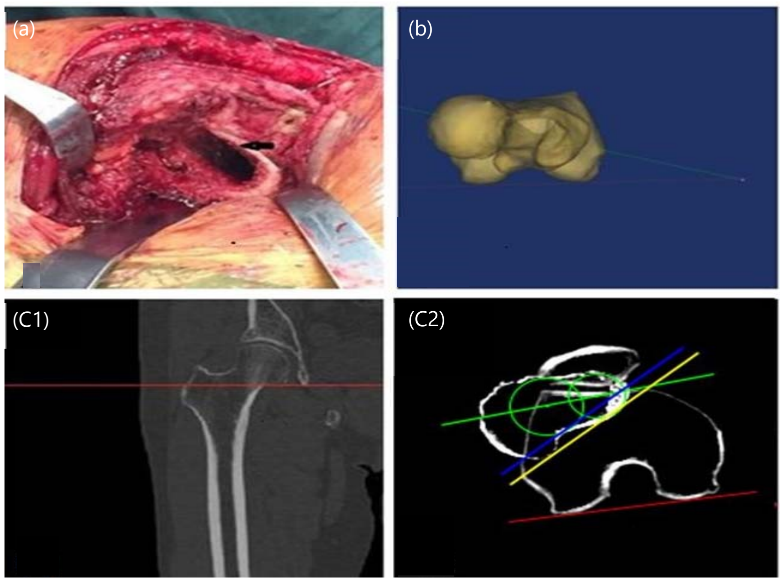

Fig. 2(a-c): Measurement of the different lines anteversion on axial sections, (a) Oblique osteotomy 15 mm above the lesser trochanter. After proximal femur reaming preparation, the femoral anteversion was parallel to the posterior cortex. Black arrow referred to posterior cortex, (b) The native femoral anteversion was measured by the angle of the femoral neck axis and the posterior condylar axis, (C1) A proximal slice was obtained in the axial plane at the level of the most proximal portion of the inferior neck that had no head portion and (C2) Green line was the midcortical line, Blue line was T-line, defined as the line connecting the direction of trochanteric fossa boundary point and the center of the medial cortex of the femoral neck. Yellow line was the posterior cortical line. Red line was the posterior condylar axis

Measurements of the different lines anteversion on axial sections: A proximal slice was obtained in axial plane at a level of the most proximal portion of an inferior neck that had no head portion[21,26,27], in turn, to make the mid-cortical line, the Transverse line (T-line) and the posterior cortical line. The posterior cortical line was defined as the line of an interior margin of the posterior cortex of femoral necks starting from combination point of posterior cortical margin of the femoral neck and digital fossae. The midcortical line was defined as the midline between anterior cortical line and the posterior cortical line. The T-line was defined as the line connecting the most medial point of true calcar femoral and centre of medial cortex of femoral neck. The posterior condylar axis was determined by drawing a line along the largest femoral condyle on a CT slice where two slices overlapped. Midcortical line anteversion referred to the angle between the midcortical line and the posterior condylar axis. The T-line anteversion represented the angle between the T-line and the posterior condylar axis. Posterior cortical line anteversion refers to the angle formed between the posterior cortical line and the posterior condylar axis (Fig. 2C).

Measurement of the different lines of anteversion on the oblique osteotomy surfaces: Three different femoral neck osteotomies in the coronal plane were studied, at a cutting level of 5, 10, or 15 mm above the lesser trochanter at the junction between the superior aspect of femoral neck and greater trochanter (Fig. 3A1-A3). Besides, an osteotomy surface was studied at 15 mm above the lesser trochanter at a junction between a high resection height of 10 mm compared to the notch of femoral neck (Fig. 3A4), as such used short stem prosthesis like Metha short stem (Aseculap, Germany)[28,29]. The posterior cortical line, midcortical line and T-line on osteotomy surfaces were studied. The mid cortical line, T-line and posterior cortical line were regarded as reference landmarks of femoral anteversion when implanting stem prosthesis. It is worthy of note that it was proposed the posterior cortical line on the cutting surface is relatively close to the native femoral anteversion, which is relatively considered for DAA-THA. Therefore, angles between the mid-cortical line, the T-line, the posterior cortical line and the frontal plane could be used as separate anteversion. The MIMICS was used to rotate the three-dimensional (3d) CT reconstruction image after osteotomy and femoral shaft was connected with the centre of condyle fossa and trochanteric fossa centre. The angle between midcortical line, T-line, posterior cortical line and posterior condylar axis was the corresponding anteversion (Fig. 3B1-2).

Postoperative complications: Intraoperative fractures requiring internal fixation, femoral, sciatic or obturator nerve injuries with or without motor loss, nausea, vomiting, chronic pain, deep infections requiring operative irrigation and debridement, aseptic loosening, periprosthetic fracture, hip dislocation and thromboembolic events (deep vein thrombosis (DVT) and/or pulmonary embolism (PE)) were thoroughly monitored during the entire follow up period and were considered as postoperative complications.

Statistical analysis: All measurements were taken using the preoperative THA planning software. Intra-observer and inter-observer measurement reliabilities were assessed using intra-class correlation coefficients (ICC). In order to minimize bias caused by intra-observer reliability and inter-observer reliability, all measurements were triplicated by consensus of 3 of the authors (J.T., J.L. and F.P.) with an interval of 1 month between measurements. The spearman correlation coefficient was used to measure correlations among variables. The calculation of R value reflected its correlation. A one-way repeated measures ANOVA was used to analyze the differences among the native femoral neck anteversion and the stem anteversions of three different cutting heights. When the one-way ANOVA was significant, differences between the native femoral neck anteversion and the stem anteversions at 5, 10 and 15 mm were determined using Tukey’s multiple comparison test. Similarly, Tukey's multiple comparison test was used to analyze the mid-cortical line anteversion, the T-line anteversion and the posterior cortical line anteversion respectively on axial sections at the same osteotomy surfaces. Group (intergroup or intragroup) differences in continuous, normally distributed data were assessed using student’s t-test.

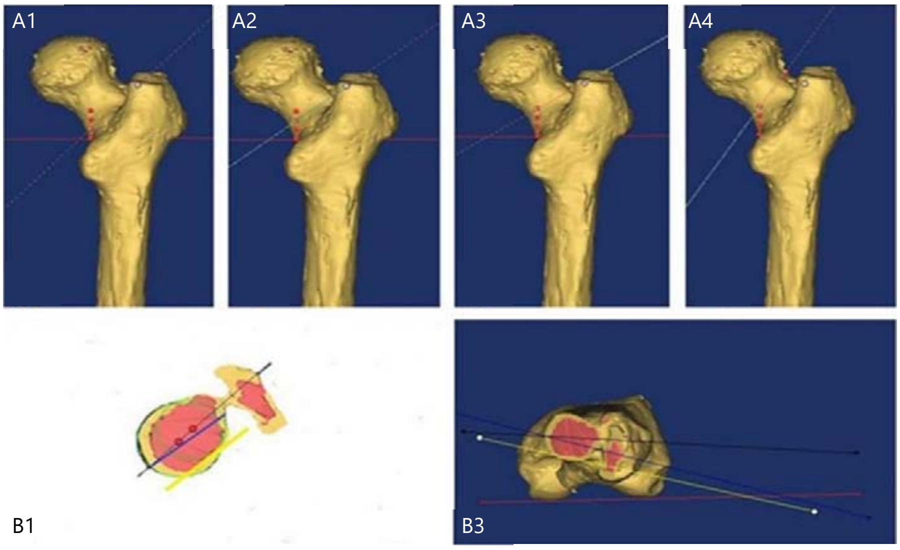

Fig. 3(a-b): Measurement of the different lines anteversion on the oblique osteotomy surfaces, (A1-A3) Computer simulations at three different cutting levels of 5, 10 or 15 mm above the lesser trochanter were performed, (A4) Osteotomy surface was studied, at 15 mm above the lesser trochanter at the junction between a high resection height of 10 mm compared to the notch of femoral neck, (B1) Osteotomy surface, (B2) Angle between the midcortical line, the transverse line, the posterior cortical line and the posterior condylar axis was the corresponding anteversion. Black line was the midcortical line. Blue line was T-line, defined as a line connecting the most medial point of the true anatomical calcar femoral (dashed line) and the center of the medial cortex of the femoral neck. Yellow line was the posterior cortical line. Red line was the posterior condylar axis

Differences in categorical data were assessed using Pearson's c^2-test. Each data was expressed as a Mean±Standard Deviation unless otherwise indicated. The SPSS Statistics 22.0 for Windows (IBM, Chicago, Illinois, USA) was used to perform all statistical analyses. In all cases, a statistical significance was accepted for p-values of <0.05.

RESULTS

Patients characteristics: A total of 63 patients underwent single-stage unilateral DAA-THA with preoperative templating. The entire study population consisted of 34 males (54%) and 29 females (46%), with a mean perioperative age of 64.9±9.5 years and a mean body mass index of 22.6±2.7 kg/m^2.

Intraobserver and interobserver reliabilities: The results indicated great measurement repeatability and reproducibility. Intra-rater and inter-rater reliabilities were excellent, as ICCs showed high levels of intra-observer and inter-observer agreement on the osteotomy surface at the 15 mm levels (Table 1). Findings from relevant studies have suggested intraobserver and interobserver variability to be a potential source of measurement errors in radiographic analyses[29]. Therefore, we potentially excluded its impact by allowing only the same trio of observers to perform all radiographic measurements.

Difference between the native femoral anteversion and different postoperative line anteversions: The mean native femoral anteversion was 15.5±4.9°. Positive correlations were found between the native femoral anteversion and the mid cortical line anteversion (r = 0.8747 and p<0.001), the T-line anteversion (r = 0.6949 and p<0.001) and the posterior cortical line anteversion (r = 0.7051 and p<0.001) on axial sections (Table 2). However, the T-line anteversion and the posterior cortical line anteversion tended to

Table 1: Intra- and Inter-observer reliability on the osteotomy surface at the 15 mm levels

Measurement	Intra-rater reliability (ICC)	Inter-rater reliability (ICC)
Midcortical line anteversion	0.989 (95% CI: 0.983-0.993)	0.984 (95% CI: 0.975-0.990)
T-line anteversion	0.990 (95% CI: 0.985-0.994)	0.993 (95% CI: 0.989-0.995)
Posterior cortical line anteversion	0.988 (95% CI: 0.981-0.992)	0.992 (95% CI: 0.988-0.995)

Each set of intra- and inter-observer reliability measurements was done in triplicate by two authors. ICC: Intra-class correlation coefficient, CI: Confidence interval, T-line: Transverse line defined as a line connecting the most medial point of true calcar femoral and centre of medial cortex of femoral neck

Table 2: Correlation analysis between the different lines anteversion and the native femoral anteversion on axial sections

	Native femoral anteversion (°)	Midcortical line anteversion (°)	T-line anteversion (°)	Posterior cortical line anteversion (°)
Mean±SD	15.5±4.9	15.8±5.3	28.9±7.7	12.9±5.3
r-value		0.8747	0.6949	0.7051
p-value		<0.001	<0.001	<0.001

Data presented as Mean±Standard Deviation, T-line: Transverse line defined as a line connecting the most medial point of true calcar femoral and centre of medial cortex of femoral neck

excessive anteversion when compared with the native femoral anteversion (the T-line anteversion 13.4±5.1°, the posterior cortical line anteversion 12.9±5.3°). However, it was not a cutting surface that can be seen directly in the operation. It was found statistically significant differences in the stem anteversions between the midcortical line and the T-line ($p<0.05$), between the midcortical line and the posterior cortical line ($p<0.05$), except for the stem anteversion between the T-line and the posterior cortical line ($p>0.05$) on axial sections.

Difference between femoral anteversion and differenT-lines anteversion on osteotomy surfaces: Positive correlations between the native femoral anteversion and the mid-cortical line anteversion ($r = 0.731$ $p<0.001$, $r = 0.8011$ $p<0.001$ and $r = 0.833$ $p<0.001$ at 5, 10 and 15 mm cutting levels, $r = 0.7908$ $p<0.001$ at 15 mm cutting levels, 10 mm resection heights, respectively) and the T-line anteversion ($r = 0.8712$ $p<0.001$, $r = 0.8623$ $p<0.001$ and $r = 0.858$ $p<0.001$ at 5, 10 and 15 mm cutting levels, $r = 0.8046$ $p<0.001$ at 10 mm resection heights, respectively) and the posterior cortical line anteversion ($r = 0.8831$ $p<0.001$, $r = 0.866$ $p<0.001$ and $r = 0.8436$ $p<0.001$ at 5, 10 and 15 mm cutting levels, $r = 0.8132$ $p<0.001$ at 10 mm resection heights, respectively, Fig. 4, Table 3). However, the midcortical line anteversion tended to retroversion (−5.1±3.6°, −5.4±3.3° and −6.0±3.2° at 5-, 10- and 15-mm cutting levels, −7.2±3.4° at 10 mm resection heights, respectively). The correlations of the T-line anteversion and the posterior cortical line anteversion were better than midcortical line anteversion. There were statistically significant differences in anteversions between the midcortical line and the T-line ($p<0.05$), between the midcortical line and the posterior cortical line ($p<0.05$), except for the anteversion between the T-line and the posterior cortical line ($p>0.05$), as regards to different osteotomy surfaces.

Consequently, the correlations of the T-line anteversion and the posterior cortical line anteversion were better than the midcortical line anteversion on different osteotomy surfaces while the midcortical line anteversion tended to retroversion. These findings suggest that the midcortical line cannot be used as a good landmark for femoral anteversion. At the same time, results confirmed the strong positive correlation between the native femoral anteversion and the T-line anteversion, suggesting it can be a reference landmark for femoral anteversion. These results corroborated the findings from Tsukeoka *et al.*[30,31]. Besides, findings also showed a good correlation between the posterior cortical line anteversion and the native anteversion. Although, it found no difference statistically significant between the T-line anteversion and the posterior cortical line anteversion ($p>0.05$).

Cases presentation: The present patient was a 68 years old Chinese female (BMI = 21.61 kg/m^2) who presented to our joint clinic with complaints of left hip pain associated with stiffness. She did not recall

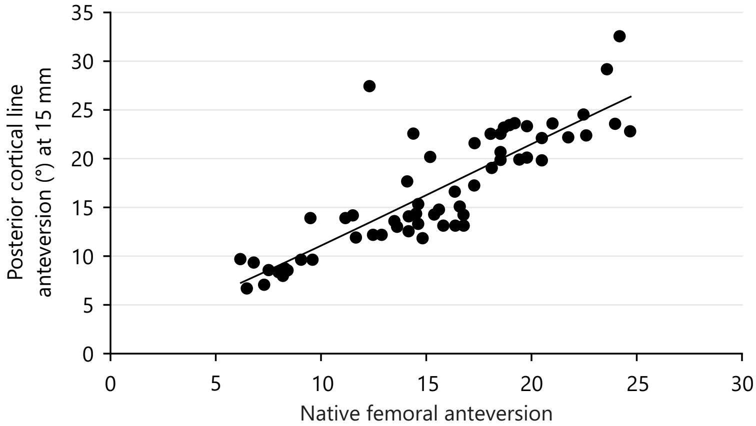

Fig. 4: Correlation between the posterior cortical line anteversion at 15 mm above the lesser trochanter and the native femoral anteversion

Table 3: Correlation analysis between the differen T-lines anteversion and the native femoral anteversion, respectively on osteotomy surfaces

Comparison Index	Mean±SD	r-value	p-value
Native femoral anteversion (°)	15.5±4.9	-	-
Midcortical line anteversion (°) 5 mm	10.4±4.7	0.7312	<0.001
T-line anteversion (°) 5 mm	19.7±6.6	0.8712	<0.001
Posterior cortical line anteversion (°) 5 mm	19.1±6.6	0.8831	<0.001
Midcortical line anteversion (°) 10 mm	10.1±4.5	0.8011	<0.001
T-line anteversion (°) 10 mm	19.0±6.6	0.8623	<0.001
Posterior cortical line anteversion (°) 10 mm	18.1±6.4	0.8660	<0.001
Midcortical line anteversion (°) 15 mm	9.5±4.2	0.8330	<0.001
T-line anteversion (°) 15 mm	18.0±6.1	0.8580	<0.001
Posterior cortical line anteversion (°) 15 mm	16.9±6.0	0.8436	<0.001
Midcortical line anteversion (°) 10 mm resection heights	8.3±2.5	0.7908	<0.001
T-line anteversion (°) 10 mm resection heights	19.1±5.4	0.8046	<0.001
Posterior cortical line anteversion (°) 10 mm resection heights	18.1±5.4	0.8132	<0.001

Data presented as a Mean±Standard deviation, -: No statistic value, T-line: Transverse line defined as a line connecting the most medial point of true calcar femoral and Centre of medial cortex of femoral neck

any inciting event when the pain first started seven years ago. Since the onset, the pain had worsened and gradually progressed over time, to the point that she could find it difficult to walk and get up from a sitting position. Following clinical consultations from three different hospitals, she received the confirmation of avascular necrosis of the left hip as a final diagnosis. Her constant pain was described as moderate to severe in intensity, especially located over the left groin. The pharmacological management through hip cortisone injections and non-steroidal anti-inflammatory drugs (NSAIDs) coupled with physical therapy did not improve her condition, as she still had unremitting hip pain.

Blood tests for rheumatoid factor were normal. On physical examination, she had an antalgic gait, walking with a mobility aid, painful passive movements, restricted range of motion and fixed flexion deformity. The skin overlying the left groin was normal with no evidence of scars or sinus tracts. On digital palpitation, the pelvis was squared and there was no evidence of any leg length discrepancy. The examination of the lower spine, right hip, bilateral knee and ankles was normal. The X-ray imaging showed narrowing joint space with osteophyte formations and subchondral sclerosis (Fig. 5a). An MRI was further obtained suggesting avascular necrosis of the femoral head of the left hip.

Considering her condition and her previous experience with pharmacological pain management, she was advised a left hip total replacement. Risk and benefits of the procedure were extensively discussed with the patient and her relatives and her full consent was given for the surgical procedure. A THA via DAA was

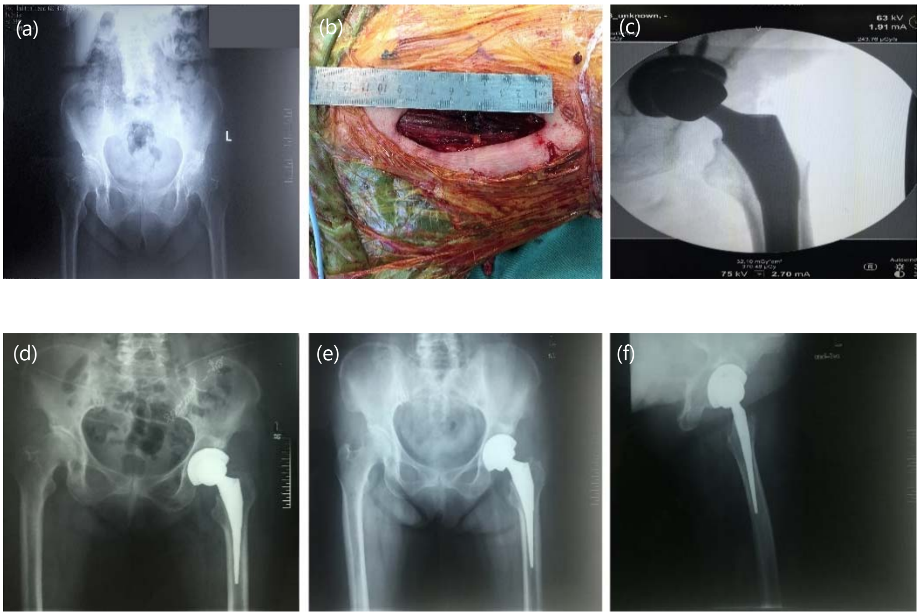

Fig. 5(a-f): Radiographs of a 68 years-old female patient with avascular femoral head necrosis of the left hip, (a) Plain radiograph of the pelvis before surgery, (b) Intraoperative photograph of the incised fasica of the TFL, (c) View of the Acetabular cup through the c-arm, (d) Postoperative AP plain radiograph showing the successful of THA-DAA. Postoperative, (e) AP and (f) Med-lateral plain radiographs during the 3-months follow up after surgery

performed on the patient, using the oblique “bikini” surgical incision (Fig. 5b). The fixation of the acetabular cup was viewed and assessed through c-arm (Fig. 5c). A postoperative AP plain radiography was taken showing successful of the surgical procedure (Fig. 5d). The post-operative pain was managed with oxycodone and acetaminophen and aspirin was given for DVT. Weight-bearing was allowed a tolerated and physical therapy was recommended. Three-months following surgery, AP and Med-lateral plain radiographs, respectively (Fig. 5e-f) attested she experienced good recovery, no pain in the left hip and was walking without support.

The present patient, a 53-year-old Chinese man (BMI = 27.76 kg/m^2) presented at our joint clinic, complaining of worsening left hip pain due to a long history of deep hip pain radiating to the inner thigh and knee. The patient described the pain as a sharp to dull ache located in the left groin which varied in intensity from moderate to severe (8/10) and radiating to the right knee. Activities such as walking fast or climbing stairs, prolonged standing, getting up from chair, bending and squatting exacerbated the pain. He additionally complained of stiffness in the left hip after sitting for prolonged periods of time. He was a former smoker who had quit 3 years ago and his medical history included hypertension and dyslipidemia that were well controlled with medications, whereas other comorbidities remain benign.

His previous experience with pain management included conservative strategies including cortisone injections, heat pads and physical therapy, but without satisfactory clinical outcomes. He reported feelings of depression owing to his reduced mobility and pain. Medical examination revealed a positive Trendelenburg sign, as well as a positive Faber and FADIR sign. Lumbar spine stenosis excluded. Hip radiographic examination revealed right osteoarthritic degeneration Tonnis grade 4 (Fig. 6a).

Considering his comorbidities and lifestyle limiting hip pain, the patient was advised of a right hip total replacement. Risks, benefits and alternatives were extensively discussed with the patient and his family.

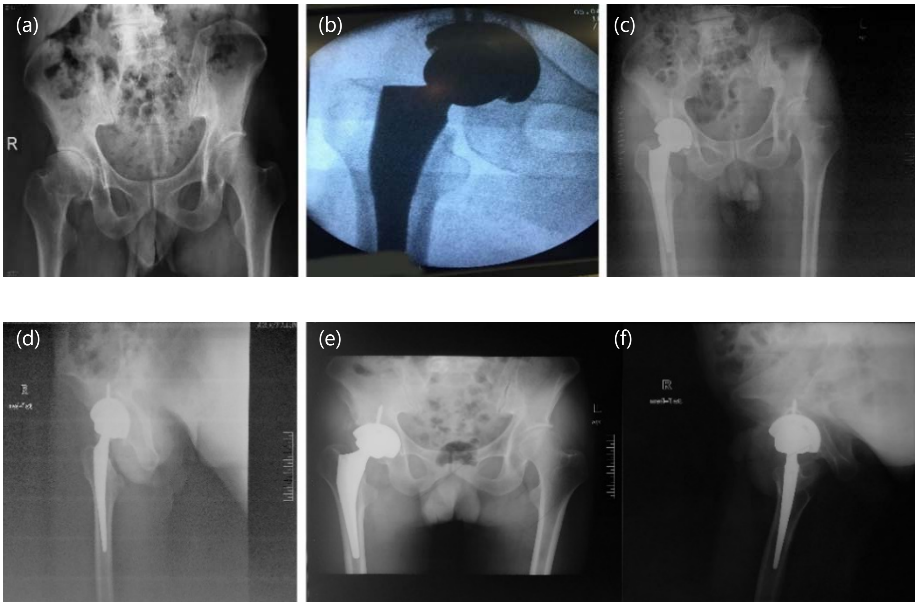

Fig. 6(a-f): Radiographs of a 53 years-old male patient with femoral head primary osteoarthritis of the right hip. (A) Preoperative plain radiograph of the pelvis, (b) Acetabular cup as viewed by c-arm, (c) Postoperative AP and (d) Med-lateral plain radiographs of the pelvis showing Total hip arthroplasty performed via direct anterior approach. Postoperative, (e) AP and (f) Med-lateral plain radiographs 3-months after the surgical procedure

He gave his full consent for the surgical procedure. A THA via DAA was performed on the patient, through a traditional longitudinal surgical incision. The stability of the acetabular cup was evaluated using a c-arm imaging system (Fig. 6b). Postoperative AP (Fig. 6c) and medial-lateral plain (Fig. 6d) radiographs of the pelvis demonstrate the successful completion of total hip arthroplasty using the direct anterior approach. The postoperative recovery and patient clinical outcomes were excellent. The patient was prescribed aspirin 325 mg BID for deep vein thrombosis prophylaxis. The 3 months following surgery, radiographic examination showed excellent clinical outcomes (Fig. 6e-f). The patient was able to walk unaided and pain-free.

This is a 78 years old Chinese male patient with ongoing left-sided hip pain for 4 years and difficulty walking for 2 years. He had difficulty squatting and sitting cross-legged. He came to our medical institution for treatment in 2015. He stated that he previously walked without difficulty and conservative management failed to achieve better clinical outcomes. He did not have any serious medical comorbidity. Radiographical examination results excluded spinal deformities but showed hip sclerotic lesions and bone spur formation at hip joint space (Fig. 7a). Concisely, he was diagnosed with primary hip osteoarthritis. He was counseled for permanent hip arthroplasty and scheduled for total hip replacement via a direct anterior approach. According to the surgical procedure, before prepping and draping the operative field, markings are made for the skin incision, outlining its position in relation to the anterior superior iliac spine (ASIS) and the tensor fascia lata (TFL) (Fig. 7b). A dissection was performed, the fascia was incised through "bikini" surgical incision (Fig. 7c) and the TFL was elevated. Afterward, range of motion was assessed post-total hip arthroplasty using the direct anterior approach, testing hip flexion at 90 degrees and both external and internal rotation (Fig. 7d). On the first postoperative day, an AP plain radiograph of the pelvis was taken, showing both hip joints with implants and no evidence of iatrogenic fracture (Fig. 7e). At 3 months postoperative, another AP plain radiograph was performed following total hip arthroplasty via direct anterior approach (DAA), exhibiting the excellent clinical outcomes of the surgical procedure (Fig. 7f).

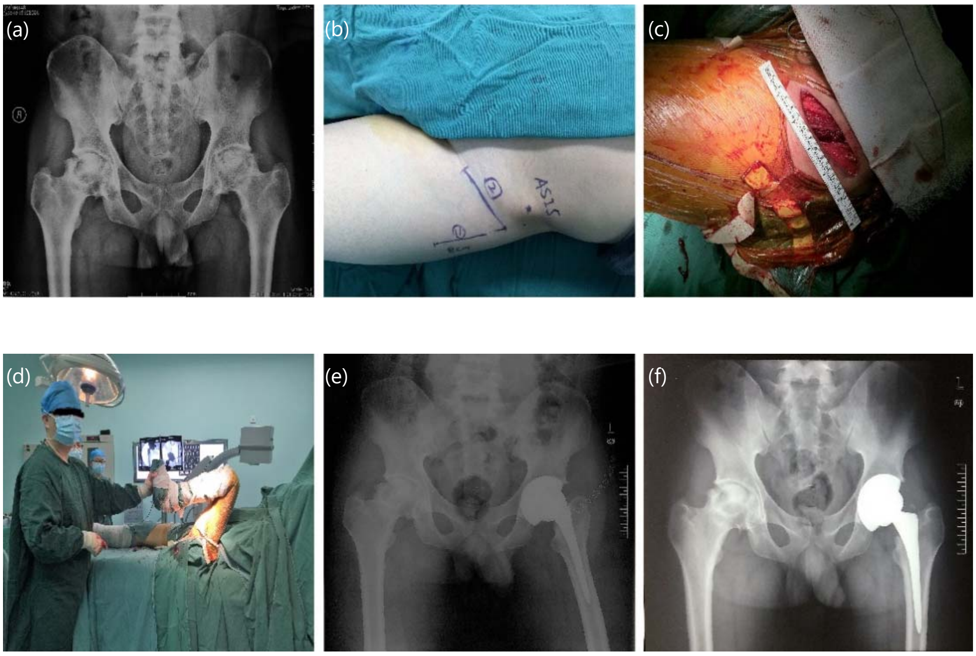

Fig. 7(a-f): Radiographs of a 78 years-old male patient with primary osteoarthritis of the left hip, (a) Before surgery, (b) Clinical photograph of the operative field seen before prepping and draping and demonstrating markings for the skin incision which is outline in relation to the anterior superior iliac spine (ASIS) and the tensor fascia lata (TFL), (c) Intraoperative photograph of the incised fasica of the TFL, (d) Intraoperatively range of hip motion testing, (e) Day-1 postoperative AP plain radiograph of pelvis with both the hip joints showing implant with no radiographic evidence of iatrogenic fracture and (f) 3-months postoperative AP plain radiograph after THA via DAA

Complications: Over the course of the hospital stay along with the follow-up period, no severe complications were recorded. However, one patient did experience nerve injury and two other patients experienced wound infections. The patient who experienced nerve injury had complete recovery over the course of the post-operative period. It did occur that the nerve might be stretched during the operation, which led to a noticeable weakness of the foot post-operatively. Although a spontaneous recovery occurred, the patient did use a foot support during the period of weakness. The two cases of wound infections were caused by *Staphylococcus aureus* and after treatment with proper antibiotics, patients had no sequelae.

DISCUSSION

There are several different approaches for THR and each of them has its own surgical and clinical advantages and disadvantages. Some purported advantages of the DAA are direct anterior's sparing of the abductor musculature and low rates of infection, dislocation and secondary surgery[6,32]. The DAA additionally facilitates single-stage bilateral procedure[5,33-35], eases the intraoperative manipulation of fluoroscopy[11,34] and is associated with a faster recovery[8,36].

In a prosthetic hip, impingement is both device- and surgeon-dependent. On one hand, the femoral head-neck ratio and features of acetabular design are influenced by the device-design factors and on another hand the surgeon controls implant position and the restoration of limb length and offset[37,38]. This dynamic process can limit hip joint range of motion, affect bone load and alter periprosthetic bone mineral density then increase loosening, thus affecting stability inducing prosthesis dislocation and finally producing poor clinical outcomes. Researchers have advocated that following acetabular component placement, it should be perpendicularly aligned in accordance with the femoral stem anteversion to obtain a safe zone line for combined anteversion[26-28].

Femoral anteversion refers to the normal femoral head and neck with respect to the anteversion of femoral shaft, the angle between the long axis and the frontal plane, usually measuring by the angle between the femoral neck axis and connecting between the femoral condyle midpoints[39,40]. The native femoral anteversion was defined as an angle between the femoral neck axis to the posterior condylar axis. The importance of correct stem anteversion and accurate component placement has been considered a prerequisite for successful THA as implant malposition directly influences postoperative stability, wear and aseptic loosening[41]. An adequate positioning of both acetabular and femoral components in a safe zone plays a pivotal role in order to achieve satisfactory anteversion[42-44]. Consequently current study focused on the posterior femoral neck osteotomy surface line as a surrogate determinant of correct stem anteversion to be deployed in DAA-THA.

Comparison outcome of THA surgical approaches to judgment of the correct stem anteversion: When using posterolateral approach in THA, the patient is positioned in a decubitus position and intra-operative stem anteversion is done by surgeons' visual assessment by referring tibia as a guide with an assumption that tibial axis is vertical to trans-epicondylar axis, due to popliteus fossa thick soft tissue, then the surgeon cannot judge accurate the posterior femoral condyle. However, the anteversion evaluation is always functional femoral anteversion and not a true native anteversion[40,41,45]. Similarly, other scholars suggested that the lesser trochanter could be set as a reference for femoral anteversion,[26,27] yet the lesser trochanter is measured about 34.1˚C±3.0 (100% mean data offset which is within 5° greater than femoral anteversion that is usually accepted).

Furthermore, as to posterolateral approach, the DAA is even more difficult to handle the stem prosthesis in a correct anteversion placement, for it is hard to elevate with full visualization of the proximal femur[46,47] along with its correct stem anteversion. Based on that aforementioned complexion, it is difficult to guarantee a true trans epicondyle line parallel to the floor. With an increased use of tables modern, DAA it is therefore hard for surgeons to determine the trans epicondylar line because of position setting. Based on such complexity upon setting the stem anteversion, as per our study we presume that the posterior cortical line is universally applicable osteotomy line to correct stem version to all THA approaches.

Landmarks and their limitations: There have been several studies suggesting reference lines for the determination of stem anteversion. Nevertheless, there are still some limitations[16,21,22]. Suh *et al.*[40] suggested the mid-cortical line as a reference for femoral anteversion, but the direction of mid-cortical line changed at different levels of sections because they just focused on axial CT sections study. Hence, not a true cutting surface can be directly observed intraoperatively. Later on, Tsukeoka *et al.*[30,31] found that the mid-cortical line is more inclined to retroversion. They used transverse line as a reference cutting surface to femoral anteversion and defined T-line as the line connecting trochanteric fossa and center of medial cortex of the femoral neck. They confirmed using the T-line as a reference guide which was apparently close to the native femoral neck anteversion. Still, it is difficult to judge the reference line when dealing with abnormality cases like developmental dysplasia of hip (DDH), because the cutting surfaces are not completely vertical, causing errors in bone cutting angle parameters[48].

Overall, these findings pave the way for having a general consensus and a universal applicable reference line to any approach to determine the correct native femoral anteversion. It relies on osteotomy surfaces and not refer to distal knee and/or femoral condyle. This might save surgeons time by not changing position intraoperatively and efficiently reducing possible contamination.

Measurements of the study: Using epicondylar axis measurements has been reported more accuracy than using a posterior condylar line at knee osteoarthritis. Nonetheless, in our study, no case of knee was studied. Therefore, a posterior line is proposed to be used. This might be easily accessible and determined by different researchers during radiography assessment.

Strengths of the study: To the best of current knowledge, little research has been conducted regarding the anatomical landmarks for anteversion of the femoral component. Suh *et al.*[40] reported that the midcortical line is compatible with the true femoral anteversion. However, findings from studies conducted by Tsukeoka *et al.*[30,31] demonstrated that the stem tended to retroversion when using the midcortical line on the cut surface of the femoral neck. They suggested that the potential explanation for this difference might be due to the reliability of the mid-cortical line measurements using different CT methodologies. Moreover, the former research team used the single CT method, while the latter team employed a 3D reconstruction method[30,31,40]. The lesser trochanter can be used to estimate the femoral anteversion of the femoral component intraoperatively. The version of the lesser trochanter was 34.1°±3.0° with 100% of the values differing from the mean by less than 5°. However, it is difficult to evaluate the version of the lesser trochanter using DAA technique. The method using the posterior cortical line on the cut surface provides a good reproduction of the native femoral anteversion during DAA-THA.

Very few studies were conducted on the accuracy of femoral component placement during a DAA-THA procedure based on the real oblique osteotomy surface. The present study analyzes the correlation strength and positive associations at different independent osteotomy heights and femoral neck cortical levels to posterior cortical line, while subsequently assessing hip postoperative clinical outcomes. It is worthy of note that utilizing posterior cortical line as a mark for cutting bone has a significant impact on native anteversion. Contrary to the transverse line, when the cutting is vertical it is difficult to achieve a normal femoral version during DAA-THA. One of the strengths of our study is that it statistically demonstrated the posterior cortical line as osteotomy reference was not affected by variations of cutting level parameters, regardless of vertical or axial osteotomy at stem anteversion. However, Floerkemeier *et al.*[48] and Moga *et al.*[49], independently suggested that the higher neck cutting parameters preserves natural anteversion, restore bone stock and could be beneficially used for short stem prosthesis. Despite this little evidence, we do not suggest the possible femoral neck landmark for correct osteotomy to achieve normal stem version. Therefore, interestingly our study provides a solution that a posterior cortical line could be applied for correct version reference to osteotomy. It is worth noting that among the strengths of our study is also fact that it includes a consecutive series of patients, who all followed the same preoperative and postoperative management protocol.

Limitations of the study: This study has several potential limitations. First, its retrospective design, small relative sample size and short follow-up period. Second, all the patients were of Han Chinese origin, making data unrepresentative of other ethnicities, as referred to natural anteversion of the femur. Third, a lack of comparison groups or cohorts using a different surgical approach and all procedures were done in a single institution. Nonetheless, this study has shown sound results of the THA via DAA and can provide potential practical and scientific guidelines for identifying the precise reference landmark on stem anteversion in DAA-THA. Concisely, further investigations with longer follow-up periods and with many more subgroup analyses are needed to assert these findings.

CONCLUSION

The posterior cortical line changes based on the femoral neck cut due to native femoral anti-torsion. So, the lower the cut, the lesser the femoral version and vice versa. This will greatly affect the stem version. It is worthy of note that although the posterior cortical line might be used as a rough guide for the femoral version, one should still aim for 5-15 degrees of stem anteversion to achieve appropriate combined anteversion. More research should be conducted to expand the height range of osteotomy to identify the effect of different osteotomy levels on the femoral version. There was no statistically significant difference between the two groups in the aspects of incision type and postoperative complication rates. The small sample size and the short follow-up period of the current study might also be considered influential factors, although we tend to design a robust study. This can also be considered among the shortcomings of the study. In summary, the posterior cortex line can be used as a simple, precise reference landmark during stem implantation in DAA-THA. Clinical application and the evaluation of the postoperative femoral anteversion should be further studied in clinical practice. In consideration of the limitations of this study, further randomized controlled trials with larger study samples are needed to extensively compare the clinical outcomes between the two groups.

SIGNIFICANCE STATEMENT

Osteoarthritis is characterized by chronic progressive cartilage degradation, osteophyte formation and synovial inflammation. The direct anterior approach for total hip arthroplasty enhances functional recovery and quality of life, yet research on femoral component anteversion landmarks is limited. Preoperative CT scans are crucial for accurate femoral anteversion assessment. Optimal stem anteversion is linked to implant stability, range of motion and impingement prevention. The quest to exploit a potential standard technique for predicting stem anteversion necessitated this study. This study examines femoral component placement accuracy using real oblique osteotomy surfaces in direct anterior hip replacement. The study analysis explores correlations between osteotomy heights, femoral neck cortical levels and postoperative outcomes, shedding light on effective hip arthroplasty practices.

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