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Original Research

Morphology of the Greater Trochanter: An Assessment of Anatomic Variation and Canal Overhang

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ABSTRACT

Background: Varus malposition is a risk of early failure in total hip arthroplasty. The degree to which the tip of the greater trochanter (GT) overhangs the canal can increase this risk. Although we know proximal femoral anatomy is variable, no study has addressed variations in medial overhang of the GT on plain radiographs.

Methods: All low anteroposterior pelvis radiographs more than 1 year were reviewed 3 times by 2 orthopaedic surgeons and one radiologist. The canal width (CW) was measured 10 cm below the lesser trochanter. Canal overhang (CO) was defined by the distance between the lateral medullary canal and a parallel line beginning at the most medial aspect of the GT. The overhang index (OI) is defined as the percentage of the canal overhung by the GT.

Results: The mean CW was 13.5 mm, mean CO 16.4 mm, and mean OI 1.22. Hips were then classified as the following: (A) OI < 0.5 (n = 8), (B) OI 0.5-1.0 (n = 78), (C) OI 1.0-1.5 (n = 191), and (D) OI > 1.5 (n = 68). Intraobserver reliability was excellent for all measures: 0.89 (confidence interval: 0.87-0.91) for CW, 0.96 (0.95-0.97) for CO, and 0.97 (0.97-0.98) for OI. Interobserver reliability was good for CW 0.75 (0.70-0.79) and excellent for CO 0.90 (0.88-0.92) and OI 0.95 (0.94-0.96).

Conclusions: Variations in the morphology of the proximal femur can predispose to varus component malposition. The degree to which the GT overhangs the canal can be quantified and classified based on plain films. This can aid in preoperative planning and help guide intraoperative proximal femoral preparation.

Introduction

Varus malposition of the femoral component in total hip arthroplasty (THA) is an accepted cause of early implant failure. In 1977, Carlsson et al. [1] documented 14 femoral stem fractures preceded by cement mantle loosening in Charnley low-friction implants, all placed in varus. Even as the implant design and fixation methods have improved, varus malposition has consistently been shown to lead to early failure [2,3]. In cemented prostheses, varus stems have a high rate of loosening, with as many as 50% of failures attributed to varus in some series [3]. The literature is less clear on the effects of varus alignment in cementless femoral components. Several studies demonstrate equivalent clinical outcomes and failure rates between neutral and varus-aligned stems. However, there exist no long-term, adequately powered studies assessing the varus position of cementless components [4-6]. It has been noted that varus-positioned cementless stems have a higher rate of stress shielding of the proximal femur, which could lead to long-term complications [7].

Varus malposition of the femoral component is a multifactorial problem that results from technical failures, poor stem selection,

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and anatomic variables. Murphy et al. [8] published a study of 200 hips attempting to determine what anatomic factors may lead to varus stem placement. They found that native hips with coxa vara had morphologic characteristics that predispose to varus stem placement. Medial overhang of the greater trochanter (GT), greater trochanteric height, greater femoral neck offset, and a lower canal flare index were all statistically significantly associated with varus stem placement.

Anatomic variations in proximal femoral morphology have been studied to varying degrees. Men have characteristically larger femoral head diameter, neck width, and radius of the GT [9]. Husmann et al. [10] classified the proximal femur based on the shape, size, and orientation of the intramedullary canal as a means of guiding stem selection for THA. Greater trochanteric height has been used as a landmark for setting the center of rotation of the femoral head but can lead to postoperative leg length inequality [11,12]. Morphologic variations in the GT also make it an unpredictable landmark for insertion of trochanteric entry femoral nails [13]. To this end, Grechenig et al. [14] developed a classification system based on the medial and anterior coverage of the piriformis fossa in the axial plane.

When preparing the femur, several techniques have been described to lateralize the entry point of the prosthesis, but the degree to which this should be performed remains a matter of experience and 'feel.' While there have been several cadaveric and radiographic studies of the proximal femur, to date, there is no literature assessing the variation in medial overhang of the GT across the population. Furthermore, there exists no clinically useful classification system to guide the preparation of the proximal femur in hip arthroplasty procedures. In this study, we aim to quantify and classify variations in medial overhang of the GT across the population. It is our hope that this will serve as an objective assessment to guide in the preparation of the proximal femur.

Material and methods

After obtaining exemption from the local institutional review board, we retrospectively reviewed sequentially obtained low anteroposterior (AP) pelvis radiographs more than a 1-year period (January 1, 2017-December 31, 2017) from the imaging database of a single-specialty orthopaedic group. All native hips in skeletally mature patients older than 30 years were included for initial review. Hips with proximal femoral or acetabular fractures or with implanted hardware were excluded. Films with poor technique were excluded as well. This included films with poor collimation of the image such that the lateral aspect of the GT is not visible, with less than 10 cm of the proximal femur visible, with insufficient penetration to accurately assess bony anatomy, or with positioning errors yielding nonstandard images. Most common positioning errors included asymmetric rotation of the femora typically due to foot positioning and rotation of the pelvis such that the coccyx was laterally deviated more than 0.5 cm from the center of the sacroiliac joint.

The technique used to obtain standing low AP pelvis films was modified from a technique described by Clohisy et al. [15] for supine AP pelvis films. Patients stand facing the source with their back against the cassette that is mounted on a locking holder. Their feet are positioned such that the lateral border of each foot is parallel to the beam using a grid on the floor. The source is then positioned 1.2 meters from the cassette, and the beam centered on the pubis and collimated shows the lateral border of the GTs bilaterally, the anterior superior iliac spine superiorly, and the proximal femur to isthmus distally. All films included a 24.5-mm radiopaque calibration sphere.

After exclusion, all films were read by 2 orthopaedic surgeons and one radiologist 3 times each separated by a minimum of 8 weeks, and measurements were made. Each provider was blinded to the reads of the other providers and their own prior reads. The canal diameter was measured at a point 10 cm distal to the apex of the lesser trochanter, and proximal femoral canal morphology was classified quantitatively and qualitatively based on the technique described by Dorr et al. [16]. Next, a novel method was used to measure the trochanteric overhang (Fig. 1). First a 4-cm line was drawn along the inner aspect of the lateral femoral cortex beginning 10 cm distal to the lesser trochanter and moving proximally. Next, a second line is drawn, parallel to the first, from the most medial aspect of the GT. The distance between the first and second lines is then measured. This represents the maximum linear overhang of the femoral intramedullary canal by the GT. We then calculated the overhang index (OI), defined as the ratio of the canal that is overhung by the GT relative to the diameter of the canal, for each femur. Finally, the distribution of OI values across the study population was evaluated to generate a clinically useful classification structure.

Data were analyzed using SPSS, version 24 (IBM, Armonk, NY). The canal width, canal overhang, and OI were continuous variables, and as such, intraobserver and interobserver reliability were determined using Pearson interclass correlation coefficient. The corresponding 95% confidence intervals (CIs) were calculated using the Fisher's Z transformation as Pearson's r values are not normally distributed. Pearson interclass correlation coefficients were interpreted such that values less than 0.20 deemed poor, 0.21 to 0.4 deemed fair, 0.41-0.60 deemed moderate, 0.61-80 deemed good, and 0.81-1.0 deemed excellent [17]. OI values were stratified into groups by the standard deviation from the mean.

Results

We initially identified 462 hips in 231 patients for review, and after exclusion, 345 hips in 202 patients were included in the study.

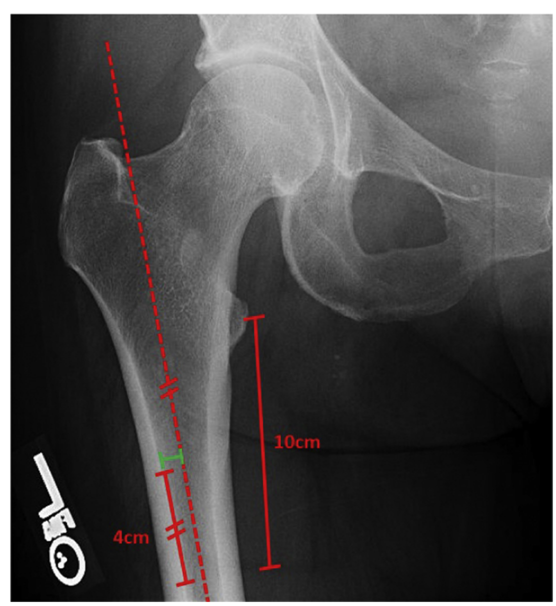

Figure 1. Technique for measuring the canal width and trochanteric overhang. The width of the diaphysis is first recorded at a point 10 cm below the lesser trochanter. Next, a line is drawn along the lateral cortex beginning at the canal width measurement and extending 4 cm proximally. A line tangential to this is drawn from the medial aspect of the greater trochanter. Finally, the distance between these 2 lines is measured.

Table 1
Mean Pearson correlation coefficients for intraobserver and interobserver reliability of the CW, CO, and OI with corresponding 95% confidence intervals.

Variable	Intrarater correlation coefficients			Combined
	1	2	3	
Canal width	0.86 (0.83-0.88)	0.91 (0.89-0.93)	0.90 (0.88-0.92)	0.89 (0.87-0.91)
Overhang	0.96 (0.95-0.96)	0.96 (0.95-0.91)	0.96 (0.95-0.97)	0.96 (0.95-0.97)
Overhang index	0.99 (0.98-0.99)	0.98 (0.97-0.98)	0.97 (0.97-0.98)	0.98 (0.97-0.98)
Variable	Inter-rater correlation coefficients			Combined
	1-2	1-3	2-3	
Canal width	0.82 (0.79-0.85)	0.79 (0.75-0.83)	0.63 (0.56-0.69)	0.75 (0.70-0.79)
Overhang	0.93 (0.92-0.95)	0.93 (0.91-0.94)	0.85 (0.82-0.88)	0.90 (0.88-0.92)
Overhang index	0.97 (0.96-0.98)	0.96 (0.95-0.97)	0.93 (0.91-0.94)	0.95 (0.94-0.96)

There were 223 (63.89%) hips classified as Dorr A, 113 (32.37%) as Dorr B, and 9 (2.57%) as Dorr C. The mean canal width was 13.5 mm (6.9-23.2 mm), and the mean trochanteric overhang was 16.4 mm (−6.2 to 32.1 mm). The OI was then calculated for each hip yielding a mean OI of 1.23 (−0.45 to 2.49).

When comparing sequential reads by the same provider, we found a mean intraobserver correlation coefficient for a canal width of 0.89 (CI: 0.87-0.91), for trochanteric overhang of 0.96 (CI: 0.95-0.97), and for the OI derived from these measurements of 0.98 (CI: 0.97-0.98). When comparing reads between different providers, we noted mean interobserver correlation coefficients for a canal width of 0.75 (CI: 0.70-0.79), trochanteric overhang of 0.90 (CI: 0.88-0.92), and OI of 0.95 (CI 0.94-0.96). Intraobserver correlation was classified as excellent for all measurements. Interobserver correlation was good for the canal width and excellent for canal overhang and OI (Table 1).

When plotted, the calculated OI values were distributed normally (Fig. 2). The mean OI was 1.23 with a standard deviation of 0.37. Stratification into groups based on the standard deviation is shown in Table 1. Although this structure is statistically sound, it is not subdivided in a way that is clinically useful. However, when divided into subgroups based on half femoral canal diameter, we generate a classification system that remains normally distributed and is much more clinically useful when assessing plain radiographs. There were 8 hips with an OI under 0.50, 78 hips with an OI between 0.50 and 1.0, 191 hips with an OI between 1.0 and 1.5, and 68 hips with an OI greater than 1.5 (Table 2).

Discussion

The purpose of this study is to better understand and quantify the anatomy of the GT. Specifically, the primary goal was to define the degree to which the GT overhangs the femoral diaphysis on plain radiographs and the degree to which this varies across the population. To this end, we developed the OI to express canal overhang in relation to the size of the canal. Interestingly, our data suggest that the GT extends medial to the isthmus in the average femur (mean OI: 1.23). We then stratified the hips into 4 groups based on trochanteric overhang in half canal diameter increments (Fig. 4). The measurements were then validated for intraobserver and interobserver reliability, which was excellent in all cases. When comparing subsequent reads by the same provider, the measurements were more consistent than when comparing reads by different providers, but this difference was small. In addition, the OI was more reliably reproducible than either the canal width or trochanteric overhang measurements individually. This suggests that any variation in individual measurements was not sufficient to alter the calculated relationship between the canal width and overhang.

Appropriate positioning of the femoral component in THA is necessary to achieve a functional and durable hip replacement. Varus malposition is one of the most common technical errors on the femoral side of the operation [2,3]. Placing the femoral component in varus tends to yield an undersized component

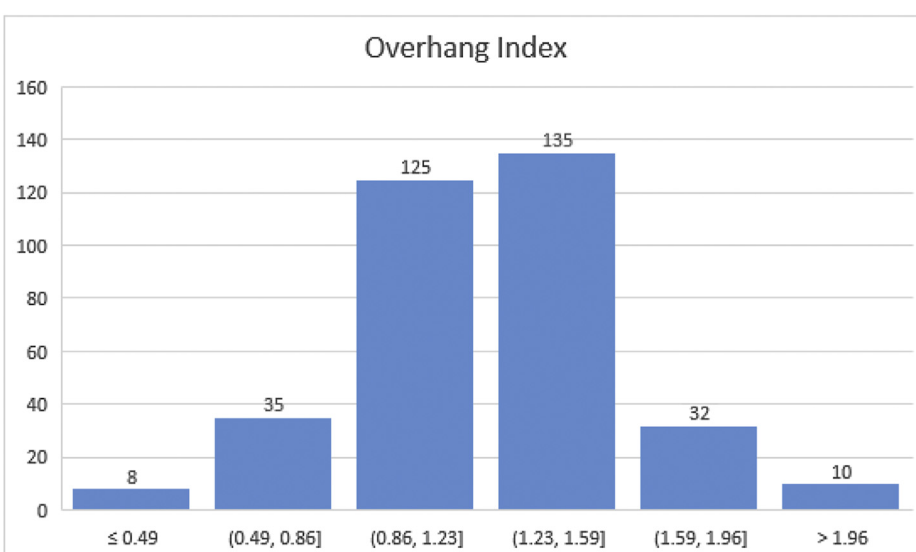

Figure 2. When stratified by the standard deviation, the calculated OI values are normally distributed with a mean of 1.23.

Table 2
Distribution of calculated OI values by the standard deviation (left) and a more clinically useful stratification by half canal diameter overhang.

OI distribution by the standard deviation		OI distribution by the canal diameter	
<0.49	N = 8	<0.50	N = 8
0.49-0.86	N = 35	0.50-1.00	N = 78
0.87-1.23	N = 125	1.01-1.50	N = 191
1.24-1.59	N = 135	>1.50	N = 66
1.60-1.96	N = 32		
>1.96	N = 10		

[4,5,8,10] (Fig. 4). Failing to adequately fill the canal or metaphysis places the patient at an increased risk for subsidence and periprosthetic fracture [18]. A stem implanted into varus is at risk of impaired longevity [1-3]. When using a cemented construct, varus malposition has been implicated in a cement mantle failure rate as high as 50% in some series [3]. Similarly, press-fit stems have a higher rate of subsidence, fibrous ingrowth, and aseptic loosening when placed in varus [4-6].

From a biomechanical standpoint, a femoral component placed in varus causes cantilever loading of the prosthesis, which alters stress distribution to the bone. Impacting a stem into a varus position, especially a stem with a coating that increases its thickness relative to its broaches, causes stress concentration at the medial calcar and lateral femoral cortex. This uneven loading of the femur during implantation has been implicated in acute intraoperative periprosthetic calcar fractures although there are insufficient data to definitively support this claim. Over time, this cantilever phenomenon can also point load the lateral cortex at the tip of the stem, causing decreased micromotion and increased lateral cortical hypertrophy because of an altered stress-strain relationship, which can be a cause of thigh pain [19]. The abnormal loading can also lead to proximal stress shielding [7].

Although not an unavoidable consequence of trochanteric overhang, failure to recognize and address increased overhang when preparing the femur can contribute to varus malposition (Fig. 3). A great deal has been written describing the anatomy of the proximal femur. This region has high morphologic variation between individuals, most notably the peritrochanteric region. Most recent anatomic studies of the GT have focused on understanding the entry point for antegrade intramedullary nailing. Grechenig et al. [14] evaluated 100 cadaveric specimens and noted substantial variation in the degree to which the tip of the GT projected medially and anteriorly. In this series, the piriformis fossa entry point would be completely covered in the cephalad direction by the GT in 25% of hips and partially covered in an additional 12%. Similarly, Farhang et al. [13] placed radiographic markers on the apex of the GT in 748 cadaveric femora before obtaining AP and true lateral fluoroscopic images of each femur. They noted substantial variation in morphology with a mean 7.1 mm of medial overhang and 5.1 mm of anterior overhang relative to the femoral diaphysis. Furthermore, rotating specimens based on anteversion to obtain perfectly orthogonal films did not significantly change radiographically apparent anterior and medial overhang.

Although these studies have focused on the reliability of radiographic landmarks in placing a cylindrical guide wire for intramedullary nailing, they illustrate the barrier to neutral canal preparation that the GT can create in the arthroplasty setting [13,14]. It is, therefore, necessary to understand and address the patient's anatomy when broaching. If an implant with a straight lateral shoulder is selected, care will need to be taken to remove sufficient bone from the trochanteric bed and potentially the tip of the trochanter to facilitate neutral stem placement. This can be accomplished by using a powered lateralizing reamer, rongeur, rasp, curettes, or the lateral aspect of the broach. Implants with a recessed lateral shoulder may avoid the need for excessive lateral bone removal. Calcar-guided short-stem designs follow the calcar and spare the trochanter entirely, allowing the surgeon to follow a curved path when inserting the broaches and stem [20]. In the setting of severe trochanteric overhang as often encountered in dysplastic hips, the GT can be osteotomized to facilitate implantation.

Although exposure of the femur is more technically demanding, utilization of the direct anterior approach may also facilitate stem insertion in patients with greater trochanteric overhang. When preparing the femur via a posterior approach in the lateral decubitus position, the GT lies atop the canal with the gluteus medius overlying it. This configuration can make it more challenging to adequately lateralize and can lead to abductor tendon injury. When

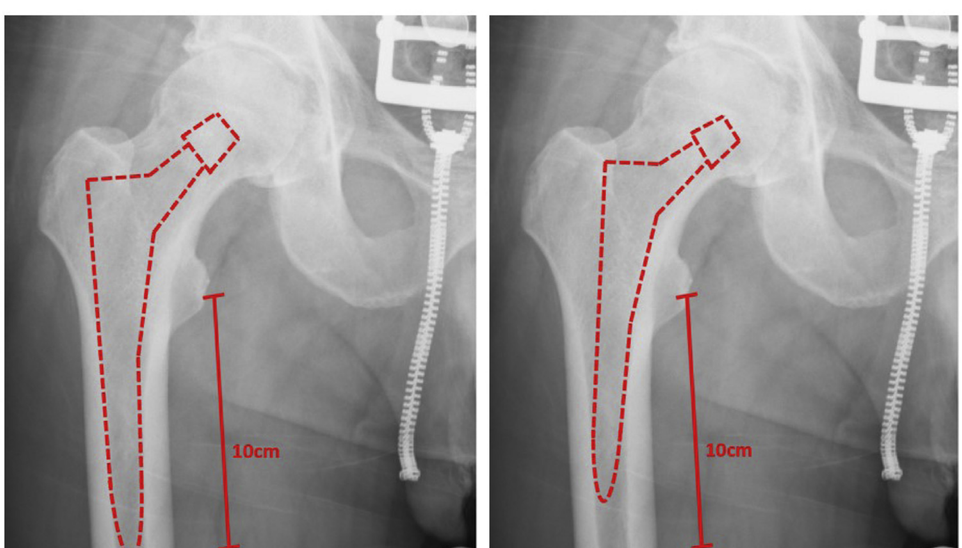

Figure 3. When preparing the proximal femur for arthroplasty, a higher overhang index predisposes to an undersized component placed in varus. Implant selection, trochanteric bed preparation, and intraoperative imaging can help mitigate this tendency.

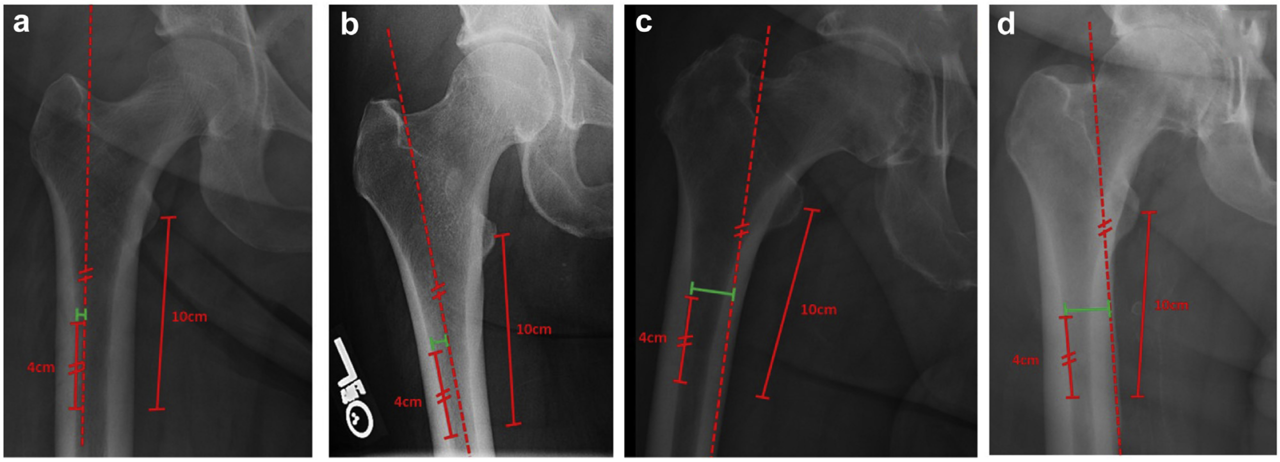

Figure 4. Examples of femora with an OI of a (<0.50), b (0.50-1.0), c (1.0-1.5), and d (>1.5).

performing a supine direct anterior approach, the femur is externally rotated, bringing the GT behind the femur, and the gluteus medius falls posteriorly away from the field, making removal of lateral bone stock easier and unobstructed by overhanging soft tissues.

The position of the GT can also affect the alignment of the stem in the axial plane. In those femora with high combined anterior and medial trochanteric overhang of the femoral canal in the axial plane, Grechenig groups 3 and 4, the broach will be pushed into a retroverted position [14]. The more the trochanter encroaches over the posterior lateral corner of the canal, the more the path of the broach is internally rotated, unless this overhanging bone is removed. If preparing for a component that relies on metaphyseal fixation, failure to address anteromedial overhang can lead to an eccentric preparation as the surgeon corrects the version after the broach clears the trochanter. Further study of cadaveric specimens or 3-dimensional imaging is needed before this effect can be quantified.

This study has several limitations. First, to have access to sequentially obtained low AP pelvis films complete with a magnification marker, we relied on preoperative templating films for arthroplasty patients. This biased our population toward an older mean age, and the hips included for review were predominantly arthritic. Despite using an older cohort of patients, the majority had qualitatively good femoral bone stock based on Dorr classification, with 64.63% of patients having Dorr A and 32.75% Dorr B proximal femora. Although these hips were arthritic, it is unlikely that this would substantially alter the measurements involved in this study. Furthermore, the purpose of this study is to guide femoral preparation for arthroplasty so these measurements would necessarily be made on arthritic hips in clinic practice. Prior morphologic studies have demonstrated increased femoral neck/shaft varus and offset and decreased mineralization of the proximal femur, but no changes in trochanteric overhang have been reported [21]. Nevertheless, we acknowledge that trochanteric osteophytes, enthesopathy, or peritrochanteric heterotopic bone formation may skew our measurements. In addition, as all measurements were based on plain radiographs, they are subject to technique- and positioning-related variability. In an attempt to mitigate rotational differences, we strictly monitored foot position when obtaining films. However, individual variations in tibial and femoral torsion, femoral anteversion, Q-angle, or limitations in range of motion secondary to arthrosis could yield films with the appearance of more trochanteric overhang than there is in reality because of posterior positioning of the GT. Plain films were chosen for this study as they are a normal part of preoperative workup for THA, making a measurement based on them more clinically useful than one based on 3-dimensional imaging. Additional research pairing plain films and computed tomography scans will be needed to validate these findings and account for rotational changes.

Conclusions

The anatomy of the proximal femur has been widely studied and is highly variable across the population. It is imperative for the arthroplasty surgeon to have a solid understanding of these anatomic variations as they can affect component positioning during hip replacement. In this study, we have quantified and classified the degree to which the GT overhangs the intramedullary canal of the femur on plain radiographs. When planning for a hip arthroplasty procedure, a better understanding of the morphology of the GT can aid in implant selection and femoral preparation. Measurement of trochanteric overhang could help minimize the risk of varus component malposition or periprosthetic fracture.

Conflict of interest

The authors declare there are no conflicts of interest.

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