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The Consistency and Reliability of the Innominate Tubercle as a Potential Landmark in Anterior Hip Arthroplasty: Anatomical Insights and Surgical Implications

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ABSTRACT

Introduction: The innominate tubercle (IT), a bony prominence at the anterior inter-trochanteric line of the femur, plays a crucial role as a surgical and radiological landmark in orthopaedics. Despite its clinical importance in intertrochanteric fracture classification and femoral osteotomy during hip arthroplasty, limited literature exists on its detailed anatomy.

Materials and methods: This study investigated the morphometric and relational characteristics of the IT in 47 adult dry femora (25 right, 22 left). Measurements included IT dimensions, distances from the IT to proximal femoral landmarks, and their correlations with femoral parameters. Pearson correlation coefficient and multivariate regression tests were utilised to find the relationship between these measurements.

Results: Revealed significant correlations between the IT length and width with key proximal femoral dimensions such as femoral head diameter, neck length, and femoral axis length. The IT height, however, showed no notable associations. The intersection of the anatomical axis of femur and the line in between the centre of head (COH) to the lateral-most point of vastus lateralis (VL) ridge was most consistent landmark for topographic localisation of the IT.

Conclusion: These findings underscore the IT's anatomical consistency and reliability as a surgical landmark, particularly in the direct anterior approach to hip arthroplasty. Our study highlights the need for broader, population-specific research to enhance localisation and clinical applications of the IT.

Keywords:
innominate tubercle, intertrochanteric fractures, anatomical landmarks, hip arthroplasty, direct anterior approach

INTRODUCTION

The bony prominence normally at the junction of the upper part of the femoral neck and the greater trochanter is referred to as the 'tubercle of the femur' or the innominate tubercle (IT)[1]. This anatomical landmark has also been described by different names, including the 'cervical tubercle,' 'superior cervical tubercle,' 'femoral tubercle,' 'innominate tubercle,' and 'third tubercle'[2-5]. This prominence lies along the anterior intertrochanteric line, and it also serves as an attachment for the iliofemoral ligament and part of the joint capsule of the hip[1].

Hsu *et al*, described IT as a critical landmark for determining the lateral wall thickness (LWT) of inter-trochanteric fractures[5]. LWT must be assessed to differentiate between the A1 and A2 groups of the 2018 AO/OTA (Orthopaedic and Trauma Association) classification system[6-8], which is critical for evaluating fracture stability and the selection of implants for internal fixation[9,10]. Its radiological localisation remains challenging as it is frequently involved in inter-trochanteric fractures due to the presence of fracture lines along the inter-trochanteric line. This predicament in calculating LWT has serious clinical implications as it can mislead the surgeon to choose the wrong implant for the fracture type leading to post-operative lateral wall fracture or screw cut out[11].

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Apart from this, IT has another relevance to orthopaedic surgeons as it can act as an important landmark for femoral osteotomy in patients undergoing hip arthroplasty using the direct anterior approach[12]. This is supported by the osteological analysis that the innominate tubercle maintains a constant position on the inter-trochanteric line, not significantly affected by changes in the femoral neck dimensions, age, gender, and height[13,14].

There is paucity of literature on this important anatomical landmark which not only serves as the proximal reference point for calculation of LWT but also acts as a beacon for femoral osteotomy in hip arthroplasty using the direct anterior approach[11,12].

While the anatomical morphology of IT offers a foundational map of structural differences, the true functional impact of these variations is governed by the principles of biomechanics. The human body often compensates for morphological differences through adaptive changes in movement patterns, joint mechanics, and muscular coordination. Therefore, this research contributes not only to anatomical understanding but also to functional biomechanics, with implications for clinical practice, prosthetic design, and rehabilitation strategies. With such a background, our study aimed to perform a detailed morphometric analysis of IT and to explore its possible correlations with proximal femoral parameters.

MATERIALS AND METHODS

We have investigated 47 adult dry femora (25 right, 22 left) acquired from the bone bank of Department of Anatomy. The morphology of upper end of these femora were investigated in detail to report the variability of IT in terms of their topographic locations, dimensions and correlations with other proximal femoral parameters. Intact, well-preserved adult (18 years and older) (femora with complete epiphyseal fusion) femora of both sides with identifiable anatomical landmarks were included in the study. Damaged or incomplete femora with broken or eroded anatomical landmarks, paediatric or immature bones, deformities that alter normal anatomy (specimens with evidence of surgical interventions) were excluded.

Sexing of the bones were done by measuring the neck-shaft angle (angle between the line through centre of the neck (neck axis) and the line through centre of the femoral shaft (femoral axis) (Fig. 1) (acute in males (average 125° – 130°) to support more weight and wider in females (average 135°) to accommodate a broader pelvis. On this basis, 70 were male and 30 were female. Bone specimens with altered proximal femoral anatomy due to fractures, damage or erosions were excluded from the study.

The neck-shaft angle was assessed using an analogue goniometer, while femoral length was determined with an osteometric board. Other measurements were taken using a digital vernier calliper with a precision of 0.001mm. All measurements were taken by the same orthopaedic trauma surgeon and repeated after a four-week interval. The mean of the two measurements were taken as the final value. To mitigate intra observer bias, the surgeon strictly adhered to the standardised measurement protocol, including consistent tools, positioning of the bone in the osteometric board, and measurement techniques. During the repeat measurement after four weeks, the surgeon did not have access to the previous measurements to prevent any subconscious influence.

A translucent goniometer with concentric circles was used to mark the centre of the femoral head (COH) as the centre of the best-fit circle and the anatomical axis of the femur was drawn by connecting mid-diaphyseal points along the femoral shaft at the junctions of the proximal, middle, and distal third of the femur. The borders and the most prominent point (MPP) of IT were marked by inspection and confirmed using palpation along the inter-trochanteric line. Following this, various morphometric measurements were taken.

Dimensions of IT were measured by placing the jaws of the vernier calliper at the superior and inferior borders for length, medial and lateral borders for width, whereas the height of the tubercle was measured using a pin gauge. Distances from the MPP of IT to the centre of the femoral head (COH), the lateral-most point of the vastus lateralis (VL) ridge, the tip of the greater trochanter (GT) and the calcar was measured along the intertrochanteric line in the frontal plane (Fig. 1). Distance of the MPP of IT to the line drawn between COH and the lateral-most point of the VL ridge, the point of intersection of the anatomical axis of femur passing through the piriformis fossa and the line drawn between COH and the lateral-most point of VL ridge were also measured in the frontal plane (Fig. 2).

To measure its length, the femur was first positioned horizontally, with its anterior side facing upwards and in the centre of the osteometric board and the distance between the superior-most point of the head to the distal-most point of the medial condyle was taken as femoral length. Neck length was measured as the distance from the medial border of inter-trochanteric line to the epiphyseal line along the mid-point of the femoral neck, whereas axis length was the distance from the base of the trochanter along the neck axis to the head of femur (Fig. 1).

Diameter of the femoral head was measured as the distance between the upper and lower ends of the femoral head along the cranio-caudal axis (Fig. 3), whereas femoral neck diameter was measured at the head-neck junction and at the mid portion of the neck along the cranio-caudal axis to

Table I: Table showing the mean, median, standard deviation, minimum and maximum values of the morphometric parameters under study (IT: innominate tubercle, MPP: most prominent point, COH; centre of head of femur; VL: vastus lateralis ridge, GT: greater trochanter; AA: anatomical axis).

Parameters	Side	Value (in cm) (Mean ± SD)	Range (in cm)
IT Length	Left	13.59 ± 2.14	10.50 – 20.20
	Right	13.28 ± 2.09	10.00 – 17.60
IT Width	Left	8.45 ± 1.52	5.60 – 11.20
	Right	7.66 ± 1.50	5.00 – 10.40
IT Height	Left	3.39 ± 1.00	1.40 – 5.30
	Right	3.31 ± 0.94	2.00 – 5.00
MPP of IT to COH of femur	Left	39.51 ± 4.68	30.50 – 46.80
	Right	40.90 ± 4.39	29.30 – 48.80
MPP of IT to VL ridge	Left	29.35 ± 4.22	23.00 – 37.50
	Right	31.07 ± 4.03	23.50 – 37.60
MPP of IT to tip of GT	Left	24.20 ± 3.81	19.00 – 32.50
	Right	25.07 ± 4.38	18.40 – 35.20
MPP of IT to calcar	Left	42.79 ± 5.34	32.30 – 54.50
	Right	43.49 ± 4.03	36.00 – 51.20
MPP of IT to line joining VL and COH	Left	2.35±0.60	1.60-3.50
	Right	2.56±0.40	1.80-3.40
MPP of IT to intersection of AA and line joining VL and COH	Left	3.24±0.42	2.30-4.00
	Right	3.16±0.42	2.40-4.00
Femur Length	Left	419.18±32.90	366.00-478.00
	Right	430.46±29.66	374.00-479.00
Neck Length	Left	27.44±4.50	16.80-33.70
	Right	27.52±4.47	16.80-34.20
Axis Length	Left	88.58±8.83	68.00-102.40
	Right	92.40±8.71	74.00-107.80
Neck-Shaft Angle	Left	128.56±6.04	118.00-137.00
	Right	130.15±5.64	119.20-139.00
Head Diameter	Left	42.43±4.72	33.20-50.70
	Right	45.08±4.05	38.00-54.00
Neck Diameter at Head-Neck junction	Left	30.26±3.63	24.80-39.50
	Right	31.82±2.70	26.00-34.70
Neck Diameter at mid-point of Neck	Left	37.91±3.35	22.00-33.00
	Right	29.50±2.63	24.10-33.30
Foveal Longitudinal Diameter	Left	14.35±3.04	8.00-18.60
	Right	15.18±2.77	10.20-20.00
Foveal Transverse Diameter	Left	10.62±3.04	6.10-16.80
	Right	10.24±2.36	5.10-15.00
Foveal Depth	Left	2.88±1.13	0.80-5.60
	Right	2.53±1.24	0.40-5.60

determine its minimum diameter (Fig. 3). The longitudinal and transverse diameters of the fovea were measured along the horizontal and vertical axis of the fovea respectively and depth of the fovea was measured using the backend of the Vernier calliper.

For statistical analysis, Data was tabulated in Microsoft Excel and evaluated using JASP version 0.18.3 (University of Amsterdam, Netherlands). Data was presented as mean, median, standard deviation and standard error. Pearson correlation coefficient and multivariate regression tests were performed to find the relationship between the dimensions of IT and other femoral parameters. Unpaired t-test was used to compare the morphological parameters between the femurs of the right and left sides. A p-value <0.05 was considered statistically significant.

RESULTS

The length, width, and height of IT were slightly greater on the left side compared to the right. Most distances from the MPP of IT to landmarks like COH, GT, and VL ridge were also greater on the right side. Femur-related dimensions, including neck-shaft angle and head diameter, varied slightly between sides (Table I).

IT length showed significant positive correlations with IT width, femur axis length, head diameter, neck diameters (both at the head-neck junction and mid-point), distances from MPP to COH, lateral-most point of VL ridge, GT, and calcar along the intertrochanteric line. IT width correlated positively with IT length and distances from MPP to GT and calcar. Distances from MPP of IT to COH, VL ridge, and other landmarks showed significant correlations with femur

Table II: Table showing the pairwise Pearsons correlation coefficient along with the p values and confidence intervals of morphometric parameters in the study. (IT: innominate tubercle, MPP: most prominent point, COH; centre of head of femur; VL: vastus lateralis ridge, GT: greater trochanter).

Measured Parameters	Measured parameters	Pearson's r	p-value	Lower 95% CI	Upper 95% CI
IT length	IT width	0.378	0.009	0.102	0.600
IT length	MPP of IT to COH of femur	0.470	< .001	0.212	0.667
IT length	MPP of IT to VL ridge	0.557	< .001	0.321	0.727
IT length	MPP of IT to tip of GT	0.420	0.003	0.151	0.631
IT length	MPP of IT to calcar	0.412	0.004	0.142	0.625
IT length	Axis Length	0.509	< .001	0.260	0.695
IT length	Head Diameter	0.555	< .001	0.319	0.727
IT length	Neck Diameter at Head-Neck Junction	0.404	0.005	0.132	0.619
IT length	Neck Diameter at mid-point of Neck	0.493	< .001	0.240	0.684
IT width	MPP of IT to tip of GT	0.311	0.034	0.026	0.549
IT width	MPP of IT to calcar	0.295	0.044	0.008	0.536
MPP of IT to COH of femur	MPP of IT to VL ridge	0.488	< .001	0.234	0.680
MPP of IT to COH of femur	MPP of IT to calcar	0.290	0.048	0.003	0.532
MPP of IT to COH of femur	Femur Length	0.630	< .001	0.418	0.777
MPP of IT to COH of femur	Neck Length	0.713	< .001	0.536	0.830
MPP of IT to COH of femur	Axis Length	0.884	< .001	0.800	0.934
MPP of IT to COH of femur	Head Diameter	0.747	< .001	0.585	0.851
MPP of IT to COH of femur	Neck Diameter at Head-Neck Junction	0.479	< .001	0.222	0.673
MPP of IT to COH of femur	Neck Diameter at mid-point of Neck	0.539	< .001	0.298	0.715
MPP of IT to COH of femur	Foveal Depth	-0.321	0.028	-0.557	-0.037
MPP of IT to VL ridge	MPP of IT to tip of GT	0.602	< .001	0.380	0.758
MPP of IT to VL ridge	MPP of IT to calcar	0.318	0.029	0.034	0.555
MPP of IT to VL ridge	Axis Length	0.594	< .001	0.369	0.752
MPP of IT to VL ridge	Head Diameter	0.647	< .001	0.442	0.788
MPP of IT to VL ridge	Neck Diameter at Head-Neck Junction	0.646	< .001	0.440	0.787
MPP of IT to VL ridge	Neck Diameter at mid-point of Neck	0.616	< .001	0.400	0.768
MPP of IT to tip of GT	MPP of IT to calcar	0.385	0.008	0.110	0.605
MPP of IT to tip of GT	Axis Length	0.465	< .001	0.206	0.664
MPP of IT to tip of GT	Head Diameter	0.521	< .001	0.275	0.703
MPP of IT to tip of GT	Neck Diameter at Head-Neck Junction	0.508	< .001	0.259	0.694
MPP of IT to tip of GT	Neck Diameter at mid-point of Neck	0.436	0.002	0.170	0.643
MPP of IT to calcar	Femur Length	0.380	0.008	0.105	0.602
MPP of IT to calcar	Axis Length	0.303	0.038	0.017	0.543
MPP of IT to calcar	Head Diameter	0.391	0.007	0.117	0.610
MPP of IT to calcar	Neck Diameter at Head-Neck Junction	0.367	0.011	0.089	0.592
MPP of IT to calcar	Neck Diameter at mid-point of Neck	0.411	0.004	0.140	0.624
Femur Length	Neck Length	0.417	0.004	0.148	0.629
Femur Length	Axis Length	0.669	< .001	0.473	0.802
Femur Length	Head Diameter	0.643	< .001	0.436	0.785
Femur Length	Neck Diameter at Head-Neck Junction	0.414	0.004	0.144	0.627
Femur Length	Neck Diameter at mid-point of Neck	0.541	< .001	0.301	0.717
Neck Length	Axis Length	0.578	< .001	0.349	0.742
Neck Length	Head Diameter	0.332	0.023	0.049	0.565
Neck Length	Foveal Depth	-0.314	0.032	-0.551	-0.029
Axis Length	Head Diameter	0.869	< .001	0.775	0.925
Axis Length	Neck Diameter at Head-Neck Junction	0.664	< .001	0.466	0.799
Axis Length	Neck Diameter at mid-point of Neck	0.674	< .001	0.479	0.805
Axis Length	Foveal Depth	-0.386	0.007	-0.606	-0.111
Head Diameter	Neck Diameter at Head-Neck Junction	0.785	< .001	0.642	0.875
Head Diameter	Neck Diameter at mid-point of Neck	0.867	< .001	0.772	0.924
Head Diameter	Side	0.295	0.044	0.008	0.536
Neck Diameter at Head-Neck Junction	Neck Diameter at mid-point of Neck	0.866	< .001	0.770	0.923
Foveal Longitudinal Diameter	Foveal Transverse Diameter	0.623	< .001	0.409	0.772
Foveal Longitudinal Diameter	Foveal Depth	0.304	0.038	0.019	0.544

Fig. 1: Dried left femoral bone specimen showing: (A) most prominent point of innominate tubercle, (B) tip of greater trochanter, (C) centre of femoral head, (D) calcar, (E) lateral-most point of vastus lateralis ridge, (F) midpoint of neck at head-neck junction, (G) midpoint of intertrochanteric crest, (H) medial-most point of femoral head along the neck axis, (I) base of trochanter along the neck axis.

Fig. 2: Dried left femoral bone specimen showing: AB – Line from the femoral head centre to the lateral-most point of the vastus lateralis ridge in the frontal plane, CD – anatomical axis of the femur through the piriformis fossa, E – most prominent point of the innominate tubercle, EF – Distance from E to the intersection of AB and CD, EG – distance from E to its closest point on AB.

Fig. 3: Dried cadaveric left femoral bone specimen showing: JK – diameter of femoral head, LM – diameter of femoral neck at the head-neck junction, NO – diameter of femoral neck at its mid-point.

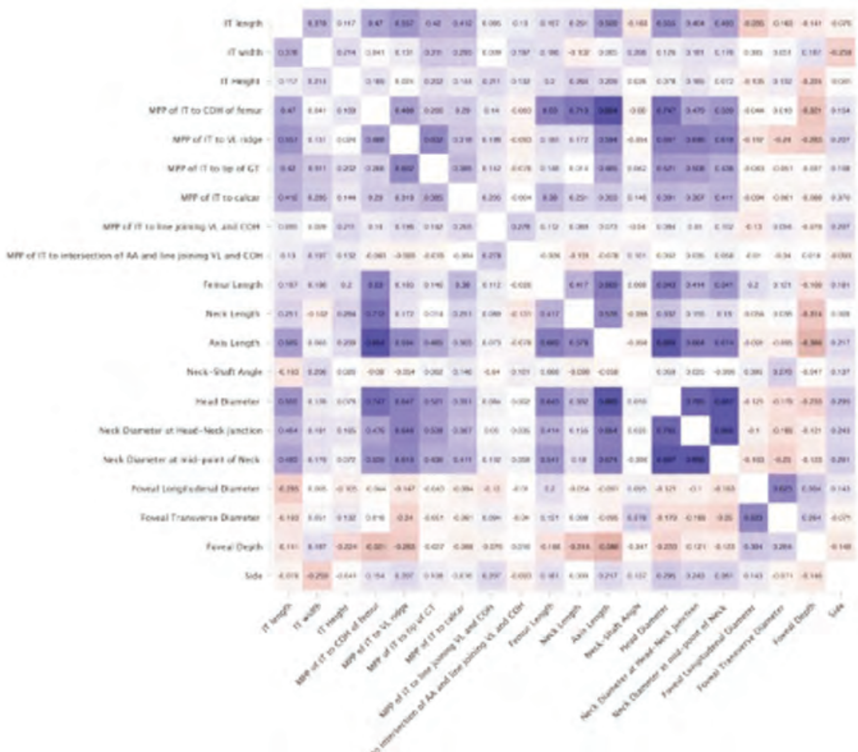

Fig. 4: Heat map showing the strength of correlations along with their significance (darker shades indicate more significance) between the various morphometric parameters in the study (IT: innominate tubercle, MPP: most prominent point, COH; centre of head of femur; VL: vastus lateralis ridge, GT: greater trochanter).

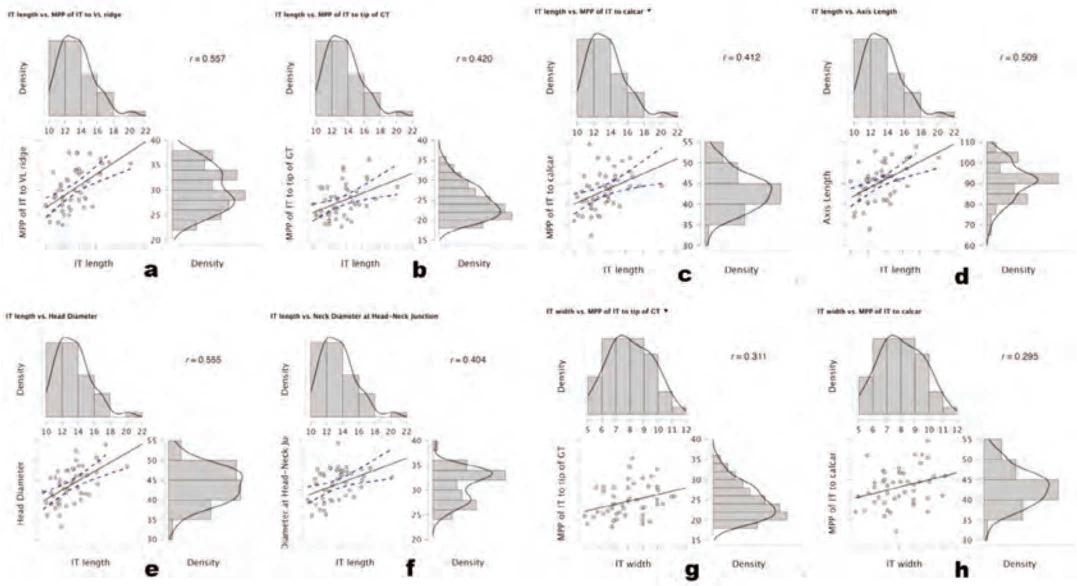

Fig. 5: Scatter plots with density graphs showing significant correlations between innominate tubercle (IT) dimensions and proximal femoral parameters: (a) IT length vs MPP-to-VL ridge distance, (b) IT length vs MPP-to-GT tip distance, (c) IT length vs MPP-to-calcar distance, (d) IT length vs axis length, (e) IT length vs head diameter, (f) IT length vs neck diameter at the head-neck junction, (g) IT width vs MPP-to-GT tip distance, (h) IT width vs MPP-to-calcar distance. (IT: innominate tubercle, MPP: most prominent point, COH; centre of head of femur; VL: vastus lateralis ridge, GT: greater trochanter).

dimensions, including axis length, head diameter, and neck diameters. Negative correlation was noted between MPP-to-COH distance and foveal depth. IT height: No significant correlations were observed (Table II). Fig. 4 provides a heat map illustrating correlation strengths.

Our results demonstrate the consistency of IT morphology and its strong correlation with neighbouring anatomical structures across a variety of variables for anterior approach. Its potential as a reliable intra-operative reference point is highlighted by its anatomical consistency for the anterior approach in hip replacement, especially in situations where traditional landmarks are obscured, like in obese patients or those with distorted anatomy.

DISCUSSION

The innominate tubercle (IT) has garnered increasing importance due to its clinical relevance in orthopaedics and radiology. Its role in classifying intertrochanteric fractures and serving as a navigational landmark during femoral neck osteotomy, particularly in the direct anterior approach, underscores its functional significance. Despite its broad application, the reliability of IT-based classifications has been inconsistent. Various studies[9-12] report only slight to moderate agreement in classifying intertrochanteric fractures, with subgroup analyses revealing even lower agreement. This variability is likely due to challenges in localising IT consistently. Thus, an accurate assessment of its anatomical location and its relationships with proximal femoral landmarks is critical for enhancing its utility in surgical procedures and imaging studies.

Prasad *et al* analysed 171 unpaired femora, concluding that IT prominence did not vary significantly with sex or laterality of the bone[12]. This finding was corroborated by Kielbasinski-Podlaszewska *et al*, who examined the IT's dimensions (length, width, and height) in 79 paired femora. Their results indicated no significant association between IT dimensions and variables such as sex, side of the femur, neck-shaft angle, neck length, or femoral length[13]. Similarly, Ward *et al* (2021) studied 195 femora, reinforcing the absence of significant sex- or side-based differences[14]. Our findings are consistent with previous studies, indicating that the position of the IT shows no significant variation based on sex or side. Consequently, the tubercle can be regarded as a dependable surgical landmark for arthroplasty procedures[15]. The mean IT dimensions in our analysis-length 13.42 ± 2.10mm, width 8 ± 1.54mm, and height 3.34 ± 0.96mm – are consistent with those reported by Kielbasinski-Podlaszewska *et al*[13]. Notably, IT prominence and its dimensions were not significantly influenced by femoral length, neck-shaft angle, or neck length.

The current study offers a comprehensive morphometric analysis of the innominate tubercle (IT) and its correlations with proximal femoral parameters, thus providing valuable insights into its anatomical and clinical relevance. Significant associations were identified between IT length and critical proximal femoral parameters, including the diameter of the femoral head, femoral axis length, and femoral neck diameter at the head-neck junction (Fig. 5). In addition, the distance from the MPP of the IT to the other anatomical landmarks including the COH, GT, the lateral-most point of the VL ridge, and calcar along the intertrochanteric line increases the functional relevance of IT. These findings are also consistent with previous reports that focused on the stability of the IT as an anatomical landmark[16,17].

Interestingly, IT width demonstrated similar correlations with proximal femoral dimensions, whereas no important associations were found between IT height and the considered features. The average distance of 40.25 ± 4.53mm between the MPP of the IT and the COH exhibited strong positive correlations with the axis length, neck length, and head diameter; this, in turn increases its validity as a point of reference for both clinical and radiological purposes[18].

Clinically, IT plays an important role in orthopaedic surgery and radiology. In total hip arthroplasty and intertrochanteric fracture fixation, it is a trustworthy landmark in ensuring the alignment of prosthetic parts and in screw positioning. Moreover, because it has constant anatomical relations with other landmarks in the proximal femur, it can also be of value in radiologic studies especially in fracture patterns and in planning for surgical approaches[10]. These findings underscore the importance of IT not only as a structural element of the proximal femur but also as a critical landmark for improving surgical accuracy and outcome. Further studies on the biomechanical relevance of IT and its application across different populations may further improve its clinical usefulness.

The IT is a secondary ossification centre that appears in late foetal life and continues its development postnatally while the proximal femoral morphology is sculpted by biomechanical forces and weight-bearing activities. Thus, development of the IT is affected by attachments such as that from the iliopsoas, and from the vastus lateralis to make it peculiar in the sense that it stands out as a palpable and a radiologically identifiable feature[1].

Morphological features of the proximal femoral epiphysis are significant in anthropology, forensic sciences, and clinical studies. Length and total stature of long bones bear a relation with ethnicity, genetic inheritance, climatic conditions, and nutrition. The measurement of the proximal femur is specifically helpful in estimating the length of the femur in subjects related to physical anthropology, forensic identification, and medical jurisprudence[12]. The femoral neck angle (FNA) is absent at birth and progresses with growth[2]. Its maturation is associated with upright posture and walking, attaining stable values by around eight years of age. This process closely correlates with the individual's age and femoral length[18]. Notably, the development of FNA is impacted in cases of reduced or absent weight-bearing during growth, such as in children with congenital hip dysplasia[19,20]. Although its importance as a landmark for the direct anterior approach (DAA) in hip arthroplasty is growing, the innominate tubercle remains underrepresented in textbooks and research[21,22]. In the article by Kielbasinski-Podlaszewska *et al* (2017), IT was described as a "lighthouse", aiding in precise femoral neck cuts and minimising soft tissue disruption during osteotomy[13]. The limited studies on IT in South Asian populations underscore the necessity for region-specific research to better understand anatomical variations and improve localisation across diverse patient groups[23,24].

While biomechanical comparisons with other anatomical landmarks could offer further insights, our findings lay the groundwork for future investigations that could incorporate biomechanical modelling or cadaveric testing to validate the functional significance of IT in surgical settings, particularly in comparison with conventional landmarks.

Although our study provides valuable insights into the anatomical relationships of IT, certain limitations must be acknowledged. Use of unpaired femora precluded age and gender determination, which could affect anatomical interpretations. Limited sample size may not capture the full spectrum of variability across populations. Future studies should incorporate larger, diverse cohorts and advanced imaging modalities to explore its role further. Moreover, dynamic studies assessing IT's function during movement could elucidate its biomechanical significance.

CONCLUSION

The findings of the study underscore the IT's anatomical consistency and reliability as a surgical landmark, particularly in the direct anterior approach to hip arthroplasty. Our findings provide novel evidence supporting the IT's operative relevance for the anterior approach in hip arthroplasty. This adds a new dimension to surgical anatomy by proposing the IT as a practical intra-operative guide where other landmarks may be less accessible. By improving our understanding of its morphological and clinical relationships, this study contributes to refining surgical techniques and enhancing radiological interpretations in hip pathology.

CONFLICT OF INTEREST

Authors declare no potential conflict of interest.

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