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PMCT-based sex determination using posterior segment of greater sciatic notch in North Indian population

Ruchi Kumari[1], Jay Narayan Pandit[2*], Surya Kiran Panga[1], Swati Tyagi[1], Abhishek Yadav[1] and Sudhir Kumar Gupta[1]

Abstract

Background Digital tools, which offer superior accuracy compared to manual metrics, utilize radiological images for noninvasive data collection, providing a convenient means of obtaining skeletal data. The greater sciatic notch exhibits high sexual dimorphism and resistance to damage, and therefore serves as a viable tool for sex determination in poorly preserved skeletons, particularly in scenarios involving mass disasters, highly putrefied, and skeletonized cases. In addition to the width and depth of the greater sciatic notch, the length and angle of the posterior segment are highly specific parameters. This study aims to obtain accurate and standardized values for determining sex by measuring the posterior segment of the greater sciatic notch using postmortem computed tomography with a 16-slice multidetector row computed tomography scanner.

Results The study revealed that except for depth and the distance between the ischial spine and deepest point, all measured variables of the greater sciatic notch were greater for women than men on both sides. The length of the posterior segment and the posterior angle on both sides showed the highest positive correlation and provided highly significant differences between males and females. These findings not only reinforce the utility of the greater sciatic notch in sex determination but also highlight the potential for more accurate and noninvasive methods in forensic investigations.

Conclusions Postmortem computed tomography accurately determines sex by measuring the posterior sciatic notch segment, achieving a 90.9% accuracy rate. This study, the first of its kind in India, utilized postmortem computed tomography ruler measurements for sex determination, specifically evaluating the role of the posterior segment dimensions of the greater sciatic notch in the North Indian population.

Keywords Postmortem computed tomography, Sex determination, Anthropometric measurement, Greater sciatic notch

Background

Sex determination from skeletal remains is a crucial and challenging task in medicolegal cases (Soltani et al. 2018). However, the skeleton holds the greatest value for sexing in very old or dismembered bodies, as it is the second last, and the enamel of the tooth is the last part of the body to decompose after death (Raut et al. 2013). Almost all bones of the body exhibit some degree of sexual dimorphism (Deshmukh and Devershi 2006). The pelvic and skull bones are considered most useful in

*Correspondence:
Jay Narayan Pandit
jaynarayan59@gmail.com
[1] Department of Forensic Medicine & Toxicology, All India Institute of Medical Sciences, New Delhi 110029, India
[2] Department of Forensic Medicine & Toxicology, Katihar Medical College, Katihar, Bihar 854106, India

determining an individual's sex, and in the presence of both bones, about 98% accuracy can be achieved (Krogman 1973).

In the pelvis, the greater sciatic notch (GSN) is highly sexually dimorphic and resistant to damage, making it useful even in poorly preserved skeletons (Raut et al. 2013; Philip and Walker. 2005). Various methods, including visual examination, anthropometric measurements, X-ray examination, and microscopic examination, are employed for sex determination from skeletal remains (Soltani et al. 2018; Dnyanesh et al. 2013). With the emergence of digital autopsy worldwide, postmortem computed tomography (PMCT) stands out as a perfect instrument, offering more advantages than other methods due to its rapid functioning, high-level detailing of bones, and, importantly, the avoidance of the need to remove soft tissues, preventing damage from physical manipulation (Soltani et al. 2018; Decker et al. 2011).

Apart from the width and depth of GSN, the length and angle of the posterior segment are highly specific parameters suggested by various studies (Soltani et al. 2018; Raut et al. 2013; Kim et al. 2018). However, many of these studies using PMCT were conducted outside India, and those done in India were primarily morphometric. Furthermore, several studies had unequal sample size distribution for both sexes. This study, the first of its kind in India, utilized PMCT digital ruler measurements for sex determination, specifically evaluating the role of GSN and pelvic dimensions in the North Indian population. The aim is to contribute standard values for the determination of sex.

Methods

Study design and participants

This is a prospective cross-sectional study with a sample size of 408 cases, comprising approximately an equal number of both sexes across different age groups. As part of a research project conducted at the Centre for Advanced Research and Excellence, these individuals underwent PMCT prior to a conventional autopsy. The study received prior approval from the Institutional Ethics Committee and was carried out between September 2021 and January 2023 at AIIMS, New Delhi, as part of the autopsy examination process.

Inclusion and exclusion criteria

In this prospective study, individuals of both sexes aged 10 years and above, who underwent postmortem computed tomography (PMCT) during the study period, were included. This inclusion criteria were established considering the presence of sexual dimorphism in the juvenile age group too (Schutkowski 1993; Sutter 2003). Those under the age of 10 years were excluded due to underdeveloped GSN. Deceased individuals with unknown age, severe pelvic injuries of any kind, or those with deformed/malformed bones or congenital abnormalities were also excluded from the study.

Procedure followed for data collection

After conducting whole-body PMCT using a 16-slice multidetector row CT scanner (Canon Medical System Aquilion Lightning TSX-035A), image acquisition was performed through volumetric spiral scanning with a detector collimation of 1.0-mm thickness, facilitated by Vitrea software (Version 6.9.2). The volume-rendered 3D images of the hip bones for all included individuals were analyzed. Landmarks, including the posterior inferior iliac spine (point A), ischial spine (point B), and deepest point of the GSN (point C) on both sides, were identified, as described below and illustrated in Fig. 1.

Identification of landmarks

Incorporating Kim's methodology (Kim et al. 2018) at the outset, our study employs a meticulous approach to examine GSN dimensions within the intact bony pelvis by 3D volume rendering image of PMCT. The 3D image of the pelvic bone is viewed from the posterolateral side and rotated such an extent to visualize the GSN for each side sequentially. Landmarks labelled as A, B, and C (representing the tip of the posterior inferior iliac spine (PIIS), the tip of the ischial spine, and the approximate midpoint of the GSN's deepest point, respectively) guide the precise drawing of straight lines (AB, AC, BC) using the Vitrea software's ruler tool, known for its accurate calibration. Special attention is given to precision, especially concerning the small and specific PIIS and ischial spine tips. Notably, identifying point C, representing the midpoint of the GSN's deepest point, requires additional care. Post-landmark identification, the rotation of the 3D rendering does not introduce measurement variations, contributing to the overall comprehensiveness and reliability of our approach.

All measurements were collected by two observers, and a set of 40 randomly chosen samples underwent measurement by both observers at various intervals. The analysis of intra- and inter-observer variations, quantified through Cohen's kappa value within the range of 41.3 to 64.6% ($p < 0.001$), underscores the reliability and repeatability of the measurements, thereby ensuring the accuracy of GSN dimension assessments in the intact bony pelvis (details of intra- and inter-observer variation are provided in Supplementary material as Table 1).

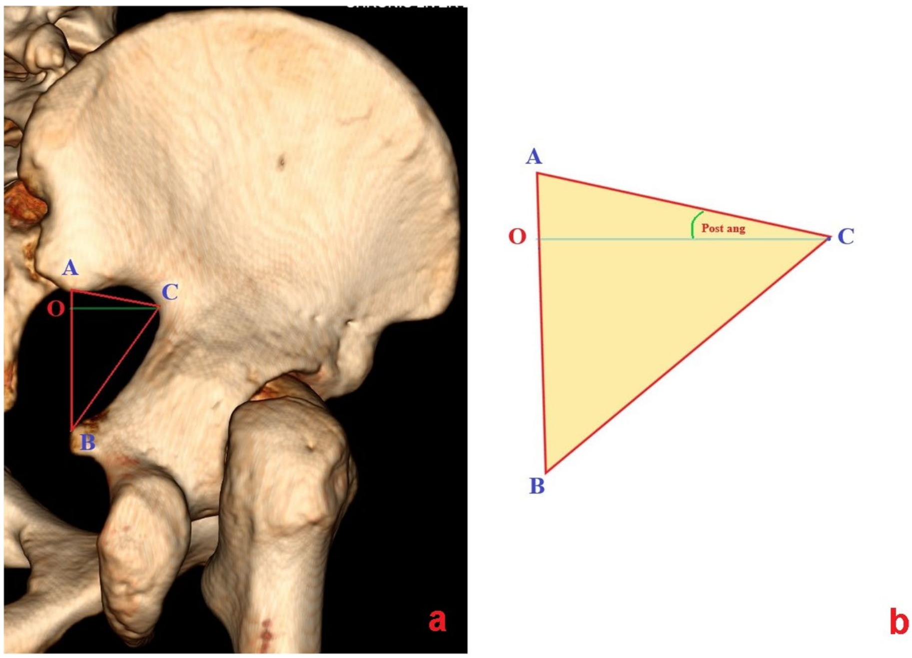

Fig. 1 **a** PMCT 3D image of greater sciatic notch with landmarks. Point "A" is posterior uppermost prominent point of GSN (posterior inferior iliac spine), point "B" is anterior lowermost prominent point of GSN (ischial spine), and point "C" is deepest point of GSN. A perpendicular line was drawn on the imaginary line between A and B to determine the depth of GSN (OC) and posterior segment length (AO) from the triangle ABC and angle of posterior segment (OCA) calculated. **b** 2D representation of 3D image of GSN

Subsequently, these measurements were entered into a Microsoft Excel sheet, and various parameters were automatically determined using simple trigonometric formulas.

Formula used:
AB = a, BC = b, AC = c
$S = \frac{a+b+c}{2}$, *where* S = semiperimeter of the triangle ABC.
Area of ABC obtained by Heron's formula.
ABC (Ar) = $\sqrt{S(S-a)(S-b)(S-c)}$
Also, area of triangle ABC (Ar) = ½ x AB x OC
Now, from triangle AOC
$AO^2 + OC^2 = AC^2$
AO = Length of posterior segment (Psl)
And angle of ACO (Post ang) $\tan\theta = \frac{AO}{OC}$

Parameters used for sex determination:
ABR: Width of GSN (distance between point A and point B) of right side
ABL: Width of GSN (distance between point A and point B) of left side
BCR: Distance between point B and point C of right side
BCL: Distance between point B and point C of left side
ACR: Distance between point A and point C of right side
ACL: Distance between point A and point C of left side
Ar R: Area of GSN (ABC) of right side
Ar L: Area of GSN (ABC) of left side
Depth R: Distance between point O and point C of right side
Depth L: Distance between point O and point C of left side
Psl R: Posterior segment length (AO) of right side
Psl L: Posterior segment length (AO) of left side
Post ang R: Posterior angle (OCA) of right side
Post ang L: Posterior angle (OCA) of left side

Statistics
We utilized IBM SPSS Statistics Version 25 software to analyze the data. Descriptive statistics, such as mean and standard deviation, were computed. Comparisons were conducted using independent *t*-tests, paired *t*-tests, and linear discriminant analysis. Statistical significance was defined as a p-value < 0.001 for high significance and < 0.05 for significance.

Results
Among the 408 samples studied, males accounted for 210 (51.5%), and females comprised 198 (48.5%). The mean age was 38.11 ± 16.83 years. The distribution of individuals based on age in our study is as follows: 8 individuals were under the age of 18 years, 32 were between 18 and 25 years old, 117 were between 26 and 35 years old, 72 were between 36 and 45 years old, 86 were between 46 and 55 years old, 45 were between 56 and 65 years old, 25 were between 66 and 75 years old, and 23 were above the age of 75. Correlations of all parameters with age were examined using Pearson's correlation coefficient test. No significant difference was found between age and any of the GSN parameters in men (p-value > 0.05). However, a significant correlation was observed for ABR ($r = 142$, $p = 0.046$), ABL ($r = 140$, $p = 0.049$), BCR ($r = 0.168$, $r = 0.018$), Ar R ($r = -0.144$, $p = 0.043$), Ar L ($r = 0.188$,

$p=0.008$), and Depth of the left side ($r=0.168$, $p=0.018$), and highly significant correlation was found for BCL ($r=0.256$, $p<0.001$) with age in women (as shown in Supplementary material as Table 2). With the exception of the depth and distance between the ischial spine and deepest point of the GSN (BC), all measured variables were greater for women than men. All variables exhibited highly significant differences (p-value < 0.001) for both sexes, except for the depth of the GSN on the right side, whose value was significantly different (p-value < 0.05), as shown in Table 1.

No significant difference was observed between the two sides for the same variables (p-value > 0.05), except for the width (AB) of the GSN (p-value < 0.05), which was higher on the right side, as indicated in Table 2.

The discriminant model achieved a positive prediction of 91.4% for males and 90.4% for females, as presented in Table 3.

The highest positive correlation was observed between the length of the posterior segment (AO) and the posterior angle (OCA) on the left side, followed by the correlation between the length of the posterior segment and

Table 1 Comparison of different measurements of GSN in both sex

Measurements	Male		Female			
	Mean	SD	Mean	SD	*t*	*P**
ABR	46.21	4.60	53.08	5.70	− 13.43	< 0.001
BCR	49.10	3.94	45.20	3.86	10.09	< 0.001
ACR	33.31	5.68	36.72	6.62	− 5.59	< 0.001
Ar R	733.03	142.76	810.27	166.67	− 5.04	< 0.001
Depth R	31.62	4.63	30.34	4.14	2.94	**< 0.05**
Psl R	9.42	5.62	20.04	7.26	− 16.57	< 0.001
Post ang R	15.70	7.82	32.36	8.34	− 20.83	< 0.001
ABL	46.04	4.61	52.72	5.63	− 13.15	< 0.001
BCL	49.22	4.23	44.93	4.07	10.43	< 0.001
ACL	33.51	5.67	36.58	6.37	− 5.15	< 0.001
Ar L	734.67	140.77	801.72	160.63	4.49	< 0.001
Depth L	31.83	4.63	30.23	3.95	3.74	< 0.001
Psl L	9.48	5.56	19.93	7.24	− 16.41	< 0.001
Post ang L	15.74	7.70	32.21	8.82	− 20.12	< 0.001

* p-value < 0.001 is considered as highly significant, and p-value < 0.05 is significant

Table 2 Correlation of different GSN parameters in right and left side

Parameters	Total			Male			Female		
	Mean	SD	*p*-value	Mean	SD	*p*-value	Mean	SD	*p*-value
ABR	49.54	6.20	**0.030**	46.21	4.60	0.303	53.08	5.70	**0.041**
ABL	49.28	6.11		46.04	4.61		52.72	5.63	
BCR	47.20	4.36	0.572	49.10	3.94	0.456	45.20	3.86	0.133
BCL	47.13	4.67		49.22	4.23		44.93	4.07	
ACR	34.96	6.38	0.793	33.31	5.68	0.314	36.72	6.62	0.527
ACL	35.00	6.20		33.51	5.67		36.58	6.37	
Ar R	770.51	159.39	0.349	733.03	142.76	0.733	810.27	166.67	0.101
Ar L	767.21	154.25		734.67	140.77		801.72	160.63	
Depth R	31.00	4.44	0.682	31.62	4.63	0.248	30.34	4.14	0.497
Depth L	31.05	4.38		31.83	4.63		30.23	3.95	
Psl R	14.58	8.37	0.887	9.42	5.62	0.787	20.04	7.26	0.657
Psl L	14.55	8.28		9.48	5.56		19.93	7.24	
Post ang R	23.79	11.60	0.811	15.70	7.82	0.913	32.36	8.34	0.644
Post ang L	23.73	11.66		15.74	7.70		32.21	8.82	

Table 3 Predictive performance of linear discriminant model in terms of the right variables

		Predicted sex	
		Male *N* (%)	**Female *N* (%)**
Original	Male	192 (91.4))	18 (8.6)
	Female	19 (9.6)	179 (90.4)
Cross-validated	Male	190 (90.5)	20 (9.5)
	Female	19 (9.6)	179 (90.4)

90.9% of original grouped cases correctly classified. 90.4% of cross-validated grouped cases correctly classified

the posterior angle on the right side. The lowest correlation was noted between the distance between the ischial spine and deepest point (BC) and the posterior angle of the GSN on the left side, as shown in Table 4.

Discussion

PMCT has emerged as a valuable tool in forensic medicine, leveraging 3D images for advanced anthropometric measurements. This approach not only saves time but also minimizes hazards to anthropologists during the examination of decomposing tissue, reducing damage associated with manual specimen handling (Soltani et al. 2018; Decker et al. 2011).

The study proved that this was an effective and accurate alternative over manual metrics, utilizing radiological images for noninvasive data collection and providing a convenient means of obtaining skeletal data. Given the complex morphological and metrical variations within the human body, especially between sexes and individuals of the same sex, adopting unequivocal criteria is vital to prevent subjective bias. The GSN stands out as a useful parameter for sex determination (Soltani et al. 2018; Philip and Walker. 2005; Bytheway and Ross 2010; Pretorius et al. 2006).

This study aims to establish a robust criterion for sex differentiation by utilizing various parameters of the GSN, as demarcated in 3D images obtained through PMCT. A comprehensive comparison of our findings with data from different studies is presented in Table 5. Notably, there is currently no study available for the Indian population that focuses on sex determination using the GSN with a 3D model. However, a study based on dry bones indicated slightly smaller values for the posterior segment length and angle, emphasizing a significant difference between males and females. While not directly comparable to the Indian population, studies conducted on the Iranian and Korean populations, utilizing 3D models of the GSN, are available in journals. Examination of 3D images in relation to the Iranian population demonstrated comparable outcomes (Soltani et al. 2018). In contrast, when compared to the Korean population, it revealed reduced values for both the length of the posterior segment and the posterior angle of the GSN, possibly due to different ethnicity (Kim et al. 2018).

We considered seven parameters obtained directly and indirectly from GSN on both sides. Consistent with previous research, width (AB), posterior segment length (AO), posterior angle (OAC), area (ABC), and distance between posterior inferior iliac spine and deepest point (AC) of GSN were greater in women ($p < 0.001$ on both sides). Conversely, depth (OC) ($p < 0.05$ on the right side and $p < 0.001$ on the left side) and the distance between the ischial spine and

Table 4 Correlation of different parameters of GSN within group matrix

	ABR	BCR	ACR	Ar R	Depth R	Psl R	Post ang R	ABL	BCL	ACL	Ar L	Depth L	Psl L	Post ang L
ABR	1.000													
BCR	0.503	1.000												
ACR	0.490	0.067	1.000											
Ar R	0.753	0.434	0.899	1.000										
Depth R	0.322	0.250	0.920	0.861	1.000									
Psl R	0.576	−0.224	0.864	0.740	0.621	1.000								
Post ang R	0.518	−0.377	0.692	0.559	0.420	**0.943**	1.000							
ABL	0.888	0.452	0.474	0.701	0.334	0.530	0.473	1.000						
BCL	0.452	0.822	0.033	0.348	0.160	−0.179	−0.290	0.507	1.000					
ACL	0.447	0.048	0.880	0.788	0.800	0.774	0.640	0.467	−0.010	1.000				
Ar L	0.693	0.372	0.806	0.892	0.758	0.680	0.540	0.753	0.396	0.883	1.000			
Depth L	0.310	0.194	0.797	0.740	0.842	0.567	0.419	0.310	0.179	0.916	0.855	1.000		
Psl L	0.488	−0.187	0.775	0.658	0.577	0.866	0.811	0.530	−0.284	0.868	0.713	0.618	1.000	
Post ang L	0.418	−0.301	0.636	0.510	0.426	0.803	0.823	0.467	**−0.416**	0.716	0.547	0.440	**0.954**	1.000

Table 5 Comparison of the variants with different studies

Authors with year	Ethnicity	Material	*N*	Width of GSN		Depth of GSN		Post. seg. length		Ang. of post. seg		Area of GSN	
			T (M, F)	M Mean (SD)	F Mean (SD)	M Mean (SD)	F Mean (SD)	M Mean (SD)	F Mean (SD)	M Mean (SD)	F Mean (SD)	M Mean (SD)	F Mean (SD)
Soltani et al. (2018)	Iraniana	3D CT scan of pelvis	237 (116,121)	44.9 (5.9)	52.9 (8.1)	30.2 (4.4)	30.0 (4.0)	9.4 (4.9)	20.4 (7.8)	16.6 (9.7)	32.9 (9.7)	_	_
Raut et al. (2013)	Indian (Maratha)	Dry bone	183 (125.58)	35.7 (4.3)	43.5 (6.1)	27.1 (3.5)	25.4 (3.4)	8.9 (3.6)	17.9 (6.2)	18.4 (6.3)	34.77 (9.4)	_	_
Dnyanesh et al. (2013)	South Indian	Dry bone side	100[b] (57, 43)	40.1 (5.1)	47.0 (5.1)	32.3 (5.3)	31.3 (2.7)	11.4 (2.8)	21.9 (4.6)	19.2 (4.2)	34.3 (5.0)	_	_
Kim et al. (2018)	Korean	3D model	202 (101,101)	45.8 (5.7)	56.2 (7.1)	34.7 (4.4)	32.1 (3.4)	11.3 (5.6)	25.45 (5.8)	17.4 (7.2)	38.2 (6.2)	_	_
Kalsey et al. (2011)	North Indian	Dry bone	100 (80, 20)	44.9 (4.4)	48.4 (4.8)	27.7 (3.8)	29.6 (3.9)	6.1 (0.5)	13.8 (2.2)	13.7 (4.8)	25.8 (3.9)	_	_
Shah et al. (2011)	Indian (Gujrat)	Dry bone	268 (174, 94)	38.5 (4.6)	42.7 (4.8)	24.1 (3.8)	22.3 (3.5)	6.8 (2.9)	12.5 (3.3)	16.6 (6.3)	29.9 (7.7)	_	_
This study (2022)	North Indian	PMCT of pelvis	408 (210,198)	46.2 (4.6)	53.1 (5.7)	31.6 (4.6)	30.3 (4.1)	9.4 (5.6)	20.0 (7.2)	15.7 (7.8)	32.4 (8.3)	733.0 (142.8)	810.3 (166.7)

[a] Considering the value of right side. [b]Included both sides of hip bone, the mean and SD are considered for right side only

the deepest point (BC) ($p < 0.001$ on both sides) were greater in men (Soltani et al. 2018; Raut et al. 2013; Kim et al. 2018).

Significant differences were found in the width of GSN on both sides in female samples ($p < 0.05$), with the right side exhibiting greater width in both sexes. We could not ascertained the reason for this difference on right side width of GSN, it is possibly due to right dominancy during various activities; a further study is needed to find out the underlying cause. Variations in observations between studies may be attributed to differences in ethnicity, population affinities, or sample size (Soltani et al. 2018; Kumar Jain et al. 2013; Kalsey et al. 2011).

The study suggests that the depth of GSN can be utilized for sex differentiation, with the depth of the right side being less significant compared to other parameters. The mean GSN depth was greater in males than in females on both sides. Some studies found no significant difference between males and females in GSN depth on either side, while our study aligns with those showing a significant difference between the sexes (Soltani et al. 2018; Raut et al. 2013; Dnyanesh et al. 2013; Kalsey et al. 2011; Naqshi et al. 2016).

Both sides of the GSN exhibited a highly significant difference in the posterior angle between males and females ($p < 0.001$ for both sides), consistent with findings from multiple studies (Soltani et al. 2018; Raut et al. 2013; Dnyanesh et al. 2013; Kalsey et al. 2011; Singh and Potturi 1978).

The length of the posterior segment also showed a highly significant difference between both sexes on both sides ($p < 0.001$), with a larger length in females compared to males. No significant difference was observed between the right and left sides of the posterior segment length in the overall sample (Raut et al. 2013; Dnyanesh et al. 2013; Naqshi et al. 2016; Shah et al. 2011; Alizadeh et al. 2013).

A highly significant difference was observed in the area of GSN between the sexes on both sides ($p < 0.001$), consistent with findings from a study by Kim et al. The area was greater in females compared to males (Kim et al. 2018).

The length of the posterior segment and posterior angle of both sides showed the highest positive correlation and provided highly significant differences between males and females consistent with the Soltani et al. and Takahashi H. et al. studies (2018; 2006).

The discriminant model considering all parameters achieved a positive prediction of 91.4% for males and 90.4% for females. This study proposes considering all parameters for differentiating between the sexes, achieving 90.9% accuracy. The statistical discrepancy in the discriminant model, particularly the "Depth R" parameter's p-value, suggests nuanced anatomical variations. While statistically significant, Depth R's unique variation warrants further investigation. This prompts a careful evaluation of its practical significance in forensic applications, emphasizing the need for future research to refine sex estimation models.

A study conducted by Vlak D. et al. suggested age-related changes in the morphology of the greater sciatic notch (GSN) in both sexes, and their regression analysis indicated a decrease in the GSN angle with increasing age, while the depth increased with age (Vlak et al. 2008). Our study did not show very high significant correlation of these parameters with age except for BCL ($p < 0.001$). However, a significant correlation was observed for ABR, ABL, BCR, Ar R, Ar L, and Depth of the left side ($p < 0.05$ for each) with age in women. Further investigation in a broader context, with a specific focus on sexual dimorphism in conjunction with age, is warranted.

Conclusions

The use of 3D images through PMCT represents an advanced technological approach for precise data collection. Importantly, there was no significant variation observed in the age-related parameters of GSN among males. However, females displayed significant variations in most GSN parameters with age. This observed age-related variation in females may be attributed to factors such as hormonal changes throughout different life stages, multiple childbirths, lifestyle choices, obesity, nutritional factors, and other related considerations. To summarize, accurate sex determination is accomplished by employing PMCT measurements of the posterior segment of the greater sciatic notch, with an impressive 90.9% accuracy rate. This method is equally applicable to dry bones, as it merely requires the identification of the GSN landmarks. A limitation of our study is the inability to collect data from across Pan India or a specific region where only the indigenous population resides. Instead, our study comprises a predominantly large population from one region, juxtaposed with a smaller population from another region. This mixed population primarily consists of individuals undergoing autopsy procedures at our center. While this approach provides valuable insights, the sample size, particularly from the latter region, is comparatively to enhance accuracy; it is recommended to adopt a multi-institutional approach and involve a larger sample size in future investigations.

Abbreviations

GSN Greater sciatic notch
PMCT Postmortem computed tomography
PIIS Posterior inferior iliac spine

Supplementary Information

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Additional file 1: Table 1. Intra- and inter observer error of the measurements from 3D models. **Table 2.** Correlation of GSN parameter with age.

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Authors' contributions

Dr. RK, substantial contribution to the concept of the work. Dr. JNP, substantial contribution and interpretation of the data. Dr. SKP, drafting the article. Dr. ST, drafting the article. Dr. AY, critical revision of the article. Dr. SKG, approved the version to be published.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available to maintain confidentiality but can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This research project, conducted at the Center for Advanced Research and Excellence, received approval from the Institutional Ethics Committee. It took place between September 2021 and January 2023 at AIIMS, New Delhi, as an integral component of the autopsy examination process. Any kind of identity of individual has not been disclosed at any time of the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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