

Morphometric and Morphological Analysis of the Genial Tubercle in a Libyan Population by Sex: A Cone-Beam Computed Tomography Study

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Abstract

Detailed knowledge of genial tubercle (GT) morphology and orientation is critical for prosthodontic planning, implantology, sleep apnea surgery, and forensic identification. This study aimed to evaluate the morphometric variations, categorical configurations, and sexual dimorphism of the GT in a Libyan population using cone-beam computed tomography (CBCT). A retrospective analysis of 200 high-resolution CBCT scans (100 males, 100 females) was conducted. Linear measurements including maximum horizontal and vertical GT diameters, distance to the central incisor apex, distance to the menton (GT-M), and symphyseal thickness were measured. Categorical morphological variations were classified. Total absence of genial tubercles was observed in only 0.5% of subjects ($n = 1$). Significant sexual dimorphism was identified across all measured parameters ($p < 0.001$). Males demonstrated significantly greater mean GT width (6.83 ± 0.78 mm vs. 5.12 ± 0.86 mm) and vertical height (9.87 ± 1.17 mm vs. 7.40 ± 1.45 mm) than females. Morphologically, a median vertical ridge (24.5%) and paired superior tubercles with a single inferior fossa were predominant in males ($n = 29$ vs. $n = 10$), whereas the classical tetrad pattern was more prevalent in females ($n = 18$ vs. $n = 7$). Mean GT-M distance was 12.65 ± 1.78 mm in males and 9.87 ± 1.41 mm in females. The genial tubercles exhibit marked anatomical heterogeneity and significant sexual dimorphism in the Libyan subpopulation. CBCT provides precise mapping of these features, offering crucial landmarks for surgical safety, prosthodontic retention, and forensic profiling.

Keywords. Genial Tubercle, Mental Spine, Cone-Beam Computed Tomography, Sexual Dimorphism, Mandibular Morphometry, Oral Radiology.

Introduction

The mandibular mental spines are synonymously designated as genial spines, genial tubercles (GTs), or the genial apophysis [1]. Linguistically, the nomenclature originates from classical roots: "mental" stems from the Latin *mentum*, whereas "genial" originates from the Greek *genion*, both denoting the anatomical chin [2]. Anatomically, these structures present as minor bony prominences on the lingual surface of the mandibular symphysis. In most individuals, the mandible features four genial spines arranged in two distinct pairs: an upper set recognized as the superior genial tubercles, and a lower set classified as the inferior genial tubercles [3].

Functionally, the superior aspect of these bony processes anchors the genioglossus muscle, whereas the inferior region serves as the site of insertion for the geniohyoid muscles. These associated muscles govern tongue motor control and swallowing, which are indispensable for speech production and food intake [4]. Traditionally, the typical mandible is described as possessing four mental spines; however, emerging anatomical studies document notable structural variations. Specifically, individuals may present with only one or two isolated spines rather than the classic quadruple pattern [2]. Although conventional 2D radiography—particularly occlusal views—can detect genial tubercles, it lacks the capability for precise linear quantification. In contrast, cone-beam computed tomography (CBCT) provides superior multiplanar visualization, allowing for optimal 3D assessment of GT morphology, dimensions, and spatial position [5,6]. Precise characterization of genial tubercle (GT) morphology, spatial dimensions, and anatomical location is essential across several clinical domains. Key applications include preoperative mapping for genioglossus advancement in obstructive sleep apnea therapy [6,7], establishing safety margins during inter-foraminal mandibular implant placement [8], and assessing mandibular asymmetry via CBCT imaging [3].

While the radiographic characteristics of genial tubercles (GTs) are well-documented in global literature [9], empirical data specific to the Libyan demographic remain lacking. To address this knowledge gap, the present study sought to analyze the morphometric variants and demographic distribution of GTs within a Libyan cohort utilizing CBCT. The aim of this study was to characterize the morphological patterns and demographic distribution of genial tubercles (GTs) in a Libyan population using cone-beam computed tomography (CBCT).

Methodology

Study Design and Data Source

This study utilized patient CBCT records that were retrospectively retrieved from the radiological archives of Al-Amal Dental Centre in Benghazi, Libya, covering the period from January to December 2025.

Eligibility criteria

CBCT scans of male and female patients aged 18 to 69 years were included in the study. Eligible scans were required to demonstrate high diagnostic clarity of the anterior mandibular region, extending from the alveolar crest to the inferior mandibular border.

Exclusion Criteria

Scans were excluded from the analysis if they presented incomplete CBCT datasets or lacked essential patient demographic information. Cases showing evidence of osseous pathologies, prior fractures, or anatomical malformations that could distort mandibular bone structure were also excluded to ensure methodological consistency. In addition, scans affected by severe metallic scatter artifacts, such as those arising from dental implants or osteosynthesis hardware, were omitted due to the risk of compromised image quality. Finally, individuals younger than 18 years of age were excluded from the study population in order to maintain a standardized adult cohort.

CBCT Image Acquisition and Analysis

All scans were acquired using an X-Mind Prime CBCT unit (SOPRO, Acteon Group, La Ciotat, France) operating at exposure parameters of 84 kV and 12–16 mA. Images were captured with a field of view (FOV) of ~ 12 cm and an isotropic voxel size of 0.200 mm. Reorientations across multiplanar reformations (axial, coronal, sagittal, and reconstructed panoramic views) were automatically generated to achieve full three-dimensional mandibular rendering. The resulting Digital Imaging and Communications in Medicine (DICOM) datasets were archived and subsequently analyzed by a single calibrated examiner using Acteon Imaging Suite (AIS) software (version 4.6.1). Linear and angular measurements were anchored as persistent screen overlays to maintain spatial consistency throughout the image volume.

Morphological and Pattern Assessment of Genial Tubercles

Initial anatomical localization of genial tubercles (GTs) was established via reconstructed panoramic images using the inferior mandibular border as a baseline reference, followed by cross-sectional analysis at 1 mm slice intervals.

A two-tier categorization system was applied:

Primary Categorization

Evaluation based on the presence or absence of GTs.

Morphological Classification

Typological classification based on GT shape and configuration, supplemented by 3D volume-rendered models.

The anatomical variations of the genial tubercles (GTs) were analyzed using three-dimensional mandibular reconstructions. Representative examples are shown in (Fig. 1), where distinct morphologies can be observed: (A) two superior tubercles with an inferior depression, (B) a single large median vertical spine, and (C) two superior tubercles with a fused inferior tubercle. Based on these observations, the GTs were categorized into six morphological patterns, as summarized in (Table 1). The classic description of four spines (two superior and two inferior) was identified as Type 1, while additional variations included single superior/inferior tubercles (Type 2), a prominent median vertical spine (Type 3), two superior tubercles with a fused inferior tubercle (Type 4), two superior tubercles with an inferior depression (Type 5), and cases with dull demarcation between tubercles (Type 6).

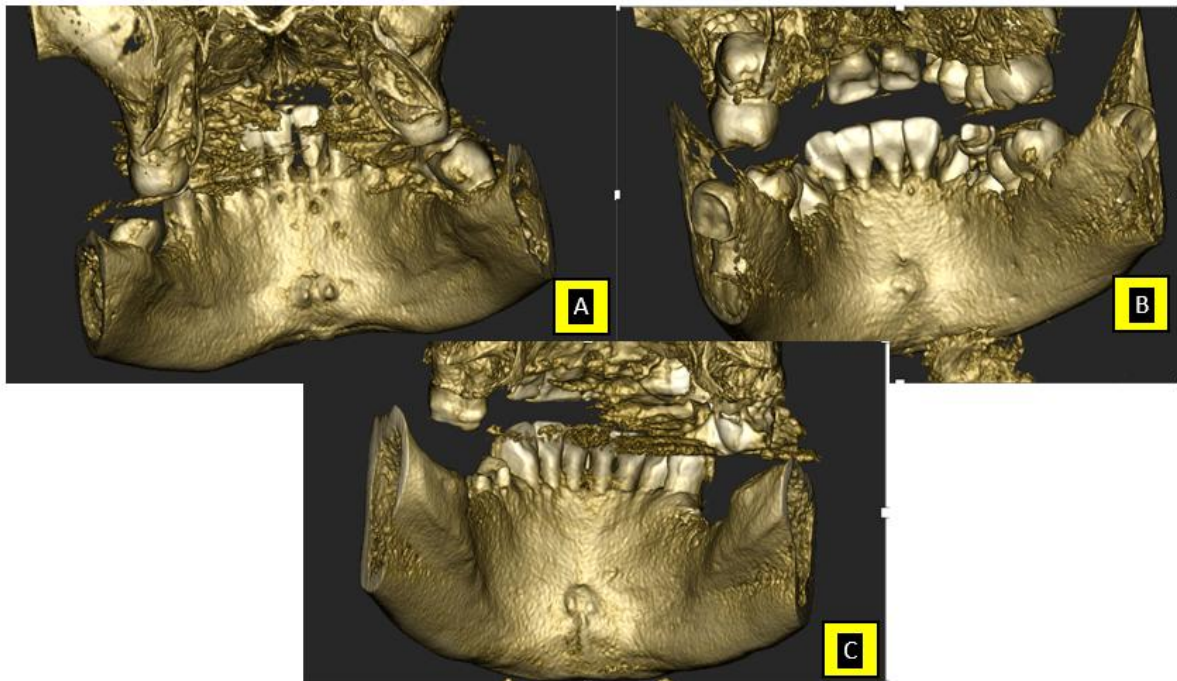


Figure 1. Mandibular 3D reconstruction showing various patterns of the GT. A: two superior tubercles with an inferior depression, B: One large median vertical spine, C: 2 superior tubercles with a fused inferior tubercle

Table 1. The morphological patterns of the genial tubercles

Type	Pattern Description
1	The classic description of four spines, two superior and two inferior tubercles
2	One superior tubercle & one inferior tubercle
3	One larger median vertical spine
4	Two superior tubercles with one fused inferior tubercle.
5	Two superior tubercles with an inferior depression
6	Dull demarcation between the tubercles

Assessment of Genial Tubercle Dimensions and Spatial Position

Multiplanar reconstruction (MPR) views were adjusted to determine maximum linear dimensions: sagittal planes were utilized to measure GT height (fig. 2), whereas axial slices were employed to quantify width (fig. 3). In instances presenting multiple tubercles, the GT exhibiting the maximum overall dimensions was selected for linear assessment. Linear measurements were recorded in millimeters across all evaluated anatomical dimensions, as outlined in (Table 2):

Table 2. Quantitative morphometric variables of the GT were evaluated in millimeters (mm).

The parameter	Definition
GTW	The largest width of the GT in the axial cut
GTH	Measurement from the base to the apex of the GT in the sagittal cut
GT-INC	Distance from GT to the apex of the lower central incisor.
GT-M	Distance from GT to the lower border of the menton.
MT	Mandibular thickness at the center of GT.

Spatial positioning was quantified using specific anatomical landmarks. GT-INC was determined by constructing a tangent from the root apices of the lower central incisors to the superior margin of the GTs (fig. 4). However, GT-M was defined as the linear distance extending from the inferior edge of the GTs to the inferior border of the mandible at the level of the menton (Fig. 5). The thickness of the mandible was also evaluated at the menton (MT) (fig.6).

Statistical analysis

Sample size

Given the reported global prevalence of genial tubercles at 90% [10], a subset of 200 cone-beam computed tomography (CBCT) scans was selected from the available pool of 564 examinations. This sample size was calculated to achieve a margin of error of 5% with a confidence level of 95%. To ensure methodological rigor, a simple randomization procedure was employed as the sampling strategy for image selection.

Evaluation of methodological errors

Anatomical landmark consistency for the genial tubercle (present vs. absent) was calculated using Cohen's kappa. Observer precision was further assessed using a bidirectional random-effects intraclass correlation coefficient (ICC), where $p < 0.05$ and a 95% confidence interval established statistical acceptability.

Comparison of the different parameters

Continuous measures were evaluated for normality via the Kolmogorov–Smirnov test and subsequently expressed as mean values with corresponding standard deviations. Between-group comparisons were conducted using Student's t-test assuming equal variances. Non-continuous and categorical variables were converted to percentages and assessed using chi-square analysis. Data execution was performed in SPSS Statistics (v26.0).

Compliance with ethical standards

This study was conducted in full compliance with the ethical guidelines established by the Institutional Ethics Committee in Benghazi, Libya. Owing to the retrospective design of the protocol, the requirement for formal informed consent was explicitly waived by the reviewing board.

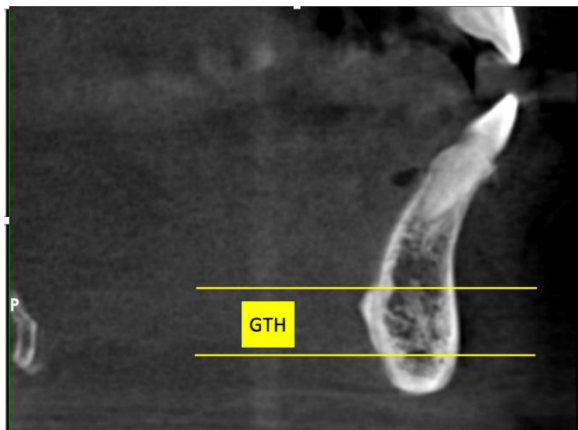


Figure 2. Measurement of the height of the genial tubercle using sagittal cuts.

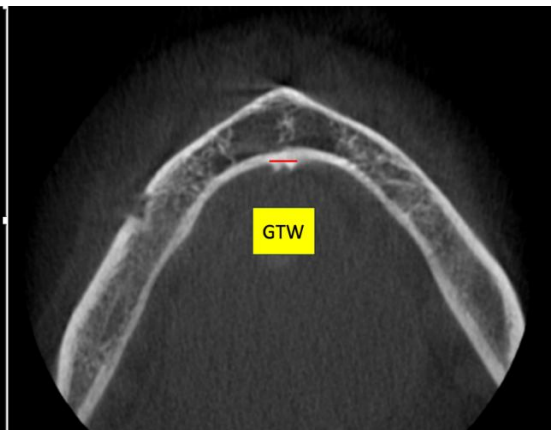


Figure 3. Measurement of the maximum width of the genial tubercle by using the axial cut.

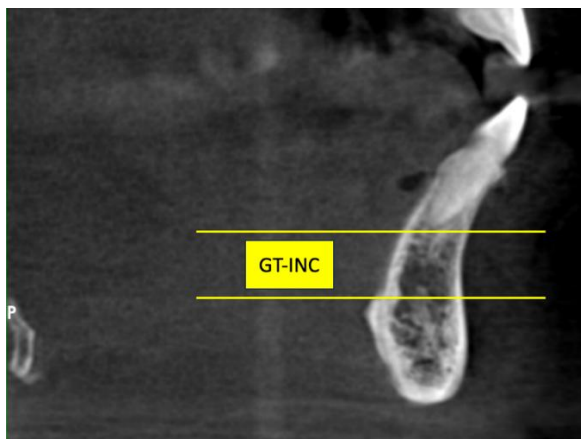


Figure 4. Measurement of the distance from the root apices of the lower central incisors to the superior margin of the GTs (GT-INC).

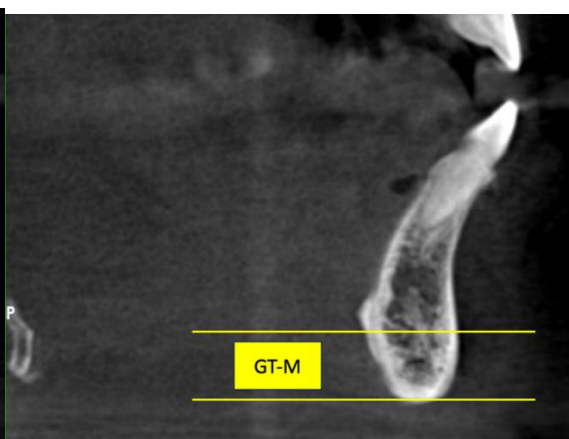


Figure 5. Measurement of the linear distance extending from the inferior edge of the GT to the inferior border of the mandible at the level of the menton.

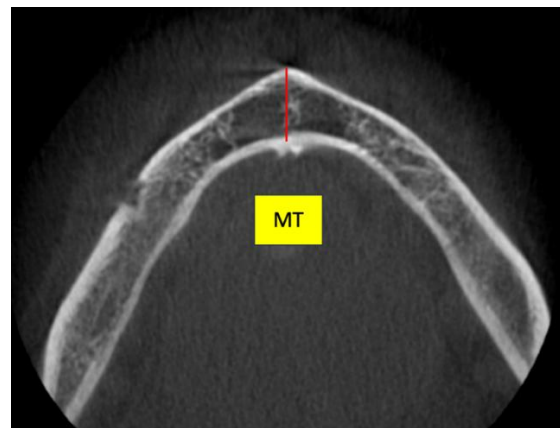


Figure 6. The thickness of the mandible has been evaluated at the menton (MT).

Results

A sample size calculation determined that 159 participants were required to estimate tubercle frequency at a 90% expected prevalence (95% CI, 5% precision threshold). Consequently, a final cohort of $n = 200$ individuals was enrolled in the study. From an initial archive of 564 CT scans, 322 were omitted for failing to fulfill the primary eligibility criteria. An additional 42 scans were excluded due to missing mandibular central incisors, extensive anterior periapical pathology, or inadequate radiologic image quality. Consequently, a final sample of 200 subjects was included, consisting of an equal sex distribution (100 males, 100 females) with a mean age of 44.5 ± 14.72 years (range: 18–69 years). Evaluation using the Shapiro–Wilk test confirmed that all continuous variables were normally distributed ($p > 0.05$). Furthermore, measurements of genial tubercle (GT) dimensions demonstrated high intra-examiner concordance, yielding excellent reliability scores ($ICC \geq 0.996$). (Table 3).

Table 3. Demonstrates the high intra-examiner reliability

Parameter	<i>r</i>	P value
GW	0.998	< 0.001
GH	0.996	< 0.001

Complete absence of genial tubercles was observed in only one mandible (0.5%), with the remaining cohort exhibiting diverse morphological variations of the mental spines. Sexual dimorphism was evident: male subjects demonstrated a higher prevalence of median vertical ridge configurations ($n = 32$ vs. $n = 17$) as well as two superior tubercles paired with a single fused inferior tubercle ($n = 29$ vs. $n = 10$). Conversely, female subjects displayed a higher frequency of the classical tetrad pattern consisting of four distinct genial tubercles ($n = 18$ vs. $n = 7$). Additionally, ill-defined anatomical demarcation between the tubercles was significantly more pronounced in females. These sexual dimorphisms were statistically significant ($p < 0.001$; Table 4).

Table 4. Distribution of the different patterns of GT among male and female subjects

PATTERN OF GT	M	F	NO.	Percentage %
Absent	-	1	1	0.5
One superior & one inferior	5	7	12	6
Two superiors & two inferiors	7	18	25	12.5
One larger median vertical spine	32	17	49	24.5
Two superior with one fused inferior	29	10	39	19.5
Two superior with inferior depression	14	27	41	20.5
Dull demarcation between the tubercles	13	20	33	16.5
TOTAL	100	100	200	100

For all subjects, the mean maximum horizontal and vertical diameters of the genial tubercle (GT) were 5.98 ± 1.19 and 8.63 ± 1.8 mm, respectively. Regarding linear spatial relationships, the mean distances from the GT to the central incisor apex and to the menton were 11.56 ± 1.98 and 11.26 ± 2.12 mm, respectively. Additionally, the mean mandibular thickness at the menton measured 12.7590 ± 0.86205 mm (Table 5).

Table 5. The mean, SD, and range for all measured parameters

Parameter	GTW	GTH	GT-INC	GT-M	MT
Mean	5.9826	8.6389	11.5685	11.2634	12.7590
Median	5.9000	8.7000	11.3000	11.1500	12.6000
Std. Deviation	1.19158	1.81378	1.98607	2.12646	0.86205
Range	4.20	6.40	7.70	7.70	3.00

Difference between male and female

As detailed in (Table 6), male subjects demonstrated significantly greater values across all evaluated morphometric parameters compared to females ($p < 0.001$). Specifically, the mean width of the GT was 6.83 ± 0.78 in males versus 5.12 ± 0.86 mm in females. Similarly, GT height was markedly greater in males (9.87 ± 1.17) than in females (7.40 ± 1.45 mm). All remaining linear dimensions were likewise significantly larger in male participants; however, mandibular thickness exhibited the smallest inter-gender variance.

Table 6. Sex-based comparison of mandibular and genial tubercle measurements

Parameter	Gender	Mean	Std. Deviation	Sig. (2-tailed)
GTW	M	6.8390	0.78893	$P < 0.001$
	F	5.1262	0.86604	$P < 0.001$
GTH	M	9.8778	1.17643	$P < 0.001$
	F	7.4000	1.45882	$P < 0.001$
GT-INC	M	12.8230	1.59367	$P < 0.001$
	F	10.3140	1.48651	$P < 0.001$
GT-M	M	12.6557	1.78340	$P < 0.001$
	F	9.8710	1.41152	$P < 0.001$
MT	M	13.2430	0.79509	$P < 0.001$
	F	12.2750	0.62318	$P < 0.001$

Discussion

Classical anatomical literature generally characterizes the mental spines as four distinct bony prominences situated on the lingual aspect of the mandibular symphysis, configured in two superior-inferior pairs [11, 12–14]. Nevertheless, subsequent anatomical and radiological studies have demonstrated significant structural variability, showing that human mandibles may feature anywhere from one to four spines [6, 11, 14]. This retrospective CBCT study evaluated the presence and morphological variability of the genial tubercles within a representative Libyan subpopulation. Findings demonstrated that the vast majority of individuals possessed at least one mental tubercle, with total absence observed in under 1% of cases. A prominent median vertical ridge accounted for approximately 24.5% of the morphological presentations, followed by a configuration featuring two superior tubercles with a single inferior fossa, observed in 29 males compared to 10 females. Conversely, the classical arrangement—comprising two superior and two inferior tubercles—was identified in 12.5% of subjects, demonstrating a clear female predominance (18 vs. 7). Such morphological variations of the mental spines have been extensively documented in prior literature [6, 11, 14].

In an osteological evaluation of 1,200 dry adult mandibles, Singh et al. [3] reported complete aplasia in only 22 specimens (1.83%), whereas a configuration consisting of two superior spines paired with a median inferior depression predominated, comprising nearly 47% of cases. Conversely, a solitary median vertical ridge was observed in merely 9% of their sample. In contrast, a CBCT investigation of 155 individuals by Araby et al. [6] revealed a higher rate of tubercle absence (10%), though paired superior tubercles with an inferior depression similarly constituted approximately half of all cases. Furthermore, Hu et al. [14] examined 102 mandibles, observing that anatomical boundaries were markedly distinct between superior tubercles, whereas inferior tubercles exhibited a more fused, poorly demarcated morphology. During craniofacial development, the mandibular body, housing the mental spine, translates anteriorly under the biomechanical influence of the ascending ramus and maxillary alveolar process [15]. Although generally diminutive, these tubercles may undergo hypertrophy or enlargement secondary to enthesophyte formation/calcification at the genioglossus and geniohyoid tendinous insertions, particularly in cases of severe mandibular resorption. Clinically, the mental spines contribute significantly to complete denture support; in patients with extensively resorbed edentulous ridges, these bony prominences provide a stable foundation capable of bearing vertical occlusal forces [16].

Consequently, this phenomenon may precipitate genial tubercle fracture, occurring either spontaneously or secondary to trauma from an ill-fitting complete prosthesis [17–20], which can lead to subsequent detachment of the attached musculature from the mandible. Furthermore, the thin overlying mucosa limits the tubercle's capacity to function as a primary stress-bearing area; however, following skin grafting and keratinization of the soft tissue over the muscular insertion zone, it can effectively serve as a primary supportive region [16]. Conversely, less prominent or irregular inferior mental spines may develop as a result of altered muscular traction and focal muscular weakness [11]. In rare instances, the genioglossus and geniohyoid muscles share a common mandibular origin, resulting in either a prominent solitary eminence [13] or poorly defined anatomical demarcation between individual tubercles [11]. Furthermore, genial tubercle fractures

have been documented in the literature, stemming from both spontaneous occurrences and traumatic etiologies; such fractures occur predominantly in hypertrophied tubercles, irrespective of the underlying mechanism [2]. Regarding linear morphometrics, male subjects exhibited significantly greater dimensions for the present genial tubercles than females. The spatial orientation of GT was defined relative to superior landmarks (the root apices of the central incisors) and inferior landmarks (the inferior border of the mandible at the menton). Overall, our observed values were larger than those reported by Barbosa et al. [21]. When evaluating the distance from the superior aspect of the GT base to the adjacent incisor root apex, males demonstrated significantly greater values than females.

In contrast, Nejaim et al. [22] evaluated sexual dimorphism in this parameter but observed no statistically significant intersex differences. Similarly, the distance from the inferior margin of the GT to the menton (GT-M) was significantly greater in males (12.65 ± 1.78 mm) than in females (9.87 ± 1.41 mm). This dimension has been widely investigated across other populations; our values exceeded those reported by Kolsuz et al. (8.3 ± 10 mm) [23] and Araby et al. (8.13 ± 3.07 mm) [6], whereas Wang et al. [5] recorded the lowest values (6.4 ± 8.4 mm). Precise characterization of genial tubercle morphology, spatial position, and linear dimensions carries significant clinical implications [3,24]. Genial morphometrics play a pivotal role in maintaining mandibular complete denture stability [19,25] and serve as reliable anatomical landmarks for evaluating mandibular asymmetry [3]. Furthermore, the tubercle acts as a critical reference point for establishing a safe operative zone superior to the mental foramen prior to dental implant placement, as well as a key hard-tissue parameter in the surgical management of obstructive sleep apnea (OSA) [8].

When conservative OSA therapies prove ineffective, surgical intervention- such as genioglossus advancement combined with genial tubercle advancement- is indicated to enlarge the oropharyngeal airway space and mitigate nocturnal collapse, underscoring the necessity of a thorough anatomical understanding of the symphyseal region. In forensic odontology, detailed knowledge of GT features aids human identification through radiographic correlation of anterior mandibular parameters with sex and age cohorts [26]. Additionally, cone-beam computed tomography (CBCT) provides a non-invasive, highly accurate modality for mapping facial bone structures, genial tubercle morphology [10], and mandibular linear dimensions [30]. Notably, previous studies have demonstrated no significant variance between direct cadaveric measurements and CBCT-based evaluations of the genial tubercle [10].

Conclusion

In conclusion, this study provides a comprehensive anatomical and epidemiological characterization of the genial tubercles using a robust and reliable methodology. Both vertical and horizontal dimensions of the genial tubercle demonstrated significant sexual dimorphism, with higher values observed in males. These quantitative findings provide a valuable surgical reference for accurately localizing the genial tubercles and their associated muscular attachments. Furthermore, pre-operative radiologic mapping of the genial region can optimize prosthodontic treatment planning. Future clinical investigations should aim to refine these assessment protocols and further evaluate their therapeutic efficacy.

Conflict of interest. Nil

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