Digital radiography and GIMP software in mandibular sex estimation: implications for forensic anthropology

Harshal R. Thube[1], Manish Shrigiriwar[1], Neelam Chandwani[2]

[1] Department of Forensic Medicine & Toxicology All India Institute of Medical Sciences, Nagpur - Maharashtra. India. [2] Department of Dentistry All India Institute of Medical Sciences, Nagpur-Maharashtra. India.

Corresponding author: drharshalthube@gmail.com

The authors declare that they have no conflict of interest.

KEYWORDS

Forensic Anthropology,
Mandible,
Sexual Dimorphism,
Gonial Angle,
Antegonial Angle,
Orthopantomogram,
GIMP Software

J Forensic Odontostomatol 2026. Apr; (44): 1 -58:64
ISSN :2219-6749
DOI: doi.org/10.5281/zenodo.19689555

ABSTRACT

Background: Forensic anthropology frequently utilizes mandibular features to establish biological sex. The mandible, being the most resilient cranial bone, demonstrates marked sexual dimorphism. Among its indices, the gonial and antegonial angles have emerged as reliable parameters for sex differentiation. With digital imaging widely available, open-source tools such as GIMP allow precise, reproducible, and cost-effective morphometric analysis of orthopantomograms (OPGs).
Materials and Methods: This cross-sectional study analyzed 500 archived OPGs (250 males, 250 females; age 20–40 years) from AIIMS Nagpur. In orthopantogram, gonial and antegonial angles were measured bilaterally using GIMP (v2.10.34). Statistical analyses were conducted with Jamovi (v2.6).
Results: Females exhibited significantly larger gonial (130.80° ± 5.35) and antegonial (167.85° ± 2.15) angles compared to males (123.03° ± 5.43 and 162.69° ± 2.12, respectively; $p < 0.001$). Regression analysis confirmed significant dimorphism, even after adjusting for age. Discriminant function analysis demonstrated that both angles contributed positively to sex classification, yielding a robust predictive model. No significant sex-related differences were observed in age group distribution ($\chi^2 = 0.812$, df = 2, $p = 0.666$).
Conclusion: Mandibular gonial and antegonial angles measured from OPGs using GIMP demonstrate significant sexual dimorphism in the 20–40-year age group. Females consistently displayed larger angular values, supporting their diagnostic value for sex estimation. These findings underscore the relevance of digital radiography and open-source analysis in forensic anthropology, orthodontics, and maxillofacial surgery.

INTRODUCTION

Forensic anthropology involves the utilization of the expertise and techniques of anthropology, particularly in the areas of biological anthropology and archaeology, to address legal and medical matters [1]. This involves various measurements based on the requirements of the case. Many researchers have attempted somatometry, physical anthropometry, and computerized evaluation of radiological investigations to confirm the age and sex of individuals.
The mandible is the most robust section of the skull, owing to its thick layer of compact bone. Its significance lies in its sexual dimorphism and radio-morphometric features, even though it

experiences size changes and remodelling as it develops until it reaches a certain age. Mandibular dimorphism is characterized by differences in size and shape, with male mandibles generally being larger and stronger than those of females. It is the last bone in the skull to finish growing and grows significantly during the teenage years. The way the lower jaw develops, how fast it grows, and how long it takes are different for males and females. This helps in estimating biological sex. Among the various structures of the mandible, the ramus is the most sexually dimorphic. [2,3,4]

The gonial and antegonial angles of the mandible have garnered attention as dependable indicators of sexual dimorphism, offering valuable insights into the estimation of biological sex. [5] In the era of digital medicine, X-ray image of individuals are readily available. An orthopantomogram (OPG) is a type of X-ray that provides a panoramic view of the lower face, jaw, and teeth. Dental practice often relies on radiography to deliver crucial insights into teeth, including their inner core structure, developmental stages, and surrounding tissues. [6,7,8] The OPG are used instead of lateral cephalogram in this study because it provides simultaneous view of both sided angular parameter of mandibular bone which eases the measurement process. Also because of its lower radiation dose OPG were used abundantly in the dental OPD, which reproduces its utility in large population based study. Given the significance of the mandible in forensic anthropology for identifying sexual dimorphism, this study focuses on leveraging digital tools such as the GIMP software, which facilitates precise measurements of gonial and antegonial angles from OPG images.

The software provides tools for tracing lines and measuring angles, enabling quantification of the morphometric indices. Using GIMP, researchers can efficiently and cost-effectively analyze large samples of OPGs to study mandibular sexual dimorphism and other anatomical variations. The open-source nature of GIMP makes it accessible for forensic anthropology and dental research. [9] GIMP was used because of its precise nature of pixel based measurement tool. It is having advantage over other freely available software's by having linear and angular measurements without requiring additional plugins. Unlike ImageJ, GIMP provides simpler workflow, better usability for non-technical users, and consistent reproducibility across system. Proper calibration and standardized measurement protocols are essential when using GIMP to ensure the reliability and reproducibility of morphometric analysis across different OPG samples.

In a similar vein, the GIMP software, which is freely accessible, can significantly contribute due to its accurate predictions and ability to correct image errors. Digital radiography offers benefits in the analysis of facial features, allowing for the precise measurement of facial structures without the need for further dissection. This study focused on predicting sex by calculating mandibular morphometric indices from orthopantogram utilizing the GIMP software.

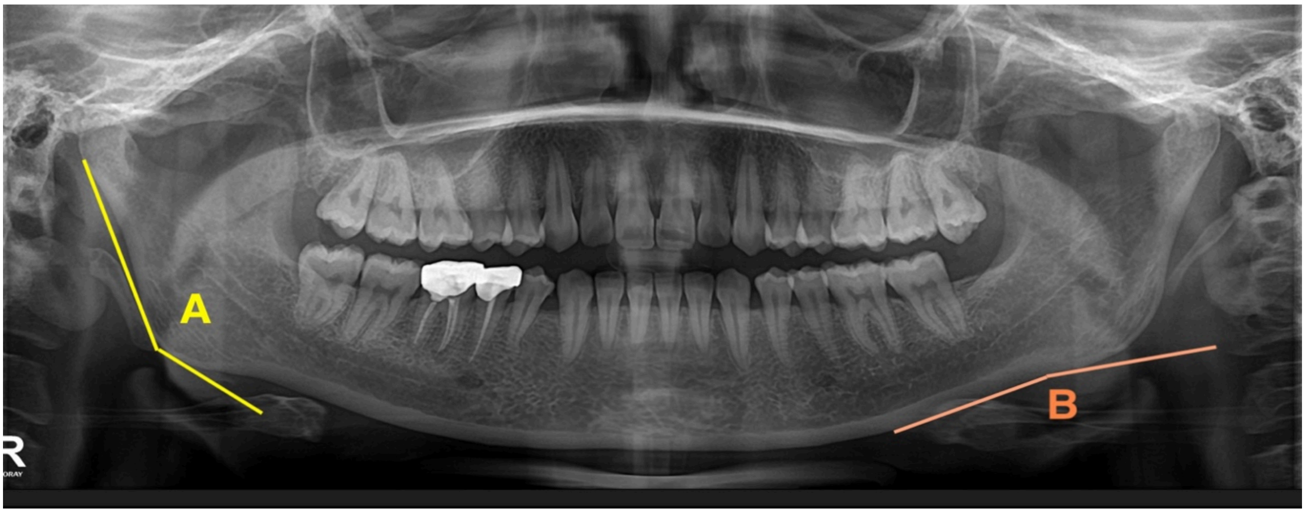
MATERIALS AND METHOD

A cross-sectional study was carried out in the Department of Forensic Medicine, AIIMS Nagpur, Maharashtra, utilizing archived dental records. From these, 500 orthopantomograms were randomly chosen, consisting of 250 male and 250 female individuals aged between 20 and 40 years. The present age group were selected taking into consideration of completed skeletal maturity with minimal bone remodelling with fewer age related wear and tear. Only those radiographs with confirmed sex, high resolution and sharpness, proper head positioning, complete permanent dentition, and without any evidence of mandibular pathology or traumatic changes were included. Images with artifacts or bone abnormalities were excluded. All orthopantogram were obtained using a Papaya Genoray unit with exposure parameters of 74 kV, 12 mA, and 14.3 seconds. The selected OPGs were processed and analyzed with GIMP software. The morphometric assessments were conducted bilaterally using GNU Image Manipulation Program [GIMP version 2.10.34 (revision 3)].

As shown in Fig 1, the Gonial Angle can be estimated by the intersection of a tangent line along the lower border of the mandibular body and angle with another tangent drawn to the posterior border of the ramus and condyle. [10] Similarly the antegonial angle is formed by two lines drawn parallel to the antegonial region, intersecting at the deepest portion of the antegonial notch. [11]

Each digital orthopantomogram (OPG) was opened as a new file in the macOS version of GIMP. Subsequently, a new transparent layer was created to delineate anatomical reference lines. The gonion was identified at the intersection of the posterior border of the ramus and the inferior border of the mandible. Utilizing the Measure Tool, a line was drawn along the posterior border of the ramus, and a second line was drawn along the inferior border of the mandible. The gonial angle was determined by activating the angle mode (SHIFT key) and measuring the angle formed at the gonion. The angle value displayed in the GIMP status bar was recorded. Measurements were conducted on both sides, with each measurement being performed three times, and the mean value was used for analysis. To ensure objectivity, the observers were blinded to the sex of the radiographs. GIMP software was advantageous as it reduced magnification errors and minimized measurement bias.

Figure 1. OPG with Angular measurements of mandibular parameters



Data analysis was carried out using Jamovi (version 2.6, The Jamovi Project, 2025), a free and open-source statistical software. Independent t-tests were employed to compare the measurements between groups, and discriminant function analysis was performed on the recorded variables.
All archived OPG of known sex and age range of 20-40 years were included in the study, except radiographs with artifacts, fractures, and trauma. To achieve a statistical power of 95% and a significance level (alpha error probability) of 0.05, the sample size was determined using G*Power software (version 3.1.9.4, Düsseldorf, Germany). The required sample size was calculated to be 482; however, a total sample of 500 OPGs was included.

RESULTS

In the present study, the archival data of OPGs from the Department of Dentistry were carefully screened, and cases were selected after applying the above-mentioned inclusion criteria and those were considered for the study. After taking measurements using GIMP software, the data were entered in MS Excel format. Data analysis using the Jamovi software yielded the following results.

Table 1 presents the comparison of angular parameters between males and females. The mean gonial angle was significantly higher in females compared to males. Similarly, the antegonial angle showed higher values in females than in males and the difference was statistically significant. These findings indicate notable sexual dimorphism in both gonial and antegonial angles. Females exhibited larger angular measurements (gonial and antegonial angles), suggesting a different mandibular shape than males.
The linear regression analysis outlined in the table 2 compares different craniofacial measurements between males and females. Each entry represents a specific parameter, reported separately for the right and left sides of the mandible, along with the mean value calculated as (R+L/2).
Additionally, a chi-square test was performed to examine the distribution of age groups across sexes. The contingency table 2 summarizes the number of male and female participants within the categories of young, middle, and old age groups.
The chi-square test results were as follows: χ^2 = 0.812, df = 2, p = 0.666, indicating no statistically significant difference in age group distribution between males and females.

Table 3 and 4 indicates the standardized coefficients of the six measurements. The positive coefficients for gonial angle, and antegonial angle suggest their relative contribution to the discrimination between the male and female groups.

Figure 2 visual comparison of the standardized and unstandardized coefficients, along with the t-values and p-values annotated above each bar. The antegonial angle had a strong positive contribution to sex classification. All variables were statistically significant ($p < 0.05$, most of them with $p < 0.001$).

Table 1. Comparison of Mandibular Measurements Between two sexes

S.N.	Parameter	Male (in mm)		Female (SD)		P value
		Mean	SD	Mean	SD	
1	Gonial Angle	123.03	(5.43)	130.80	(5.35)	<0.001
2	Antegonial Angle	162.69	(2.12)	167.85	(2.15)	<0.001

Table 2. Linear regression analysis of outcomes with gender (Female compared to Male)

S.N.	Parameter	URC (95% CI)	p-value	ARC (95% CI) *	p-value
		(R+L/2)		(R+L/2)	
1	Gonial Angle	7.77 (6.82, 8.71)	<0.001	7.77 (6.82, 8.72)	<0.001
2	Antegonial Angle	5.16 (4.79, 5.54)	<0.001	5.16 (4.78, 5.54)	<0.001

URC; Unadjusted Regression Coefficient, ARC; Adjusted Regression Coefficient, *; Age adjusted

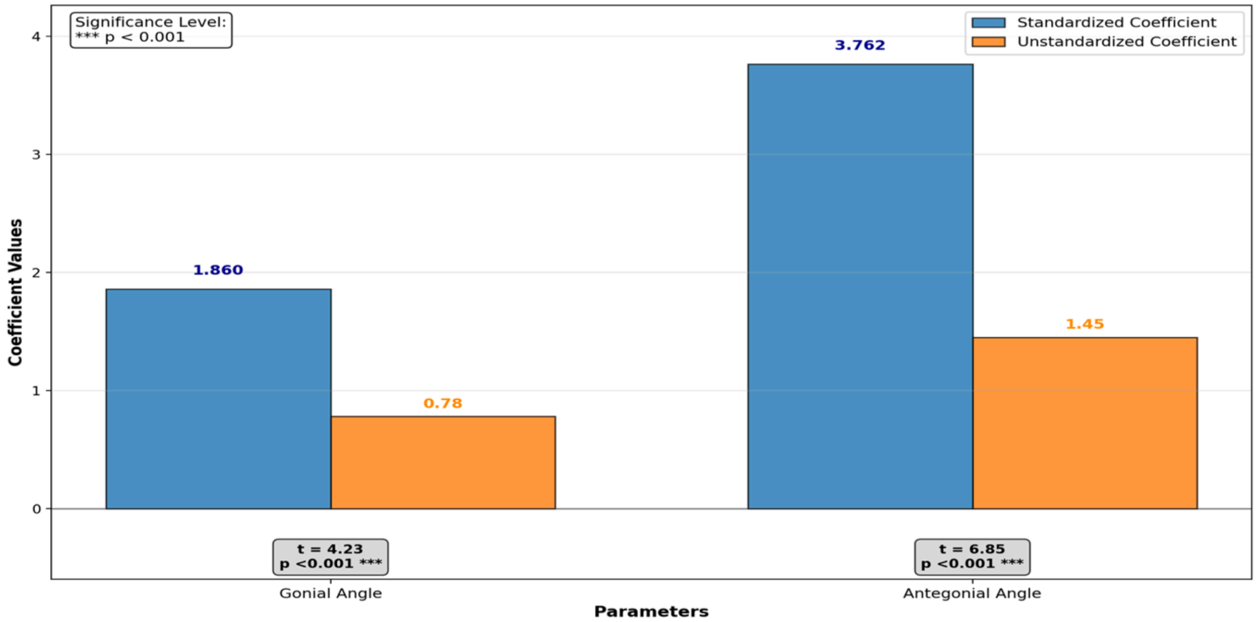
Table 3. Standard canonical discriminant function coefficients

Function coefficient	Function
Gonial Angle:	1.8595916302188826
Antegonial Angle:	3.7624129016981236

Table 4. Standardized and unstandardized coefficients

Parameter	Standardized Coefficient	Unstandardized Coefficient	t-value	p-value
Gonial Angle	1.86	0.78	4.23	<0.001
Antegonial Angle	3.762	1.45	6.85	<0.001

Figure 2. Standardized vs standardized coefficients with statistical significance (All parameters: p<0,001)



DISCUSSION

This study sought to estimate sex by analyzing mandibular morphometric indices obtained from digital orthopantomograms (OPGs) using the GIMP software. The strengths of this study lie in its age range of 20–40 years and its sample size of 500 participants, which offered a solid dataset for analysis. This approach enhances previous research that had either smaller sample sizes or broader age ranges, which may have introduced age-related variations. The results indicated significant sexual dimorphism in all evaluated mandibular parameters, with males generally having larger linear dimensions and females displaying larger angular measurements. These outcomes align closely with those of previous studies on mandibular sexual dimorphism.

The larger gonial angle in females (130.80° vs. 123.03° in males) corroborates the findings of Shahabi et al [12] in the Iranian population and Belaldavar et al [13] in Indian population. However, this finding contrasts slightly with that of Arthnari et al [14], who found minimal differences between the sexes. This variation may be due to differences in the populations.

The significantly larger antegonial angle in females (167.85° vs. 162.69° in males) aligns with the findings of Arthnari et al [14], confirming its utility in sex estimation.

In their research on the gonial angle using CT Scan images, Bulut et al [15] discovered no statistically significant differences in gonial anthropometric measurements among individuals aged 20–39 and 40–59 years. Nevertheless, it identified statistically significant sexual dimorphism in the older adult group aged 60–80 years. Despite this observation, the results suggest that the gonial angle is not a dependable indicator for estimating sex from the cranium and should not be used as the sole method for such identification. [15] In other study using similar CT images but using vastly sixteen parameters Senol et al [16] found that the accuracy rates of sex determination from mandibular measurements were 89.5% in females and 76.1% in males.

In his research, Ayoub et al [17] found that there is no notable difference in the mandibular angle for estimating sex in a young Lebanese population. The variation in the reliability of measuring either the gonial or antegonial angle for identifying sexual dimorphism is primarily influenced by differences in age, ethnicity, and population. Additional studies involving diverse ethnic groups are required to advance research in this field.

The findings indicate that females had notably smaller measurements in several craniofacial aspects, including condylar ramus height, projective ramus height, maximum ramus breadth, and minimum ramus breadth, compared to males. Conversely, the gonial and antegonial angles were significantly larger in women than in men. All p-values in the table were less than 0.001, indicating that the differences observed for each craniofacial parameter between males and females were statistically significant. Regression analysis consistently demonstrated notable distinctions between females and males in various craniofacial measurements, highlighting the necessity of accounting for sex when assessing craniofacial structures. Another parameter, such as ramus flexure, was examined on OPG by Premkumar et al [18], who found a significant sex difference in this measure. In his study of the Italian population, Nuzzolese et al [19] highlighted the importance of various landmarks on OPG, which exhibit significant sexual dimorphism.

The canonical discriminant function was used to categorize individuals into groups by analyzing their craniofacial measurements. The coefficients indicate which variables play a more significant role in differentiating between the groups. A higher score on the discriminant function suggests a greater probability of being part of a specific group (likely females, as indicated by positive coefficients), whereas a lower score suggests membership in the other group (likely males).

This analysis holds particular value in fields like forensic anthropology, where distinguishing between male and female remains through craniofacial measurements is essential. The canonical discriminant function offers a mathematical framework for categorizing individuals by sex based on their craniofacial characteristics. These coefficients can assist clinicians and researchers in identifying patterns of craniofacial development, sexual dimorphism, and variability among different populations. Furthermore, they can be applied in personalized treatment approaches in orthodontics and maxillofacial surgery, where such anatomical features may influence the treatment planning.

The use of the GIMP software for morphometric measurements in digital radiographs represents a significant advancement over previously employed methodologies. Traditional studies, such as those conducted by More et al [20], utilized Kodak Master View software, whereas Ojha et al [21] relied on ImageJ for their assessments. Although these tools are effective, they have limitations, such as cost, platform restrictions, and steep learning curves. In contrast, GIMP is an open-source, cross-platform image editing software that is freely available and user-friendly, making it accessible to a broader range of users. Furthermore, its customizable interface and wide range of measurement tools offer the potential to minimize user-induced errors, thereby reducing measurement bias and enhancing reproducibility across studies. Various dental imaging software options are available for measurement and analysis in forensic odontology, including DentaScan, ImageJ, ModelMatch3D, and Kodak Master View. These tools facilitate tasks such as the comparison of antemortem and postmortem images, odontometric analysis, and three-dimensional (3D) model comparison. These sophisticated proprietary software solutions offer high efficiency in image analysis for diagnostic and treatment purposes. However, forensic odontology typically requires only basic image analysis, which can be effectively conducted using freely available software such as GIMP.

The findings reinforce the role of angular mandibular indices in sexual dimorphism. While several studies like Shahabi et al [22] and Bulut et al [23] question the reliability of these angles in older populations, this study confirms their effectiveness in the 20–40 age group. Differences in ethnicity and age influence diagnostic accuracy, emphasizing the need for population-specific standards. Additionally, linear regression analysis confirmed the presence of sexual dimorphism, revealing significant differences even after adjusting for age related factors. This effectively addresses a limitation found in earlier studies that failed to consider age-related changes in the mandibular morphology.

CONCLUSION

This study demonstrated that mandibular morphometric indices derived from digital orthopantomograms can reliably distinguish between sexes in the 20–40-year age group, with males showing larger linear dimensions and females exhibiting larger angular values. Canonical discriminant analysis further reinforced the diagnostic utility of these measurements for sex estimation, underscoring their potential applications in forensic anthropology, orthodontics, and maxillofacial surgery. The use of GIMP software proved advantageous due to its accessibility, flexibility, and reproducibility, offering a practical alternative to proprietary imaging tools in forensic odontology. Future studies should aim to test these findings in diverse populations, incorporate three-dimensional imaging techniques, and validate predictive models with independent datasets.

In conclusion, mandibular morphometric analysis using digital radiographs and open-source software provides a cost-effective and efficient approach for sex estimation. This approach enhances the precision of forensic investigations while advancing the integration of digital tools in anthropological and clinical practice.

REFERENCES

1. Ubelaker DH. History of forensic anthropology. Am J Phys Anthropol. 2018 Apr;165(4): 915-923. doi: 10.1002/ajpa.23306. PMID: 29574835.
2. O'Shaughnessy PE. Introduction to forensic science. Dent Clin North Am 2001;45:217-27.
3. Saini V, Srivastava R, Rai RK, Shamal SN, Singh TB, Tripathi SK. Mandibular ramus: An indicator for sex in fragmentary mandible. J Forensic Sci 2011;56 Suppl 1:S13-6.
4. Carvalho SP, Brito LM, Paiva LA, Bicudo LA, Crosato EM, Oliveira RN. Validation of a physical anthropology methodology using mandibles for gender estimation in a Brazilian population. J Appl Oral Sci 2013;21:358-62.
5. Esfehani M, Ghasemi M, Katiraee A, et al.: Forensic gender determination by using mandibular morphometric indices an Iranian population: a panoramic radiographic cross-sectional study. J Imaging. 2023, 9:40. 10.3390/jimaging9020040.
6. Graber TM, Brainerd FS. Current orthodontic concepts and techniques. Philadelphia: W. B. Saunders; 1985. p.45.
7. Friedland B. Clinical radiological issues in orthodontic practice. Semin Orthod 1998;4:64-78.
8. Bruks A, Enberg K, Nordqvist I, Hansson AS, Jansson L, Svenson B. Radiographic examinations as an aid to orthodontic diagnosis and treatment planning. Swed Dent J 1999;23:77-85.
9. Solomon RW. Free and open source software for the manipulation of digital images. AJR Am J Roentgenol. 2009 Jun;192(6):W330-4. doi: 10.2214/AJR.08.2190. PMID: 19457798.
10. Mattila K, Altonen M, Haavikko K (1977) Determination of the gonial angle from the OPG. Angle Orthod 47: 107-110.
11. Graber LW, Vanarsdall RL, Vig KWL, et al. Orthodontics current principles and techniques. In: Vanarsdall RL, Blasi I, Secchi AG, eds. Periodontal-Orthodontic Interrelationships. Missouri: Elsevier; 2017:621–636. Jul;49(5):20190282. doi: 10.1259/dmfr.20190282. Epub 2020 Jan 2. PMID: 31821020; PMCID: PMC7333467.
12. Shahabi M, Ramazanzadeh BA, Mokhber N. Comparison between the external gonial angle in panoramic radiographs and lateral cephalograms of adult patients with Class I malocclusion. J Oral Sci. 2009 Sep;51(3):425-9. doi: 10.2334/josnusd.51.425. PMID: 19776510.
13. Belaldavar C, Acharya AB, Angadi P. Sex estimation in Indians by digital analysis of the gonial angle on lateral cephalographs. J Forensic Odontostomatol. 2019 Sep 30;37(2):45-50. PMID: 31589595; PMCID: PMC6981352.
14. Arthanari A, Sureshbabu S, Ramalingam K, et al. (Mar 20, 2024) Forensic Gender Prediction by Using Mandibular Morphometric Indices: A Panoramic Radiograph Study. Cureus 16(3): e56603. DOI 10.7759/cureus.56603.
15. Bulut O, Freudenstein N, Hekimoglu B, Gurcan S. Dilemma of Gonial Angle in Sex Determination: Sexually Dimorphic or Not? Am J Forensic Med Pathol. 2019 Dec;40(4):361-365. doi: 10.1097/PAF.0000000000000500. PMID: 31306169.
16. Senol GB, Tuncer MK, Nalcaci N, Aydin KC. Role of mandibular anatomical structures in sexual dimorphism in Turkish population: a radiomorphometric CBCT study. J Forensic Odontostomatol. 2022 Apr 30;40(1):53-64. PMID: 35499537; PMCID: PMC10228188.
17. Ayoub F, Rizk A, Yehya M, Cassia A, Chartouni S, Atiyeh F, Majzoub Z. Sexual dimorphism of mandibular angle in a Lebanese sample. J Forensic Leg Med. 2009 Apr;16(3):121-4. doi:10.1016/j.jflm.2008.07.014. Epub 2008 Nov 8. PMID: 19239960.
18. Premkumar A, Doggalli N, Rudraswamy S, Manjunatha BS, Peeran SW, Johnson A, Patil K. Sex determination using mandibular ramus flexure in South Indian population - A retrospective study. J Forensic Odontostomatol. 2023 Aug 27;41(2):2-9. PMID: 37634171; PMCID: PMC10473455.
19. Nuzzolese E, Randolph-Quinney P, Randolph-Quinney J, Di Vella G. Geometric morphometric analysis of sexual dimorphism in the mandible from panoramic X-ray images. J Forensic Odontostomatol. 2019 Sep 30;37(2):35-44. PMID: 31589594; PMCID: PMC6981353.
20. More CB, Vijayvargiya R, Saha N. Morphometric analysis of mandibular ramus for sex determination on digital orthopantomogram. J Forensic Dent Sci 2017;9:1-5.
21. Ojha, B., Bajracharya, D., Koju, S., Maharja, N., Saha, A., & Baral, R. (2021). Mandibular parameters as a predictor of sex: A digital orthopantomogram study. Journal of Kathmandu Medical College, 10(4), 218–223. https://doi.org/10.3126/jkmc.v10i4.43862.
22. Shahabi M, Ramazanzadeh BA, Mokhber N. Comparison between the gonial angle values in the right and left sides of panoramic radiographs in adult patients. *J Dent Tehran Univ Med Sci*. 2009;6(1):24–7.
23. Bulut O, Arslan A, Sipahioglu M, Bulut S. Evaluation of the effect of age and gender on gonial angle, antegonial angle and antegonial depth on panoramic radiographs. *J Dent Fac Atatürk Univ*. 2014;24(1):64–70.