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Radiographic evaluation of the mandible to predict age and sex in subadults

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ABSTRACT

Objective: Forensic examinations involve the identification of age and sex from living or mortal remains. The mandible comprises several growth parameters and is often recovered intact, making it an important tool for radiological identification. Therefore, the present study was conducted to determine the accuracy of various mandibular measurements on digital panoramic images in indicating sex and age in a subadult population. Methods: Panoramic images from 1,100 individuals (550 males, 550 females) ranging in age between 3 and 13 years were divided into 11 groups according to age. Ten mandibular linear dimensions (ramus height, condylar ramus height, coronoid ramus height, maximum ramus breadth, minimum ramus breadth, bigonial breadth, bicondylar breadth, bimental breadth, lateral length of mental foramen, vertical length of mental foramen) and gonial angle were measured bilaterally. Univariate discriminant and regression analyses were performed to determine the most significant predictors of sex and age.

Results: All linear dimensions were higher for males than females for all age groups. Gonial angle did not vary significantly by gender. Discriminant analysis showed linear measurements and gonial angle exhibited poor accuracy in sex determination. Despite a positive correlation between linear measurements and a negative correlation between gonial angle and age, the discriminant analysis found that age estimations made using all the recorded variables had an accuracy of only 66.72%.

Conclusion: In line with previous research on different populations, findings for the selected subadult population sample showed that the growing mandible does not present sufficient sexual dimorphism to be useful for sex and age estimations.

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Forensic odontology; digital panoramic radiography; sex and age estimation

Introduction

Chronological age and sex estimations are used in forensic medicine and anthropology mainly within the context of human identification for legal or social clarification. An important factor in criminal as well as civil investigations, the procedure may be conducted on living individuals, as is increasingly required within the context of immigration, although it tends to be performed on full cadavers or with available skeletal remains [1].

Age and sex determination involve a complex array of factors. Most of the bones that make up the adult human skeleton display sexual dimorphism, and studies claim a sexing accuracy of 90% from the skull and mandible [2]. Moreover, because the mandible and teeth are extremely fire-resistant and are usually recovered largely intact despite unfavourable conditions [3,4], forensic odontology has gained importance as a tool for identifying skeletal and dental remains.

The mandible presents greater growth than other facial bones and is associated with the most representative morphological changes in terms of size and remodelling throughout human growth [5] from both a developmental and functional point of view; therefore, the mandible is naturally expected to be an appropriate bone for use in estimating the age of children and adolescents [6]. Since growth rates and duration differ distinctly between males and females throughout the lifespan, mandibular morphology differentiates between sexes according to the age of the individual. Moreover, the numerous anatomical landmarks provided by the mandible have led many studies to be conducted using various linear dimensions as well as gonial angles to provide sex [7–12] and age [6,13] estimations of children, albeit with controversial results.

Due to the population-specificity of skeletal characteristics, population-specific osteometric standards are needed for sex and age estimation [8,9,14]. To our knowledge, there have been no published studies examining the use of the mandible for gender and age identification of the Turkish subadult population and no previous study has been conducted with such a large number of orthopanoramic radiographs, despite their wide availability.

Research into age and sex determination from dental radiographs has largely relied on the use of lateral cephalograms and panoramic radiographs. However, because superimposition of the ramus makes bilateral mandibular assessment impossible from lateral cephalograms, panoramic radiographs have gained in popularity and are routinely used in clinical practice to assess mandibular vital structures

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Radiographic Evaluation of Mandibular Measurements as Predictors of Age and Sex in a Subadult Population.

bilaterally [15]. The high rate of prescriptions for panoramic radiographs provides a great opportunity to study age-related morphological changes as well as differences and correlations between sexes in a specific population. Therefore, the present study was conducted to assess the accuracy of various mandibular linear and gonial-angle measurements on digital panoramic images as indicators for sex and age in a prepubertal Turkish population sample.

Material and methods

This retrospective study was performed using digital panoramic images of patients aged 3–13 years taken between January 2017 and May 2019 for various diagnostic purposes. All radiographs were obtained using a Sirona Orthophos XG (Sirona Dental Company, Germany) with a fixed magnification rate of 1.2 and exposure parameters of 60 kVp, 5 mA, 14.1 s according to patient age. Measurements were corrected to provide absolute values.

The sample size required for 95% confidence and 5% sensitivity was calculated using simple random sampling based on previous studies [6,16]. Accordingly, the minimum sample size for ANOVA was calculated and determined to be 13 panoramic images for both females and males of every age group. Therefore, this study was conducted with 100 digital panoramic images (50 female, 50 male) of each age group, for a total of 1,100 images (550 female, 550 male). Criteria for selection were as follows: good-quality standard panoramic images without any exposure or positioning errors; no pathological lesions, fractures or deformities; no systemic, developmental, or congenital diseases that could affect skeletal development.

All digital panoramic images were saved in JPEG format and exported to the Image J image processing program (National Institutes of Health and the Laboratory for Optical and Computational Instrumentation, USA) for linear and angular measurement. All images were viewed on a 27" monitor (Lenova L27Q-10 27" 4 ms QHD IPS, China) at an image resolution of 2560 × 1440 pixels. Image calibration was performed to obtain 1:1 magnification, and all measurements were obtained bilaterally by a single observer. Intra-observer consistency was assessed by repeating each measurement three times at one-week intervals, and the mean values for the three measurements were calculated and recorded.

Discriminant function coefficients used to determine sex were calculated using the formula D = (discriminant function coefficient of constant) + (discriminant function coefficient of measurement × measurement of the variable (mm)). Discriminant values (D) less than the centroid of the measurement function were taken to indicate a female (G) and those greater than the centroid to indicate a male (B).

A total of 11 mandibular linear and gonial-angle dimensions were measured in cm, as follows (Figure 1) [2,17,18]:

1. Ramus height (RH): The distance between the apex of the condyle and a line drawn through the most protruding point of the lower edge of the mandibular ramus parallel to the horizontal plane.
2. Condylar ramus height (CH): The distance between the apex of the condyle and the most protruding point of the lower edge of the mandibular ramus.
3. Coronoid ramus height (CrH): The distance between the apex of the coronoid process and the most protruding point of the lower edge of the mandibular ramus.
4. Maximum ramus width (MxRB): The distance between the anteriormost point of the mandibular ramus and the outermost point of the condyle.
5. Minimum ramus width (MnRB): The shortest length of the mandibular ramus in the antero-posterior direction.
6. Bigonial width (BGW): The distance between the right and left gonion, the most prominent point at which the lower edge of the mandible and the mandibular ramus intersect.
7. Bicondylar width (BCW): The distance between the outermost points of the right and left condyles.
8. Bimental width (BMB): The distance between the mesial walls of the right and left mental foramen.

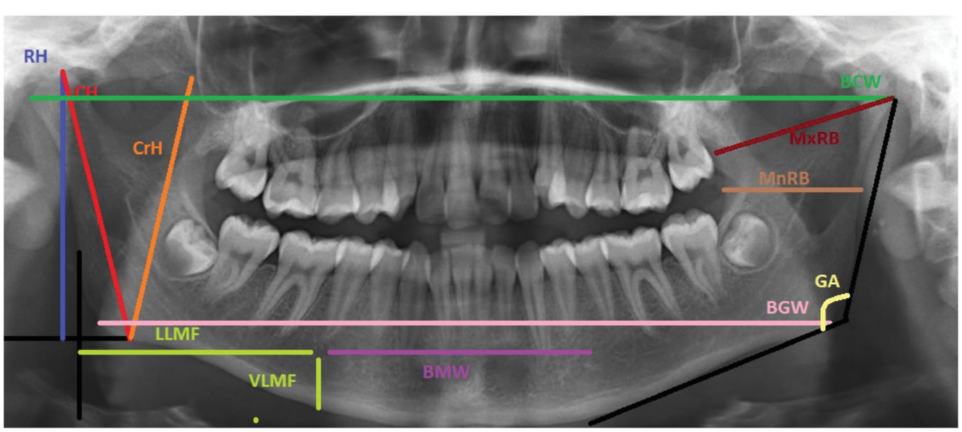

Figure 1. Digital orthopantomograph showing assessed mandibular variables. RH: Ramus height; CH: Condylar ramus height; CrH: Coronoid ramus height; MxRB: Maximum ramus breadth; MnRB: Minimum ramus breadth; BGW: Bigonial width; BCW: Bicondylar width; BMW: Bimental width; LLMF: Lateral length of mental foramen; VLMF: Vertical length of mental foramen; GA: Gonial angle.

9. Lateral length of mental foramen (LLMF): The length of a horizontal line drawn from the outer edge of the mandibular ramus to the distal border of the mental foramen.
10. Vertical length of mental foramen (VLMF): The length of the vertical line drawn from the lower wall of the mental foramen to the lower edge of the mandible.
11. Gonial angle (GA): The angle formed at the intersection of the tangential line drawn through the outer edge of the mandible ramus and the tangential line drawn on the lower edge of the mandible.

Statistical analysis

Statistical analysis of data was performed using SPSS 22.0 (SPSS Inc., Chicago IL, USA). Intra-Class Correlation Coefficients (ICC) were calculated to determine intra-observer consistency between repeated measurements with 95% confidence. Covariance analysis (by age) was used to determine differences between right and left measurements and differences between measurements of males and females. Simple linear regression analysis was performed to determine the age of each child using the explanatory variables. Canonical discriminant analysis was used to estimate sex. Data is presented as a minimum and maximum measurements with standard deviations. Differences of $p < .05$ were considered to be statistically significant.

Results

A mean ICC value of 0.981 (0.979–0.983) showed excellent consistency between repeated measurements. The analysis was revealed no statistically significant differences between right and left mandible parameters for either sex; therefore, the mean of the two sides was used in further statistical analysis.

Mean values of all the linear dimensions were higher for males than females, regardless of age (Table 1). Co-variance analysis showed that with the exception of MxRB and VLMF ($p > .05$), these differences were statistically significant ($p < .001$). No significant differences were found in gonial angle values for males and females ($p > .05$). Descriptive statistics of 11 different measurements and associated univariate F ratios and Wilk Lambda values for males and females are also presented in Table 1. According to Wilk's Lambda values and f-statistics, the mandibular measurement with the greatest dimorphism is CrH. Results of Canonical Discriminant Analysis are shown in Table 2. Calculations of the accuracy of correct predictions for each discriminant function showed CrH to have the greatest dimorphism; however, the accuracy of sex predictions for CrH was only 52.5%. Moreover, when all linear measurements and gonial angle were evaluated together, the grouping accuracy was only 55.9%, indicating that these variables were not effective in classifying gender.

Minimum and maximum values for all 11 measurements by age are given in Table 3. Statistically significant positive correlations were found between linear measurements and age, whereas gonial angle and age were negatively correlated ($p < .05$) (Table 4). Canonical discriminant analysis showed an estimation accuracy of 66.72% when all 11 variables were used in determining the age (Figure 2).

Principal component analysis conducted to determine the effects of different variables on age estimation found that

Table 1. Minimum and maximum measurements of boys and girls in cm and statistical data for 11 mandibular measurements.

Variable	Boy M	Girl M	Anova p <.001	Wilks' Lambda	F	P
CH	4.69–5.76^A	4.65–5.68^B	<.001	0.997	3.362	.067
CrH	4.44–5.53^A	4.37–5.44^B	<.001	0.996	4.633	.032
RH	4.50–5.63^A	4.48–5.56^B	.887	0.998	2.173	.141
MxRB	2.64–3.05	2.64–3.05	.044	0.999	0.005	.942
MnRB	1.96–2.36^A	1.95–2.34^B	<.001	0.999	1.120	.290
LLMF	4.54–5.50^A	4.49–5.46^B	.553	0.998	2.375	.124
VLMF	0.62–0.99	0.61–0.993	.791	0.999	0.352	.553
GA	125.3–135.1	126.55–134.25	<.001	0.999	0.381	.537
BGB	13.40–15.74^A	13.22–15.64^B	<.001	0.996	3.904	.048
BCB	14.58–16.62^A	14.5–16.55^B	.047	0.998	1.663	.197
BMB	4.42–5.36^A	4.38–5.35^B	<.001	0.999	0.762	.383

Different letters in the same row represent significant differences ($p < 0.05$).

Table 2. Discriminant function coefficients, group centroids, and percentage of correct classifications.

Variables	Discriminant function Coefficients	Group centroids	Average accuracy %
Constant	−9.263	$G = -0.065$ $B = 0.065$	52.45%
CrH	0.187		
Constant	−15.212	$G = -0.039$ $B = 0.039$	52.27%
BCB	0.098		
Constant	−10.376	$G = -0.046$ $B = 0.046$	51.91%
BGB	0.207		
Constant	−29.599	$G = -0.018$ $B = 0.018$	51.91%
GA	0.530		
Constant	−9.939	$G = -0.055$ $B = 0.055$	51.82%
CH	0.191		
Constant	−9.161	$G = -0.044$ $B = 0.044$	51.45%
RH	0.182		
Constant	−9.939	$G = -0.055$ $B = 0.055$	50.73%
LLMF	0.191		
Constant	−10.844	$G = -0.032$ $B = 0.032$	50.73%
MnRB	0.503		
Constant	−4.285	$G = -0.018$ $B = 0.018$	50.09%
VLMF	0.530		
Constant	−10.220	$G = -0.026$ $B = 0.026$	49.55%
BMB	0.209		
Constant	−13.860	$G = -0.002$ $B = 0.002$	48.82%
MxRB	0.487		
Constant	−13.815	$G = -0.164$ $B = 0.164$	55.9%
CH	0.202		
CoH	0.422		
RH	−0.401		
BGB	0.078		
LLMF	0.045		
VLMF	−0.249		
GA	0.073		
MxRB	−0.767		
MnRB	0.165		
BCB	0.017		

Table 3. Minimum and maximum values in cm for all measurements, by age.

Age	CH	CrH	RH	MxRB	MnRB	BCB	BGB	BMB	LLMF	VLMF	GA
3	4.24–4.48	3.97–4.24	4.04–4.26	2.45–2.6	1.73–1.92	13.65–14.38	11.71–12.42	3.88–4.24	4.04–4.26	0.48–0.60	134.01–135.18
4	4.44–4.75	4.14–4.52	4.28–4.49	2.56–2.71	1.9–1.99	14.21–14.72	12.72–13.52	4.24–4.67	4.28–4.49	0.56–0.68	131.26–136.76
5	4.53–4.89	4.26–4.71	4.36–4.67	2.59–2.78	1.94–2.16	14.31–15.17	13.25–14.01	4.37–4.87	4.45–4.84	0.59–0.72	129.34–135.08
6	4.79–5.10	4.54–4.88	4.63–4.96	2.67–2.86	1.99–2.20	14.81–15.72	13.74–14.53	4.47–5.01	4.54–4.93	0.61–0.74	127.86–134.4
7	4.95–5.26	4.71–5.07	4.85–5.16	2.73–2.92	2.00–2.27	15.04–16.06	14.30–15.07	4.65–5.23	4.76–5.04	0.66–0.79	128.28–133.12
8	5.13–5.38	4.91–5.14	5.03–5.20	2.75–2.94	2.06–2.26	15.13–16.40	14.46–15.34	4.73–5.30	4.87–5.23	0.70–0.84	122.33–136.91
9	5.14–5.47	4.89–5.20	5.00–5.31	2.79–3.00	2.08–2.33	15.06–16.66	14.44–15.81	4.63–5.45	5.11–5.41	0.76–0.91	126.22–132.28
10	5.23–5.60	4.90–5.31	5.11–5.45	2.8–3.02	2.10–2.32	15.30–16.91	14.56–15.83	4.70–5.52	5.08–5.49	0.83–0.97	125.18–131.24
11	5.35–5.72	5.10–5.50	5.25–5.63	2.86–3.13	2.17–2.42	15.62–17.13	14.86–16.00	4.78–5.63	5.16–5.59	0.91–1.08	125.31–130.45
12	5.56–6.00	5.36–5.82	5.42–5.89	2.95–3.15	2.22–2.42	15.70–17.17	15.12–15.86	4.90–5.57	5.33–5.61	0.95–1.17	124.59–130.95
13	5.82–6.25	5.58–6.12	5.69–6.24	3.05–3.27	2.28–2.56	15.94–17.30	15.14–16.30	4.96–5.56	5.36–5.95	0.97–1.16	124.49–128.45

Table 4. Results of Pearson's correlation coefficient analysis demonstrating correlation between age and different measurement variables.

Variables	Correlation coefficient (r)	P
CH	0.928	<.01
CrH	0.917	<.01
RH	0.940	<.01
MxRB	0.860	<.01
MnRB	0.807	<.01
BCB	0.781	<.01
BGB	0.859	<.01
BMB	0.705	<.01
LLMF	0.906	<.01
VLMF	0.908	<.01
GA	−0.613	<.01

the combined use of 3 variables (RH, CH and CrH) provided the best explanation of total variance (88.63%). However, discriminant analysis conducted using these 3 variables showed an accuracy of only 52.17% in age estimation (Figure 3). In view of the possibility that the sex of the participants was a confounding factor in age estimation, discriminant analysis was performed again using all the variables, but with each age between 3 and 13 years divided into two subgroups by sex. However, this procedure yielded a rate of correct age estimation of only 43.72% (Figure 4).

Discussion

Forensic medicine involves the use of the human skeleton to identify human remains as well as living individuals. This data is also used by anthropologists to construct ethnographic profiles of specific communities. Regarding the estimation of age and sex as a part of identification, unlike direct measurement from dry mandibles, which are rarely used, clinical images (e.g. x-rays, ultrasonography, CT scans, and MRIs …) currently provide a great amount of complementary sources of information for forensic analysis through indirect measurement [9,12,15]. The high rate of prescription of panoramic radiographs, which are commonly used in routine dental practice to assess vital mandibular and maxillary structures, offers a useful tool for the study of morphological differences between males and females and the changes that occur with age. Although the panoramic radiographs have some limitations, like difficulties in controlling the magnification and geometric distortion of the images, the interference of superimposed images are not encountered and it provides an accurate and reproducible method of measuring the chosen points with contrast, brightness enhancement, and enlargement [19]. However, as suggested by some authors [20,21] distortion of measurements can be acceptable by positioned the patient's head properly in the equipment. Thus, all radiographs in our study were made by the same experienced dental radiographer with the same apparatus and selected radiographs were of good enough image quality to reduce possible errors.

The present study was conducted with a large sample size in order to determine the reliability of applying the indirect measurement of mandibular parameters from panoramic radiographs to the identification of age and sex of living individuals at different ages of prepuberty. While the accuracy of age and sex estimation using panoramic radiographs has frequently been described in the literature for various regions and ages [2], the present study was the first large-scale investigation of a prepubertal Turkish population.

In order to avoid sampling biases, the study population consisted of equal numbers of males and females. Moreover, in order to investigate as many mandibular measurements as possible so as to identify a correlation between these parameters and age and sex, 11 variables were chosen based on evidence from previous studies that reported a high accuracy in determining age and sex using panoramic radiographs [1,2,7,8,16,17,22].

In line with previous studies [1,17,23], the present study found no statistically significant difference between right- and left-side linear and angular measurements; therefore, the means of the two sides were used in subsequent statistical analysis.

One of the most reliable methods for estimating the sex of unidentified skeletal remains, discriminant function analysis has been used increasingly as a reproducible method that reduces subjective judgement in determining sex from skeletal elements. However, it has been well established that the results of discriminant function analysis for one population cannot be applied to another [24] because of significant sex-related differences stemming from various correlated genetic, hormonal and environmental factors. Previous studies have also identified differences in growth patterns between different prepubertal populations that may affect sex identification [1,8,25,26]. This study is the first in which discriminant function analysis was performed to identify the most significant mandibular parameters for predicting sex in the Turkish population across the prepubertal period.

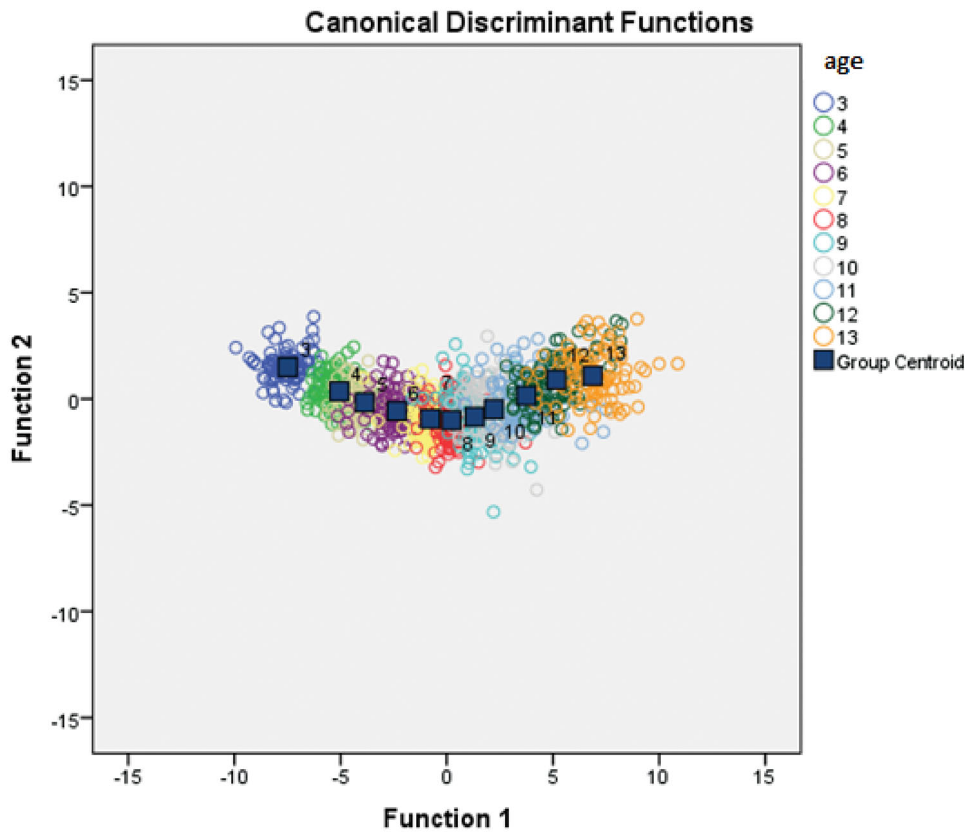

Figure 2. Canonical discriminant function graph for grouping age using all variables.

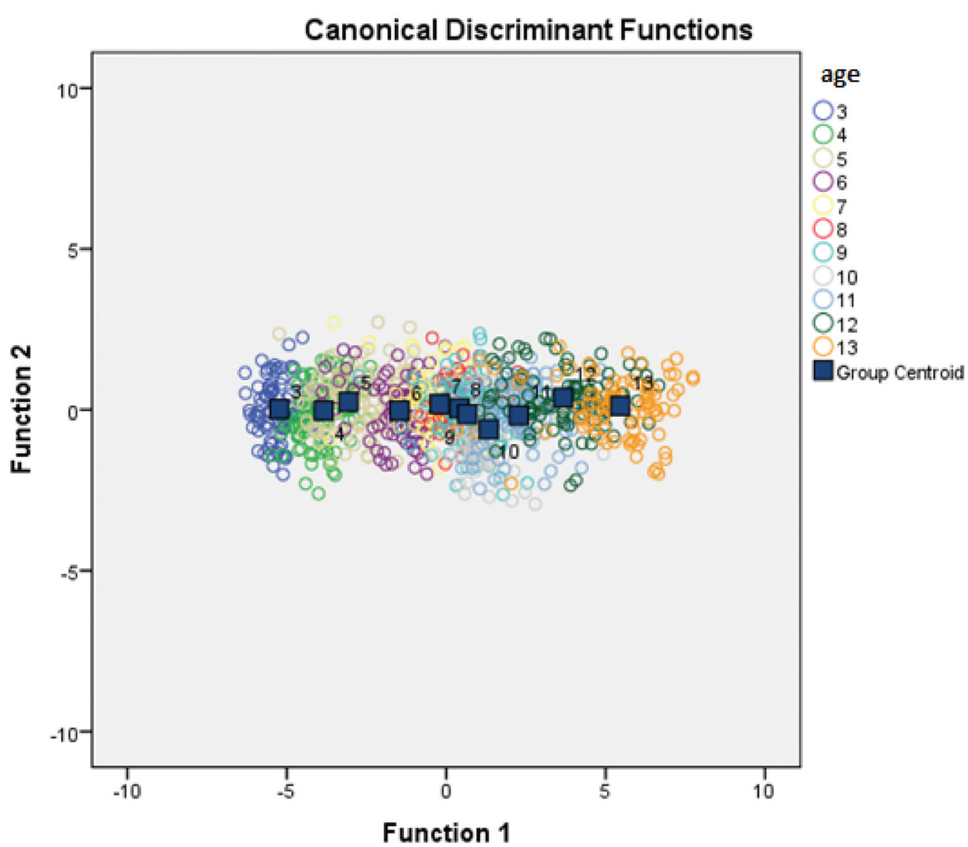

Figure 3. Canonical discriminant function graph for grouping age using ramus height, condylar ramus height and coronoid ramus height.

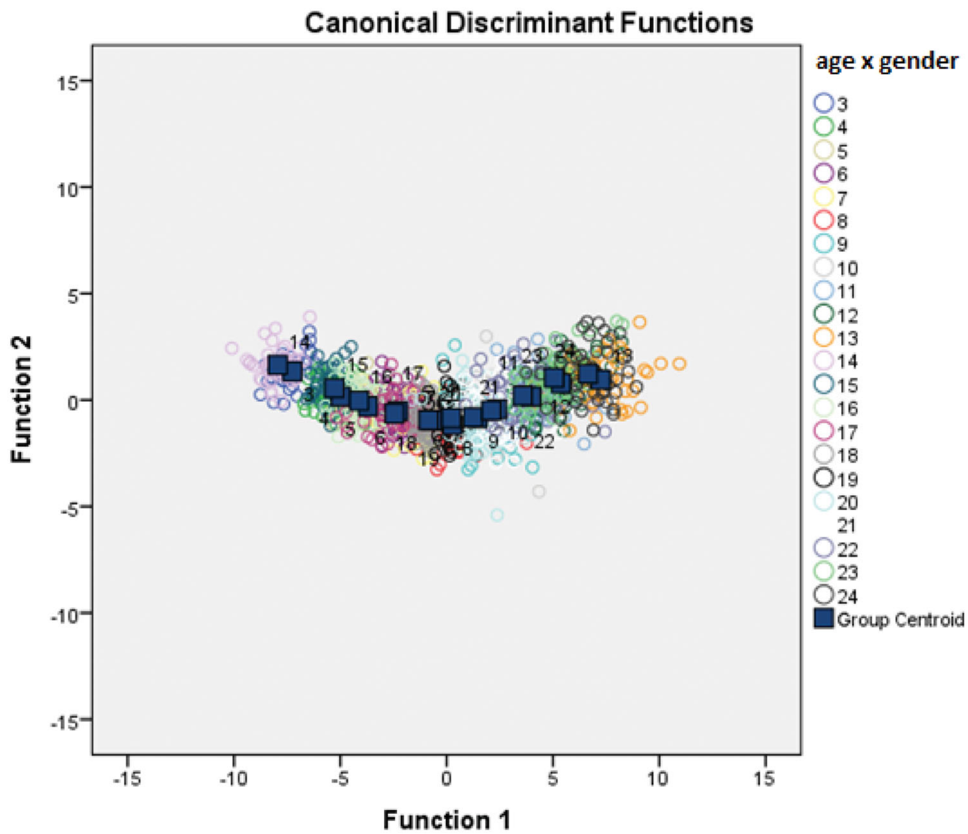

Figure 4. Canonical discriminant function graph for grouping age-gender combinations using all variables.

Consistent with previous panoramic studies [1,8,11,12,14,17], the present study found most of the measured linear mandibular variables (CH, CrH, RH, MnRB, BGW, BCW, BMW, LLMF) to be significantly larger in males as compared to females. However, discriminant function analysis revealed that the use of all measured variables generated a poor prediction of sex (55.9% accuracy), and the best single predictor (CrH) had an accuracy of only 52.5%. These results seem to indicate that mandibular dimorphism in pre-adolescence may be insufficient for determining sex during the developmental period.

This finding is in agreement with earlier phenomenal studies of children that assumed sexual dimorphism does not sufficiently occur until puberty. In a 2007 study conducted with 96 subadult mandibles aged 1–17 years, Franklin et al. [27] found no considerable dimorphism in mandibular shape or size among African American, South African, or Asian populations until approximately 15 years of age. Similarly, Akhlaghi et al. [7] found metric mandibular parameters (mean symphysial height, mental foramen to alveolar border distance, mental foramen to alveolar border distance, mental angle, minimum ramus breadth, bigonial breadth and mandibular body length) were of limited use in the sex determination of 16 mandibles (9 males, 7 females) from Iranian cadavers less than 12 years old. In another study, de Oliveira et al. [26] used lateral cephalometric radiographs from 218 patients (107 females, 102 males) aged 6–20 to measure ramus length for the purpose of sex identification. According to their results, sexual dimorphism was not observed until age 16, and sex prediction from ramus length had an accuracy of only 54%, which is similar to the rate found in the present study (51.45%).

While the size of the mandible is influenced by various factors other than sex, including genetics and nutrition [27,28], the overall size and thickness of the male mandible is generally accepted to be greater than that of the female due as a result of differences in growth patterns and muscular activities [1,29]. However, the effects of sex hormones such as oestrogen and progesterone on the speed of bone growth are observed following puberty, whereas during the prepubertal stage, growth and thyroid hormones are the dominant hormones affecting bone growth [30]. Considering that the present study was conducted on mandibles of children in the prepubertal stage, it can be suggested that the influence of sex hormones on craniofacial morphological growth during prepuberty is insufficient to allow for accurate predictions of sex from mandibular parameters.

As regards the relationship between gonial angle size and sex, the present study found no statistically significant differences between males and females. While this finding is in agreement with a number of previous studies [1,31,32], reports of the effect of gender on gonial angle have varied. Other studies have indicated a significantly higher mean gonial angle value for females [2,12,17,33,34], and still, others found a significantly higher mean gonial angle value for males [5,9]. The discrepancies among studies may be attributed to genetic differentiation among study populations as well as to differences in the age ranges of the samples examined. The fact that the present study included only prepubertal children who had not yet undergone a growth spurt suggests that the observed lack of sexual dimorphism in gonial angle value is related to the incomplete development of secondary sex characteristics during the prepubertal term.

When findings for age estimations are examined, the present study demonstrated positive correlations between age and various mandibular linear measurements, which were similar to those of previous studies conducted with children [17,26,35]. Given the pattern of mandibular growth, i.e. growth in a posterior-superior direction, resulting in an anterior-inferior displacement, the observed increases in linear measurements were predictable [36]. Yet despite these correlations, the discriminant analysis showed that prediction accuracy for age using all variables was just 66.72% overall, as the analysis was unable to distinguish between close ages. Moreover, although RH, CH and CrH provided the best combination of variables for age prediction, their combined accuracy was only 52.1%. In view of the possibility that the accuracy of age estimation was negatively affected by variations between children of different sexes at the same age, discriminant analysis was performed again separately for males and females; however, this resulted in prediction accuracy of only 43.72%, the worst performance of any of the analyses conducted. Due to differences in study populations – the current study was conducted with prepubertal children, whereas previous studies were conducted with either very young children or combined child and adult populations – it is not possible to compare the results of this study regarding age prediction from various linear measurements of the mandible.

With regard to the relationship between gonial angle size and age, the current study demonstrated a negative correlation. Despite variations in gonial angle among population groups [17], the majority of studies conducted with young subjects found significant decreases in gonial angle values with increases in age [31,32,37]. The gonial angle is formed by the line tangent to the lower border of the mandible and the line tangent to the distal border of the ascending ramus condyle. The shape of the mandibular base, especially the gonial angle, correlates with the function and shape of the muscles of mastication [38]. An increase in masseter force may play a role in reducing the size of the gonial angle in growing individuals. The smaller angle observed in older children may also be related to the posterior rotation of the mandible resulting from an age-related increase in ramus height.

The findings of this study revealed that mandibular measurements during the developmental period may not be sufficient to predict age and sex, however, the anthropometrical measurements for each age term during the growth process provide unique data for the growth variations for the involved population.

Finally, it should be noted that because this study provides average measurements of a variety of mandibular parameters taken from panoramic radiographs for each year of a subadult Turkish population between 3 and 13 years of age, it is especially significant for forensic anthropology. Differences in skeletal characteristics among populations highlight the need for population-specific bone-metric standards, and it is expected that different outcomes would be obtained with samples comprised of different age groups and nationalities.

Conclusion

The findings for the selected Turkish population in this study support those of previous studies with different populations that indicate an absence of sexual dimorphism in the growing mandible, which precludes its use in obtaining accurate sex and age estimations. Further studies with adult and elderly subpopulations and different prediction methodologies are recommended to provide standards for sex and age estimations for the Turkish population.

Ethical approval

This study was received approval from the Institutional Human Subject Review Ethics Committee (approval number 2017/397).

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Ezgi Ozkara. The first draft of the manuscript was written by Ayca Tuba Ulusoy and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Disclosure statement

The authors declare that they have no conflicts of interest related to this study.

Informed consent

For this type of study, formal consent is not required.

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