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Length of the ramus of the mandible as an indicator of chronological age and sex: A study in a group of Egyptians

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ABSTRACT

Background: The determination of age and sex is crucial for establishing a human identity. The mandible is an accessible and a durable bone that would be very useful in this respect.
Aim: To test if the length of the ramus of the mandible can be used to predict the age and the sex in a group of Egyptians
Subjects and methods: The length of the ramus of the mandible was measured in lateral craniofacial scans of 213 individuals (99 males and 114 females) with an age range of 7–58 years using cone-beam computerized tomography (CBCT).
Results: Sexual dimorphism was not observed until the age of 17 years in this sample of population. There was not found any significant differences in the length of the ramus of the mandible between males and females in the age range of 7 to less than 17 years (P-value = 0.2495). There was found a significant difference between males and females for the mean length of the mandible ramus in the age range of 17–58 years (P-value < 0.0000). It predicts sex with an accuracy of 67 %. There was a positive correlation between $\sqrt{ln\ (age)}$ and $ln\ (ramus)$ (r = 0.73, P-value < 0.0001 for females and r = 0.85, P-value <0.0001 for males).
Conclusion: The mandibular ramus length is valuable in age estimation and less valuable in sex determination. Computerized tomography examination is a safe and an accurate procedure with minimal radiation exposure, and provides valuable precise information regarding mandible measurements.

Background

Forensic identification using bone examination has been useful and reliable for a long time. It is easier, more accessible and relatively cheaper than complex methods of tissue identification. Furthermore, parts of bone have been increasingly found to be useful for answering questions related to the age and sex of an individual [1].

The mandible is the hardest and strongest bone of the skull, and it exhibits a high degree of sexual dimorphism [2,3]. The mandible helps to identify the sex in living as well as in dead individuals and human remains. In cadavers with an advanced degree of decomposition, burns or disfigurement, identification from tissue typing and DNA profiling becomes very difficult, and bone becomes a more reliable tool for identification in these cases [4].

Identification of age is needed in criminal investigations and in civil cases, such as immigration, suspected violations of the laws regarding the age of marriage and in cases of immigrant foreigners who do not have valid identification documents. Age estimation is also required in other civil cases, such as requests of asylum or old-age pension, and for adoption purposes in cases of unaccompanied minors. Additionally, it is needed in investigations of mass disasters and war atrocities [5].

The skull and hip bones are the most informative bones in terms of sex identification, as they are strongly affected by sex hormones during union and shaping of the bones at puberty. It is necessary to reduce the use of

Abbreviations: Cm, centimeters; CT, computerized Tomography; CBCT, cone beam computerized tomography; Etc, etcetera; Mm, millimeters; %, per cent; USA, United States of America; S, second.

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X-rays of the hip joint to avoid teratogenicity and to use and combine other methods for sex identification. Franklin and Cardini [6] believed that the developmental and functional aspects of the mandible render it an appropriate indicator of an individual's age and sex.

The mandible shows morphological changes related to size and remodeling during human growth. It has been found that there is a strong correlation between the chronological age and the mandible morphology, especially that of the ramus [7]. Additionally, ancestry and genetic factors are believed to modify bone age validation for chronological age determination. Thus, there is a need to establish national references for chronological age evaluation by anthropological indices before they can be used in court decisions [8].

Cone-beam computerized tomography (CBCT) utilizes divergent X-ray beams forming a cone to image bone and soft tissues. It provides much less radiation exposure than conventional CT and definitely less than ordinary X-ray imaging [9].

This study aimed to determine the efficacy of the mandibular ramus length as a tool for identification of the age and the sex using the CBCT imaging in a sample of Egyptians. Additionally, to establish reference values from the tested sample to determine the age and the sex in Egyptians by measuring the mandibular ramus length in lateral 3-dimensional craniofacial CBCT scans.

Subjects and methods

After approval of the study by the Institutional Research Board of the Faculty of Medicine at the Mansoura University, the length of the ramus of the mandible (the distance between the condylon superior (Cs) and the gonion (Go) was measured in lateral craniofacial scans of 213 individuals (99 males and 114 females) who underwent CBCT scans for various reasons (e.g. before root canal treatment) (Fig. 1). The scans of the individuals, who ranged in age from 7 to 58 years (average 26.5 ± 13.8 years), were examined. The male contributors were in age range (7–58) years, an average of 25.88 ± 13.64 years. Female contributors were (7–58) years old with the average of 27.02 ± 13.93 years (Fig. 2). Ninety-nine participants were in the age range of (7–21 years); 57 females and 42 males, and 114 participants were in the age range from more than 21 years to 58 years; 57 females and 57 males. Subjects were carefully selected during the period from June 2016 to January 2017. Cases with a history of mandibular fractures or surgery, bone diseases or metabolic disturbances were excluded. Additionally, cases with a history of orthodontic treatment, orthognathic surgery, head trauma or surgery, systemic disease, craniofacial microsomia or hereditary facial asymmetry were excluded from the study. Clinical examination was performed to exclude facial asymmetry or mandible abnormality in all subjects included in the study.

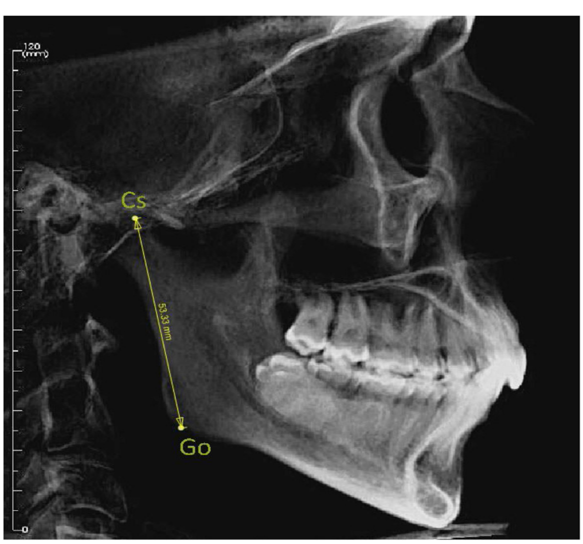

Fig. 1. Determination of the length of the ramus of mandible in millimeters by measuring the distance between condylion superior (Cs) and gonion (Go) in lateral cone beam computerized tomography (CBCT) scan.

Patients' consents were obtained, and careful history taking and medical examination were performed. Imaging by CBCT was performed for the selected subjects by the same radiologist to avoid any technical error. The device used in this study was iCat Next Generation (Imaging Science International, Hatfield, PA, USA). The imaging protocol used was as follows: Field of view, 16 cm diameterx13 cm height; voxel size, 0.25 mm; and scan time, 14.7 s. The image analysis was performed with Anatomage Invivo 5.1 software (San Jose, California, USA).

The mandibular ramus length was measured from the Cs, the highest point of the condyle of the mandible, to the 'Go'; the outermost point at the junction between the body and the ramus of the mandible. The Go point was identified as the most lateral point at the bisector of the angle of the mandible. The Cs was identified as the highest point of a straight line drawn parallel to the horizontal plane passing through the superior surface of the mandibular condyle [10].

Data were tabulated, coded and analyzed using the SAS computer program, version 14.1. Values were compared using the Welch two-sample t-test, student's t-tests, analysis of variance and the accuracy of the personal identification was assessed through general linear model analysis.

Results

The results showed that sexual dimorphism of the mandible ramus length was not seen until the age of 17 years (Table 1). There was no significant difference between males and females in the age range of 7- < 17 years (P-value = 0.2495, t = -1.17 for student's t-test). On the other hand, men showed longer ramus lengths of the mandible than women at the age range of 17–58 years, and there was found a significant difference for the mean length of the ramus of the mandible between men and women in the studied sample (P-value <0.001, t = -10.59) (Figs. 3 and 4).

The Regression models showed that, based on the mandible ramus length measurement using CBCT, it is possible to predict sex with an accuracy of 67 % (Table 2). Furthermore, it is possible to predict sex with an accuracy of 82 % when the length of ramus is greater than 5.00 cm and 89 % when the length of the ramus is greater than 5.80 cm.

Age estimation

Because sex has a very important role in the vertical development of the ramus of the mandible, we calculated the regression lines for males and females separately. The original data showed that age and ramus length had an exponential curve and had heteroscedasticitic error. A logarithmic transformation was made to obtain the linearity, and then a square root transformation was made to stabilize the error variance (Figs. 5 and 6). Based on the regression analysis, two formulae were developed to calculate the approximate chronological age of an individual using the length of the ramus of the mandible.

Female model

$$\sqrt{ln\hat{age}_f}) = -0.217\,\mathrm{SE} = 0.174) + 1.209\,\mathrm{SE} = 0.106) \times ln(ramu_f)$$

(t = -1.250, p-value = 0.2148) (t = 11.44, p-value = 0.0000)

Male model

$$\sqrt{ln\hat{age}_m}) = -0.0196\,\mathrm{SE} = 0.110) + 1.025\,\mathrm{SE} = 0.063) \times ln(ramus_m)$$

(t = -0.18, p-value = 0.859) (t = 16.18, p-value = 0.0000)

Dependent variable: $\sqrt{lnage})$ Independent variables: $ln(ramus)$ and Sex

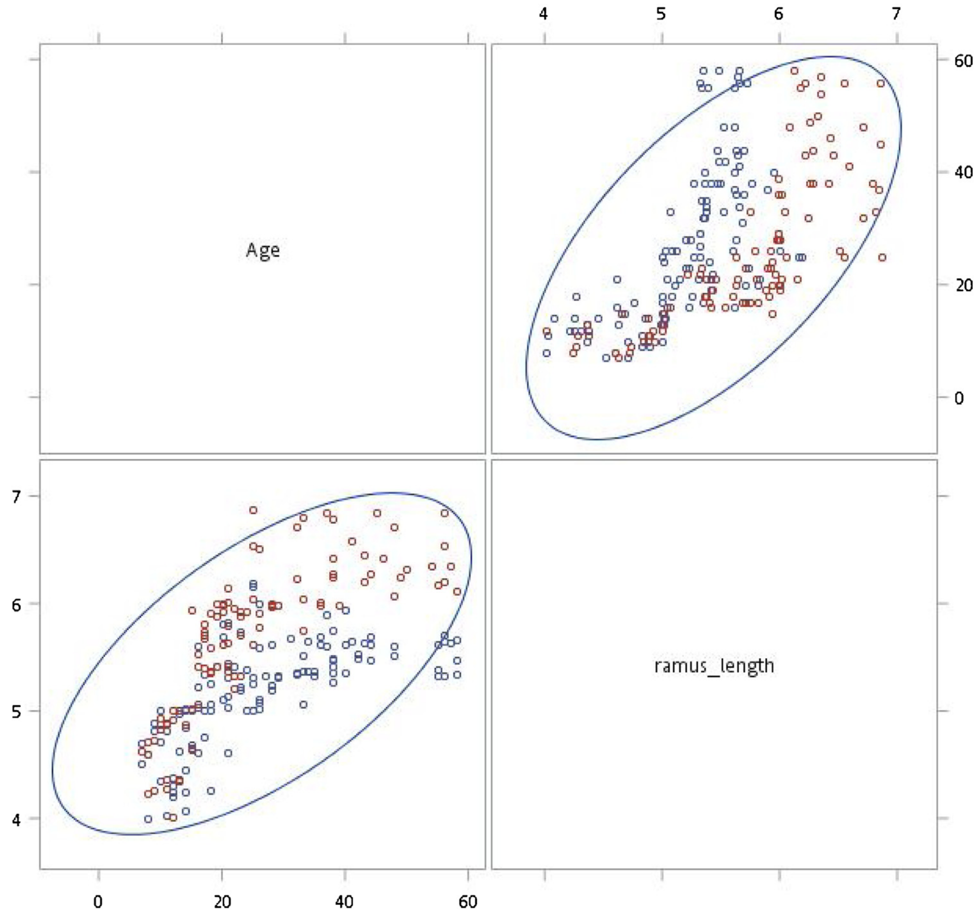

Fig. 2. Scatter plot for the raw data, red dot: male, blue dot: female.

Table 1
Mandibular ramus length in the contributors of the study according to their age and sex.

	Age (7-<17) years N. = 59		Age (17–58) years N. = 154	
	Males N. = 26	Females N. = 33	Males N. = 73	Females N. = 81
Mandible Ramus Length (Mean ± SD)	4.79 ± 0.43	4.66 ± 0.37	6.044 ± 0.42	5.42 ± 0.32
Test of Significance (P-value)	0.2495		<0.001	

N.; number, SD; Standard deviation. P-value is considered significant at ≤ 0.05.

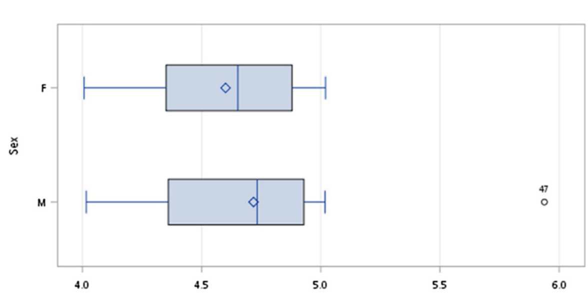

Fig. 3. Box-plot of ramus length in the age range 7 to <17 years, showing non-significant difference between males and females ($t = -1.17$, $p - value = 0.2495$). M; males, F; females.

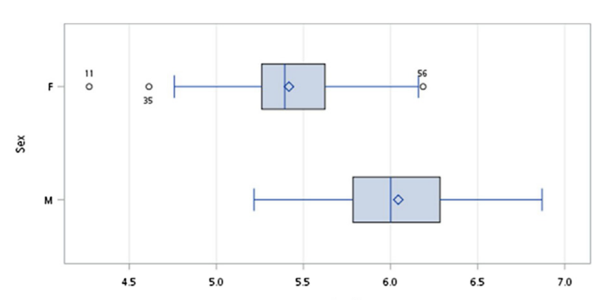

Fig. 4. Box-plot of ramus length in age range 17–58 years, showing highly significant difference between males and females.($t = -10.59$, $p - value < 0.001$).

$\sqrt{\widehat{lnage})} = -0.0331 + 1.0967 \times lnramus) - 0.1112 \times Sex$

Based upon the studied sample, men showed greater mean of *ln*(ramus lengths of the mandible) than women's at the age range of 17–58 years with $\overline{X}_m = 1.7968$, $\overline{X}_f = 1.6878$ where t = 10.53 and p-value = 0.000. There is no significant difference between 7 and 16 years for mean of *ln* (ramus) ($\overline{X}_m = 1.5626$, $\overline{X}_f = 1.5367$, t=-1.170 and p-value = 0.2451.). (Figs. 3 and 4). So, sexual dimorphism and the length of the ramus are useful in explaining the mean of an individual's age. We make

Table 2
Regression Models for sex differentiation from Mandible Ramus Length.

ANOVA Table					
Source	Df	Sum squares	Mean sum squares	F value	Pr > F
Model	2	3.15172	1.57586	172.46	<.0001
Error	210	1.91883	0.00914		
Corrected Total	*212*	*5.07055*			
Root MSE		0.09559	R square		0.6216
Mean Dep Var.		1.76476	Adjust R^2		0.6180
C.V.		5.41655			
Estimates of parameters					
Variable	df	Parameter estimates	Standard error	T value	Pr > |t|
Intercept	1	−0.03308	0.09759	−0.34	0.7350
ln(rams)	1	1.09668	0.05911	18.55	<.0001
Gender_1	1	−0.11115	0.01420	−7.83	<.0001

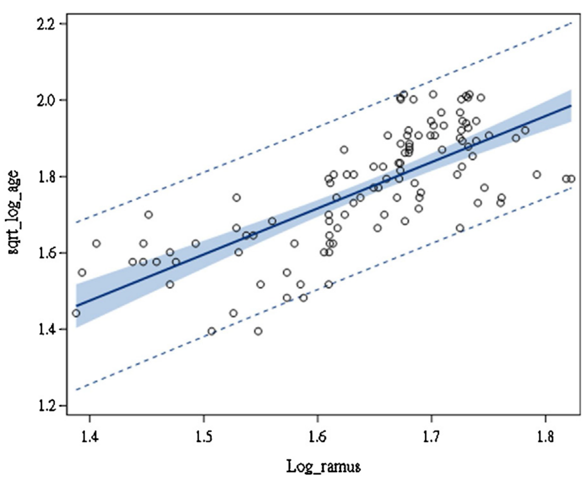

Fig. 5. Female fitted model, Mean Square Error (MSE) = 0.0114, r = 0.734. The dash lines are predicting confidence interval, bold line is fitted regression line and dots are observations (after transformation).

transformations for age and length of the ramus to $\sqrt{lnage)}$ and *lnramus*). We run a linear regression model for the dependent variable $\sqrt{lnage)}$, with the independent variables, sex and the *lnramus*). The regression model can be written as $\sqrt{lnage)} = \beta_0 + \beta_1\ lnramus) + \beta_1\ sex + \varepsilon_i$. The result is in Table 2. ANOVA table shows the model is significant and the result is as follows.

$\sqrt{\widehat{lnage})} = -0.0331 + 1.0967 \times lnramus) - 0.1112 \times Sex$, where $R^2 = 0.6212$. Also, simple linear regression models were constructed for males and for females, separately. The estimated model is as follows, for females, $\sqrt{\widehat{lnage_f})} = -0.217 + 1.209 \times ln(ramus_f)$ where $R^2 = 0.5388$, SE = 0.174, t = −1.250 and p − value = 0.2148 for intercept ; SE = 0.106, t = 11.44 and p − value = 0.0000 for the slope. For males, $\sqrt{\widehat{lnage_m})} = -0.0196 + 1.025 \times ln(ramus_m)$ where $R^2 = 0.7297$, SE = 0.110, t = −0.18 and p − value = 0.859 for intercept ; SE = 0.063, t = 16.18 and p − value = 0.0000 for slope. We notice that male model has better explainability than female model due to higher R^2.

Based on the fitted models, from the ANOVA table and assuming normality, the probability was calculated; if a male has a mandibular ramus length of 6.5 cm or more, he is 65 % likely to be 30 years or older. Furthermore, we calculated a 90 % predict confidence interval at the mandibular ramus 4.5 cm, 5.5 cm and 6.5 cm for males (4.5 cm, 5.5 cm

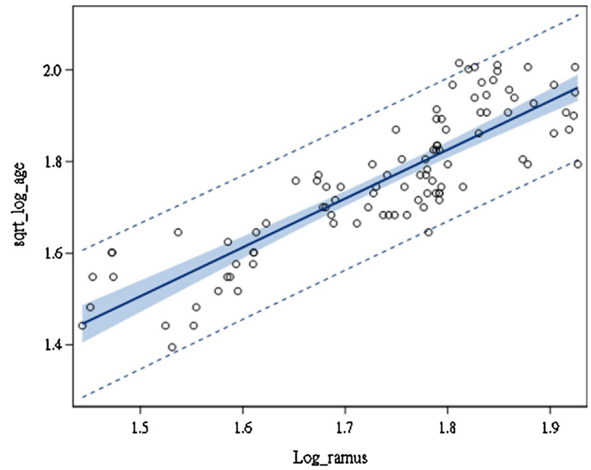

Fig. 6. Male fitted model, Mean Square Error (MSE) = 0.0061, r = 0.860. The dash lines are predicting confidence interval, bold line is fitted regression line and dots are observations (after transformation).

and 6.0 cm for females). If the mandible ramus length is 6.5 cm, this predicts that the mean age is 37.31 years old and it 90 % predicts age confidence interval (23.03, 62.58). If the ramus length is 6.0 cm, this predicts that the mean age is 44.55 years old and it 90 % predicts age confidence interval (22.83, 92.75) (Table 3).

The results showed that sexual dimorphism is not seen until the age of 17 years, and based on the mandibular ramus length measurements in this sample; it is possible to predict sex with an accuracy of 67 %. Also, there was a positive correlation between $\sqrt{ln\ (age)}$ and *ln* (*ramus*) (r = 0.73, p-value<0.0001 for females, and r = 0.85, p-value<0.0001 for males)

Discussion

Skeletal identification has a long history in forensic anthropology. New methods are continuously introduced and routinely used methods are constantly evolving [1].

The observation of the union of the epiphyses and the length of the diaphyses of long bones is the most frequently used method for identifying age, and an examination of the skull and hip bones is the most commonly used method for identifying sex. In this study, we used the mandible to identify both the age and the sex of individuals. We used three-dimensional lateral craniofacial CT scans because this imaging modality is non-invasive and can be used for living and dead individuals and in both civil and criminal cases.

CT proved efficient, simple, rapid, reliable and safe as an imaging technique for forensic practice. CT has been demonstrated to be more accurate and more informative than routine X-ray and conventional CT methods in forensic practice [9].

We found CBCT to be reliable and safe with minimal radiation exposure. It was efficient in determining sex with an accuracy of 67 %. There was no significant difference between males and females before the age of 17 years (P-value = 0.2438) in the mandibular ramus length. One formula was developed to estimate the age for males, and another formula was developed for females based on the mandibular ramus length using the data in this sample of Egyptians.

Franklin and Cardini [6] had similar results when they investigated the potential of mandibular morphology as a developmental marker for estimating age in subadult individuals of South African Bantu and African American origin. They found that that there was no statistically significant difference between girls and boys for the mean of the mandible ramus length from the age of 6–17 years. The investigators only derive a simple linear regression model for their observations, and concluded that the ramus length can be used to predict age in the

Table 3
Confidence intervals for prediction of the mean age for different lengths of the ramus of the mandible.

Ramus Length	Sex	predict	Lcl_	Ucl	Predict_mean Age (year)	Lcl_age (year) 90 %	Ucl_age (year) 90 %
4.5 cm	F	1.728	1.550	1.906	19.82	11.05	37.85
5.5 cm	F	1.843	1.665	2.022	29.90	16.00	59.56
6.0 cm	F	1.948	1.769	2.128	44.55	22.83	92.75
4.5 cm	M	1.511	1.378	1.644	9.80	6.67	14.90
5.5 cm	M	1.724	1.594	1.855	19.57	12.68	31.23
6.5 cm	M	1.902	1.771	2.033	37.31	23.03	62.58

Cm; centimeters, Lcl; lower confidence interval, Ucl; Upper confidence interval, %; per cent, F; Female, M; Male.

subadult skeleton with standard error rates between +/-1.1 years and +/-2.4 years (an accuracy, closely approaching that of standards based on the dentition).

In this study, sexual dimorphism and logarithm of ramus length can be useful to explain the mean of square root for logarithm of age from age 7 to 58 in a group of Egyptians. Simple linear regression models are derived to estimate the mean of $\sqrt{lnage}$) for male and female, separately.

These results are also in accordance with those obtained by De Oliveira et al. [11], who studied the length of the ramus of the mandible as an indicator of the age and the sex in a group of Brazilians. They found that the sex could not be distinguished based on the mandibular ramus length measurement until the age of 18 years, and that measurement could be used to determine sex with an accuracy of only 54 % using lateral cephalometric radiographs.

This finding means that, compared with a conventional CT or an X-ray imaging, the CBCT increases the efficacy of the ramus length as a tool for sex identification.

This latest conclusion agrees with the results obtained by Motawei et al. [9], who investigated the frontal sinus using CBCT as a tool for sex differentiation and found that the CBCT can be used to determine sex with an accuracy of 76.7 %. However, another group of researchers investigated the frontal sinus using plane X-ray scans and found that sex could only be determined in 64.6 % of their study sample [12]. This difference in accuracy of sex differentiation may be attributed to the differences in ethnic groups of the studied populations, the sample size, the method and equipment used by the different investigators.

Holmes and Ruff [13] stated that dietary factors affect human mandible development. Silva et al. [14] and Ichijo et al. [15] stated that ethnicity affects human mandible development and measurements. Filho et al. [16] found that stressful lifestyles affect mandible development and function.

Our results agree with the results of More et al. [17], who analyzed 1000 dental X-rays of an Indian population to determine whether the length of the ramus of the mandible could be used to determine sex. They concluded that measuring the length of the mandible ramus is helpful for sex determination with an overall accuracy of 69 %.

Mandible shape and measurements are affected by sex hormones. Weinberg et al. [18] observed a biological link between androgen exposure in prenatal period and the development of male facial characteristics.

Coquerelle et al. [19] investigated whether the human mandible is sexually dimorphic during early postnatal development and adulthood. They concluded that males, by birth, have more advanced age-specific shapes than females and that sex differences decrease quickly between the ages of 4 and 14 years. Then, from puberty to adulthood, sexual dimorphism is observed and they are more at the ramus and the mental regions and are controlled by the surge of sex hormones [19].

Kasperk et al. [20] stated that certain skeletal sites have androgen-sensitive receptors that may contribute to the development of sex-related differences in skeletal morphology. Cattaneo et al. [21] agreed with this statement and stated that it is helpful in age and sex determination in legal settings. This finding may explain the fact that some bones, such as hip bones and the skull are more accurate in sex determination than other bones, as these bones contain more of the androgen-sensitive receptors than facial bones, the sternum and other bones [22].

Our results do not agree with the findings of Rai et al. [23], who used measurements of the mandible in a group of Indians ranging from 7 to 20 years to determine sex. The investigators measured the length of the body of the mandible (the distance between the condylion superior and the gnathion), mandibular length (distance between the condylion and the gnathion), and mandible height (distance between the condylion and the gonion). They concluded that mandibular measurements provide information on the age but not the sex, as they found no difference between males and females in the mandibular linear growth.

A study performed by Ishwarkumar et al. [7] in South Africa concluded that the length of the mandibular ramus generally has higher sexual dimorphism than any other mandibular segments (P-value = 0.000). The authors found that the length of the mandibular ramus on the right and left sides was statistically significant with sex (P-value = 0.040).

Hazari et al. [24] reviewed articles that studied the mandible as a tool for age and sex identification. They stated that out of 16 radiographic studies, 14 showed that the adult mandible could be used with increased sensitivity to identify sex, and two studies showed insignificant results. Of the 20 morphometric studies of dry mandibles, 15 studies showed a positive correlation between sex and mandibular parameters, and five studies did not show any positive correlations between the two parameters.

This finding demonstrates that the mandible provides more accurate age and sex information when combined with other data.

Conclusion

In this study, sexual dimorphism in the mandible ramus length was not observed until the age of 17 years. The mandible ramus length can be used to estimate the sex with an accuracy of 67 % using CBCT and can estimate the age with a high degree of accuracy. Two separate formulae were derived to estimate age in males and in females.

The most commonly used procedures in the forensics of human remains are too invasive to use in living individuals. A multidisciplinary approach including forensic odontology will be useful in this respect, indicating the value of this study.

Limitations and further recommendations

This study can be repeated with a larger sample size. The height of the individual and other mandibular measurements, e.g. the total height of the mandible, the distance between the two mandibular rami, etc, can be combined for the age and sex identification of a person.

Consent for publication

Not applicable. There are no individual person's data in any form in the manuscript (No individual details, pictures, images or videos).

Authors' contribution

SM Motawei has the concept of the study, collected data, organized them and sent for analysis, shared in interpretation of the results and writing the results and the discussion sections. SM Motawei is the corresponding author; responsible for the manuscript submission for publication and replying to editors and reviewers' comments. AMN Helaly wrote the introduction section and shared in interpretation of the data and the results. WM Aboelmaaty provided with the cases that achieved the inclusion criteria for the study, and K. Elmahdy helped in the collection of the cases and the data acquisition. All cases were informed and gave written acceptance before sharing in the study. H. Liu performed the statistical analysis. O. Shabka shared by opinions and the response to the latest reviewers' comments. All authors shared in reviewing the article before approving the final manuscript for submission for publication.

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None.

Ethical approval

Approved from the local ethical committee of the Faculty of Medicine in Mansoura University. Patients' consents were done before their sharing in the study.

Data availability

Please contact the corresponding author for data requests.
Declaration of Competing Interest
None.

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Not applicable.

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