Utility of radiomorphometrics indexes of the mandible for age estimation in adults

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ABSTRACT

Introduction: the mandible undergoes changes in morphology and density related to the aging process. These changes are measured by radiomorphometric indices that allow inferring bone density indirectly. Also, the age estimation process in adults is challenging since the modifications in the anatomical structures are gradual and require long intervals of time to be noticeable. Objective: this study aimed to evaluate the usefulness of radiomoformometric indices of the mandible in age estimation in adults. The sample consisted of 230 digital panoramic radiographs of individuals of both genders (115 men and 115 women), with chronological ages between 20 and 81 years, where radiomorphometric indices were obtained in the premolar region and the mandible ramus, using the software ImageJ. An analysis of variance was conducted considering individuals' gender and age group classification categories with Tukey's post hoc test. Results: a downward trend was observed in means indices values for the older age groups, showing lower values for females. Based on the interaction detected between gender and age groups, multiple regression models were applied to estimate age. These showed a better adjustment for males between 50 and 59 years (R^2=82,85%) and males over 60 (R^2=80,16%). Conclusions: the radiomorphometric indices used in this study allowed to infer age from 50 years onwards in males.

INTRODUCTION

Different methods are used to determine adults` age. Some of them consider the macroscopic, histological, or biochemical characteristics of the teeth, while others study the macroscopic particularities of the bones. [1-4] However, their applicability is compromised by the availability of the anatomical piece being examined and the individual's age. In adulthood, age-related changes are due to the individual´s chronological age (CA) and exogenous factors, such as disease, nutrition, and physical stress.[3] On the other hand, a decrease in the precision of the CA estimation has been demonstrated, which seems to be related to, in the one hadn, the time interval that must elapse for the changes to be observable in the examined structures or tissues, and on the other, the sensitivity of the methods in detecting these changes. Therefore, an error in the CA estimation has been reported in the order of 1.5 to 12 years.[5]

The mandible undergoes modifications during the aging process. Studies have shown that a continuous remodeling of the inferior mandibular cortex occurs with age, which seems to be influenced by the state of dentition and gender.[6,7] Similarly, it has been observed that mandible density decreases as the individual ages, and that changes in the trabecular pattern apper.[8]

Mandibular bone density has been determined in dental radiographs through linear and angular measurements (morphometric analysis), and, also by densitometric analysis, which can be optical, when obtained in conventional radiographs, or digital, in which case it is expressed in grayscale values.[9] Based on this, some radiomorphometric indices (RI) have been evaluated in relation to their applicability in this task, such as, the the thickness of the inferior mandibular cortex in the premolar area,[6,10,11] the degree of alveolar bone resorption, Panoramic Mandibular Index[12] (PMI), Gonial Index[13] (GI) and the Antegonial Index[14] (AGI).

According to the United Nations High Commissioner for Refugees 79.5 million people were displaced from their country of origin at the end of 2019. Events like persecution, political conflict, human rights violations, and others led them into irregular situations[15]; for example, not having a valid identification document makes them vulnerable to exploitation or abuse. Hence the need to study the applicability of minimally invasive age estimation methods. The objective of the present work was to evaluate the utility of radiomorphometric indices in the mandible of adult subjects, in order to contribute to the age estimation in medicolegal identification procedures.

MATERIAL AND METHODS

The sample consisted of 230 digital panoramic radiographs of individuals of both genders (115 men and 115 women), with ages between 20 and 81 years (Table 1). The radiographic images were obtained for clinical reasons, so that there was no additional exposure of the subject to ionizing radiation, according to the guidelines of the Declaration of Helsinki[16] for the study in humans. Five age groups were formed for each sex (Group I: 20-29; Group II: 30-39; Group III: 40-49; Group IV: 50-59; Group VI: 60 ≥)

Table 1. Sample distribution according age groups and gender.

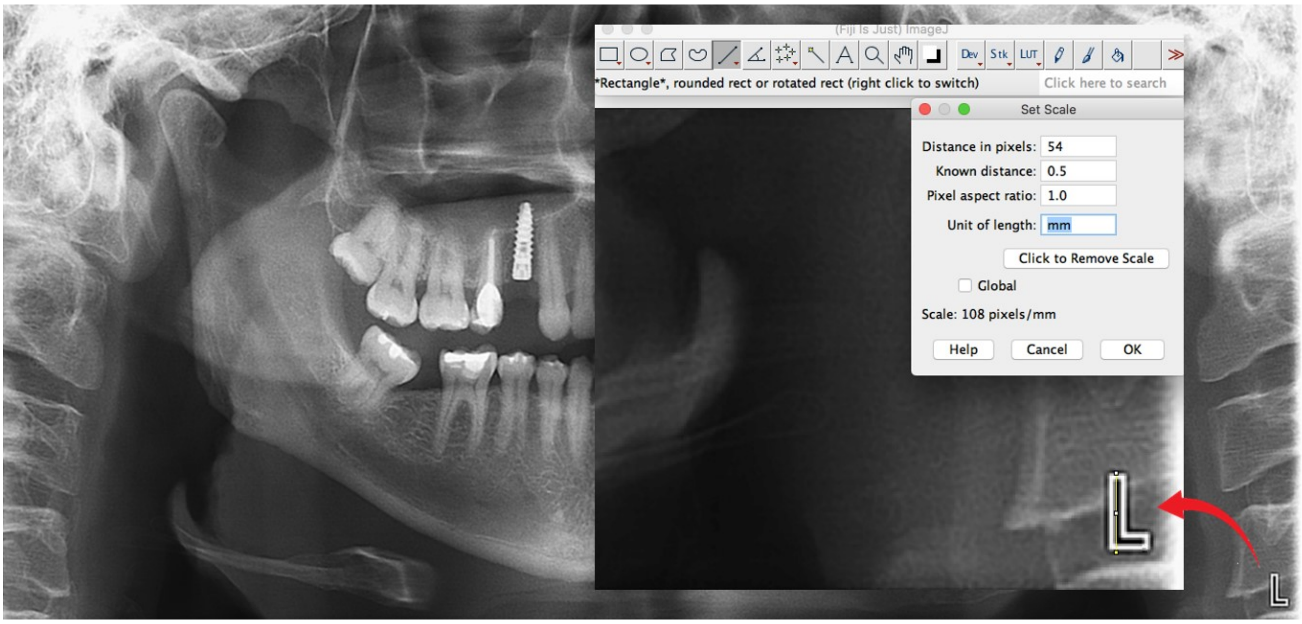
	Gender					
Age groups	**Masculine**		**Femenine**		**Total**	
	N	**%**	**N**	**%**	**N**	**%**
20 - 29	16	13,9	16	13,9	32	13,9
30 - 39	14	12,2	16	13,9	30	13,0
40 - 49	16	13,9	16	13,9	32	13,9
50 - 59	27	23,5	26	22,6	53	23,0
60 - +	42	36,5	41	35,7	83	36,1
Total	115	100.0	115	100,0	230	100.0

Image acquisition and analysis

All radiographic images were obtained on a Planmeca Promax direct digital panoramic equipment (SCARA 3, Helsinki, Finland), with the following factors: 54 to 84 kVp, 16 mA and 16 seconds of exposure time. The radiographs were selected according to the following criteria: minimal distortion, no positioning errors and visible mental foramen on both sides of the mandible, and absence of cystic, tumor or trauma-caused bone lesions. These images were initially processed with Romexis 5.0 software (Planmeca, Helsinki, Finland) to improve their contrast, density and sharpnes. Later, they were stored in JPG format with a resolution of 300 dpi for further analysis. Each radiograph was assigned a code to protect the identity of the patient.

Images were analyzed using ImageJ software (https://imagej.net/software/fiji/). Before making the measurements to obtain the RI, the magnification of the radiographic images was corrected, according to the protocol developed in a previous study, [17] using the software's set scale tool. For this purpose, the radiopaque indicator on the left side of the radiograph was used, assuming a real size of 0.5mm, in such a way that the values obtained were expressed in millimeters for later comparison (Figure 1). All panoramic radiographs were evaluated by a single calibrated observer, who could use the brightness, contrast and magnification resources of the software. Ten percent of the sample was reevaluated 15 days apart to determine intraobserver variability.

Figure 1. Representation of the magnification correction using the ImageJ software set scale tool, through the radiopaque indicator on the left side of the panoramic radiograph.



The following RI were obtained in each radiograph (Figures 2 and 3):

Mandibular height (MH): Distance between the lower border of the inferior cortex of the mandible and the alveolar crest, measured in a perpendicular line to the tangent through the inferior border of the mandible. [11]

H: Distance from the center of the mental foramen to the lower border of the mandibular cortex. [10]

h: Distance from the lower border of the mental foramen to the lower border of the inferior mandibular cortex. [12]

Resorption of the alveolar ridge (RAR: Ratio between MH and the distance from the center of the mental foramen to the lower border of the mandibular cortex (H).[10]

Cortical thickness below the mental foramen (MI): Distance between the superior and inferior border of the cortex, measured on the line drawn for the measurement of MH. [14]

Panoramic mandibular index (PMI): Ratio between the distance from the lower border of the mental foramen to the lower border of the inferior mandibular cortex (h) and MI. [12]

Antegonial index (AGI): Thickness of the inferior mandibular cortex in the antegonial region, measured at the intersection of a tangent that passes through the anterior border of the mandibular ramus and a tangent to the inferior border of the mandible. [14]

Gonial index (GI): Thickness of the inferior cortex measured at the bisector of the gonial angle between a tangent that passes through the lower border of the mandible and another tangential line to the posterior border of the mandibular ramus. [13]

Maximum height of the ramus (MHR): Distance between the points cd (condylion) -tgo (Intersection of the tangents that form the gonial angle) measured on a tangent line to the posterior border of the mandibular ramus. [18]

Gonial angle (GA): Angle between the tangents to the posterior border of the mandibular ramus and the inferior border.[18]

Figure 2. Representation of the tracing and measurement of the radiomorphometric indices studied in the premolar region of the mandible, using ImageJ software, MH: Metal region height; MI: Thickness of the inferior cortex of the mandible; H: Distance from the center of the mental foramen to the inferior border of the inferior cortex; h: Distance from the inferior border of the mental foramen to the inferior border of the inferior cortex.

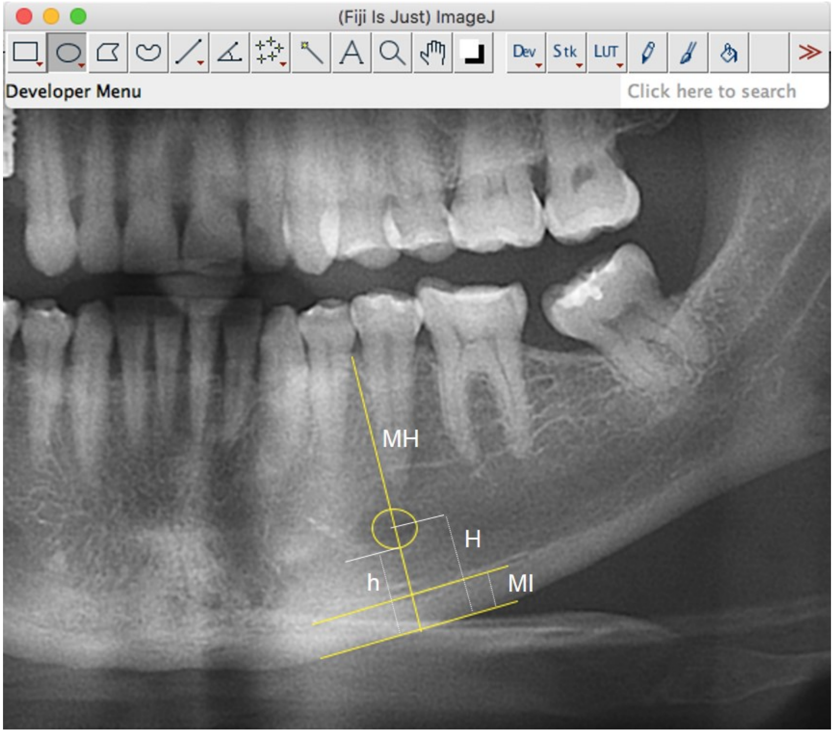
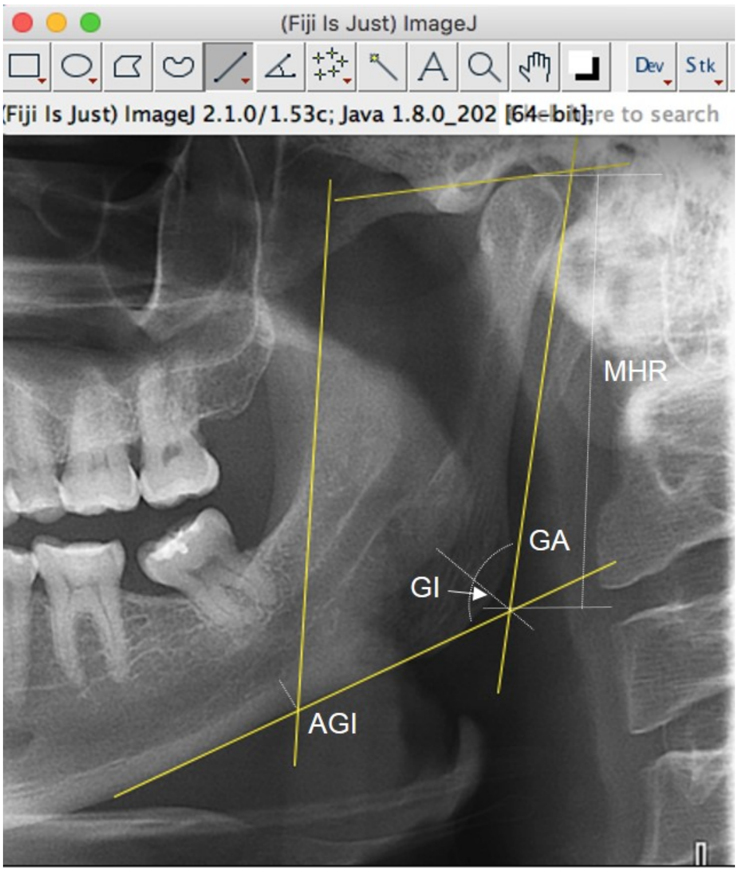


Figure 3. Representation of the tracing and measurement of the antegonial index (AGI), gonial index (GI), gonial angle (GA) and maximum height of the (MHR).



Statistical analysis

The data were processed with MiniTab version 20 software (MiniTabInc., Pennsylvania, USA.) and SPSS version 15 (SPSS Inc., Chicago, USA.). Agreement analysis was calculated via Intraclass Correlation Coefficient (ICC) with a 95% confidence interval. Pearson's correlation coefficient was calculated between the RI determined on both sides of the mandible. Means and standard deviations of the RI were obtained. An analysis of variance (ANOVA) was conducted considering the gender and age group of the individuals as classification categories with Tukey's posthoc test. The gender-age group interaction was analyzed graphically. Multiple linear regression models were built for the quantitative variables considering all individuals classified by gender and age group and gender-age group. The selection of variables was carried out on these regression models using the step-by-step methodology (Stepwise); in addition, the regression models were cross-validated using the folds method with ten folds. The significance level was set at 5%.

RESULTS

The ICC ranged from 0.804 to 0.984 (p = 0.000), which demonstrated the reproducibility of the measurements made. Significant Pearson correlations ((p=0,000) were observed between the values found for the RI on both sides of the mandible: MH (0,893); RAR (0,610); H(0,214); h(0,755); MI (0,696); AGI (0,555); GI (0,563); MHR (0,867); GA (0,942). The mean obtained was used in the different statistical tests.

Table 2 shows the mean and standard deviation for the RI values by gender and age group. In general, the values decrease with age and are lower in female individuals. According to the ANOVA, all variables showed at least one statistically significant effect for gender, age group, or gender-age group interaction. Concerning gender, only the MI and AGI variables did not show statistically significant differences. MH, H, h, RAR, GI, and MHR had a higher mean in males, while, in females, PMI and GA variables were higher. Only H, MI, and AGI variables did not show differences according to age for the age group. MH, AGI, GI, and MHR presented the highest mean in the subjects between 20- 29 years and the lowest mean in older individuals. However, h and RAR showed the opposite behavior. On the other hand, PMI showed the highest average in individuals aged 40 to 49 years and the lowest in individuals over 60 (Table 3).

In the gender-age group interaction (Table 3), MI, PMI, AGI, and GA variables presented statistically significant results. Women showed a higher MI means between 40 and 59 years, and the opposite behavior for the rest of the ages. For PMI, women presented a higher mean between 20 to 29 years and 40 years and older, while for all subjects between 30 to 39 years, the means were homogeneous. For AGI, men showed a higher mean for the ages 30 to 39 years and from 60 years onwards, while the means of women were higher in the remaining age groups. For GA, women had a higher mean up to 59 years, while the means were homogeneous for subjects 60 and over (Figure 4). These results indicate that the regression models could behave differently depending on the gender and age group; in other words, the quality of the estimated models could improve if they are classified by age and gender.

The multiple linear regression models showed a low adjustment coefficient (R^2 = 30.79%) for all individuals. This result was verified by applying a cross-validation (R^2 = 26.02%). For gender, the models showed a better fit for men (R^2 = 45.48%) than for women (R2s = 30.26%). This behavior was maintained for the cross-validations done (R^2 = 38.36%, R^2 = 28.78%, respectively). When analyzing age, the age group 60 years or older showed an adjustment greater than 30% (R2 = 35.78%) and validated in R^2 = 28.40%. For gender and age combined, the models performed better for males between 50-59 years and 60 and over (R^2 = 82.85%, R^2 = 80.16%, respectively). For these two groups, the cross-validations resulted in R^2 = 67.96% and R^2 = 70.69%, respectively. In addition, all the models for men showed adjustment coefficients greater than 30%. On the other hand, for women, although the age groups between 30 and 59 years old showed adjustment coefficients over 40% (Group 30-39: R^2 = 55.32%, Group 40-49: R^2 = 49.71%, Group 50-59: R^2 = 47.27%), their validated adjustment coefficients were low (R^2 = 21.97%, R^2 = 30.43%, R^2 = 22.47%) (Tables 4-7).

Table 2. Mean and standard deviation of the radiomorphometric indices by age group and gender.

RI	Age groups											
	20-29		30-39		40-49		50-59		60≥		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	Sd
MH Mas Fem	28.72 26.25	3.49 2.54	27.19 26.39	3.52 2.41	28.50 24.99	2.13 3.16	27.36 23.82	2.23 4.84	27.21 24.29	2.89 1.90	27.64 24.85	2.88 3.21
RAR Mas Fem	2.42 2.57	0.30 0.25	2.30 2.54	0.31 0.24	2.39 2.49	0.28 0.25	2.23 2.24	0.23 0.35	2.16 2.32	0.20 0.24	2.26 2.39	0.27 0,30
MI Mas Fem	3.18 3.00	0.38 0.61	3.20 2.73	0.75 0.66	3.28 3.33	0.72 0.77	2.72 3.12	0.67 0.48	2.98 2.74	0.68 0.72	3.01 2.94	0,68 0.68
H Mas Fem	11.99 10.28	1.83 1.31	11.86 10.46	1.27 1.16	12.07 10.06	1.40 0.97	12.39 10.68	1,46 2.15	12.70 10.59	1.64 1.24	12.34 10.48	1.56 1.46
h Mas Fem	10.42 8.72	2.08 1.46	10.38 8.97	1.41 1.22	10.29 8.20	1.22 0.89	10.94 9.26	1.58 2.34	11.46 9.12	1.66 0.82	10.90 8.95	1.67 1.46
PMI Mas Fem	0.31 0.35	0.06 0.08	0.32 0.31	0.09 0.10	0.32 0.41	0.08 0.11	0.26 0,37	0.08 0.17	0.27 0.30	0.09 0.07	0.29 0.34	0.09 0.11
AGI Mas Fem	2.41 2.65	0.43 0.61	2.42 2.38	0.31 0.63	2.43 2.66	0.49 0.37	2.34 2.55	0.44 0.48	2.13 1.87	0.59 0.48	2.29 2.31	0.50 0.61
GI Mas Fem	1.31 1.30	0.28 0.37	1.39 1.27	0.37 0.32	1.28 1.18	0.40 0.35	1.15 1.16	0.22 0.28	1,25 0,93	0.32 0.23	1.25 1.12	0.32 0.32
MHR Mas Fem	65.17 54.17	9.05 4.18	59.25 54.02	4.20 5.95	61.82 50.76	5.66 3.65	60.65 52.56	6.83 4.27	58,38 51.78	4.74 3.52	60.44 52.46	6.36 4.29
GA Mas Fem	124.74 134.26	28.88 34.15	118.98 124.40	4.79 5.51	118.18 124.75	7.71 8.74	120.54 136.04	9.08 33.84	125.36 134.91	7.58 34.55	122.40 132.00	13.00 29.30

Legend: M: mean; SD: standard deviation; RI: radiomorphometric index; Mas: masculine; Fem: feminine. Group 1: 20-29 years old; Group 2: 30-39 years; Group 3: 40-49 years; Group 4: 50-59 years; Group 5: ≥ 60 years. MH: Mandibular height at the mental foramen; RAR: Degree of resorption of the alveolar ridge; MI: Thickness of the inferior cortex of the mandible; H: Distance from the lower border of the MI to the center of the mental foramen; h: Distance from the inferior border of the MI to the inferior border of the mental foramen; PMI: Panoramic mandibular index; AGI: Antegonial index; GI: Gonial index; MHR: Maximum height of the ramus; GA: Gonial angle.

Table 3. Tukey's homogeneous means and groups of means for the variables classified by age group and gender.

Variable	Class	N	MH	H	h	RAR	MI	PMI	AGI	GI	MHR	GA
Gender	F	115	24.84^{B}	10.47^{B}	9.00^{B}	5.69^{B}	2.97^{A}	0.34^{A}	2.30^{A}	1.07^{B}	52.14^{B}	125.06^{A}
	M	115	27.63^{A}	12.20^{A}	10.75^{A}	6.51^{A}	3.05^{A}	0.29^{B}	2.31^{A}	1.18^{A}	60.37^{A}	121.08^{B}
Age Group	20-29	32	27.38^{A}	11.19^{A}	9.57^{AB}	6.04^{AB}	3.05^{A}	0.33^{AB}	2.47^{A}	1.24^{A}	58.92^{A}	120.99^{A}
	30-39	30	26.77^{AB}	11.09^{A}	9.57^{AB}	6.00^{AB}	2.98^{A}	0.31^{AB}	2.40^{A}	1.25^{A}	56.18^{AB}	122.05^{A}
	40-49	32	26.60^{AB}	10.93^{A}	9.18^{B}	5.81^{B}	3.27^{A}	0.37^{A}	2.51^{A}	1.15^{AB}	56.27^{AB}	121.96^{A}
	50-59	53	25.40^{B}	11.47^{A}	10.08^{A}	6.16^{AB}	2.98^{A}	0.31^{AB}	2.42^{A}	1.14^{AB}	56.74^{AB}	123.50^{A}
	60+	83	25.98^{AB}	11.55^{A}	10.24^{A}	6.24^{A}	2.93^{A}	0.28^{B}	2.05^{B}	1.01^{B}	54.95^{B}	124.40^{A}
Effect	Sex	p	<0.001*	<0.001*	<0.001*	<0.001*	0.448	<0.001*	0.783	0.014*	<0.001*	<0.001*
	Age	p	0.018*	0.114	0.001*	0.007*	0.120	0.001*	<0.001*	<0.001*	0.004*	0.159
	Sex×Age	p	0.346	0.214	0.164	0.074	0.020*	0.035*	0.031*	0.070	0.085	0.008*

Legend: (*) Statistically significant differences at 5%. Means with the same letter in the superscript do not present statistically significant differences according to Tukey's honest significant difference test. MH: Mandibular height at the mental foramen; H: Distance from the lower border of the MI to the center of the mental foramen; h: Distance from the inferior border of the MI to the inferior border of the mental foramen; RAR: Degree of resorption of the alveolar ridge; MI: Thickness of the inferior cortex of the mandible; PMI: Panoramic mandibular index; AGI: Antegonial index; GI: Gonial index; MHR: Maximum height of the ramus; GA: Gonial angle.

Figure 4. Gender-age interaction groups.
Note: Bars represent 95% confidence intervals for the mean.
MI: the thickness of the inferior cortex of the mandible; PMI: Panoramic mandibular Index; AGI: Antegonial index; GA: Gonial angle.

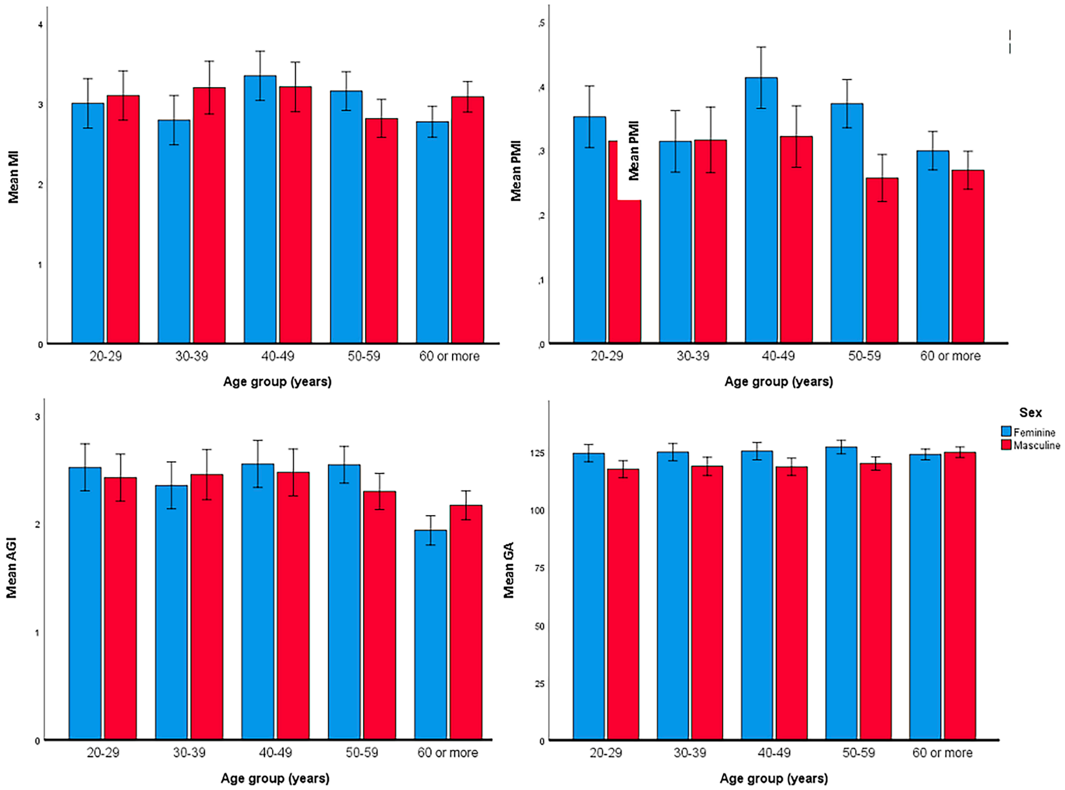


Table 4. Regression models showing the total sample and the individuals classified by gender.

Group	Predictor	Beta	P value	Model statistics
Total	Constant	68.733	<0.001*	$p_{model}<0.001^*$ $S=13.84$ $R^2=30.79\%$ $R^2_{adj}=28.60\%$ $S_{valid}=14.0595$ $R^2_{valid}=26.02\%$
	Gender	3.842	0.082	
	MH	-1.739	<0.001*	
	MI	10.603	<0.001*	
	PMI	-70.738	<0.001*	
	AGI	-9.767	<0.001*	
	GI	-11.859	0.001*	
	GA	0.420	0.001*	
Females	Constat	127.409	<0.001*	$p_{model}<0.001^*$ $S=13.87$ $R^2=32.10\%$ $R^2_{adj}=30.26\%$ $S_{valid}=13.9598$ $R^2_{valid}=28.78\%$
	AGI	-8.695	0.002*	
	GI	-19.437	<0.001*	
	MHR	-0.697	0.029*	
Males	Constant	-17.066	0.533	$p_{model}<0.001^*$ $S=12.36$ $R^2=45.48\%$ $R^2_{adj}=41.92\%$ $S_{valid}=12.6737$ $R^2_{valid}=38.36\%$
	MH	-3.162	<0.001*	
	H	-8.069	0.003*	
	RAR	27.944	<0.001*	
	MI	9.425	<0.001*	
	AGI	-11.529	<0.001*	
	MHR	-0.443	0.068	
	GA	0.798	<0.001*	

Legend: $^*p<0.001$. R: Pearson's correlation; R^2: Coefficient of determination; S: Standard error; Adj: Adjusted. MH: Mandibular height at the mental foramen; RAR: Degree of resorption of the alveolar ridge; MI: Thickness of the inferior cortex of the mandible; H: Distance from the lower border of the MI to the center of the mental foramen; PMI: Panoramic mandibular index; AGI: Antegonial index; GI: Gonial index; MHR: Maximum height of the ramus; GA: Gonial angle.

Table 5. Regression models by age group.

Age group	Predictor	Beta	P Value	Model statistics
20-29	Constant	30.821	<0.001*	$p_{model}=0.052$ $S=2.82101$ $R^2=12.06\%$ $R^2_{adj}=9.12\%$ $S_{valid}=2.89422$ $R^2_{valid}=1.26\%$
	AGI	-2.444	0.052	
30-39	Constant	27.277	0.007*	$p_{model}=0.043$* $S=2.27352$ $R^2=26.55\%$ $R^2_{adj}=18.07\%$ $S_{valid}=2.37424$ $R^2_{valid}=7.57\%$
	Sexo	2.182	0.032*	
	MH	-0.382	0.022*	
	GA	0.125	0.096	
40-49	Constant	26.848	<0.001*	$p_{model}=0.014$* $S=2.61515$ $R^2=18.54\%$ $R^2_{adj}=15.83\%$ $S_{valid}=2.7214$ $R^2_{valid}=5.91\%$
	GA	0.140	0.014*	
50-59	Constant	32.906	<0.001*	$p_{model}=0.001$* $S=2.55159$ $R^2=36.66\%$ $R^2_{adj}=28.39\%$ $S_{valid}=2.71468$ $R^2_{valid}=17.39\%$
	Sex	1.507	0.094	
	MI	3.036	0.001*	
	PMI	-9.068	0.025*	
	AGI	-2.462	0.022*	
	GI	-2.909	0.024*	
	GA	0.183	0.001*	
≥ 60	Constante	96.940	<0.001*	$p_{model}<0.001$* $S=5.04112$ $R^2=39.70\%$ $R^2_{adj}=35.78\%$ $S_{valid}=5.29084$ $R^2_{valid}=28.40\%$
	Sex	4.575	0.036*	
	MH	-0.419	0.118	
	H	-1.871	0.004*	
	AGI	-5.192	<0.001*	
	MHR	0.216	0.125	

Legend: *$p<0.001$. R: Pearson's correlation; R^2: Coefficient of determination; S: Standard error; Adj: Adjusted. MH: Mandibular height at the mental foramen; MI: Thickness of the inferior cortex of the mandible; H: Distance from the lower border of the MI to the center of the mental foramen; PMI: Panoramic mandibular index; AGI: Antegonial index; GI: Gonial index; MHR: Maximum height of the ramus; GA: Gonial angle.

Table 6. Regression models estimated by age group and gender, females.

Age Group	Predictor	Beta	P Value	Model statistics
20-29	Constant	29.225	<0.001*	p_{model}=0.080 S=2.80237 R^2=20.29% R^2_{adj}=14.60% S_{valid}=2.97241 R^2_{valid}=0.00%
	GI	-3.730	0.080	
30-39	Constant	49.140	<0.001*	p_{model}=0.018* S=2.00305 R^2=55.32% R^2_{adj}=44.15% S_{valid}=2.29227 R^2_{valid}=21.97%
	H	0.933	0.126	
	GI	-6.050	0.014*	
	MH	-0.353	0.015*	
40-49	Constant	20.829	0.022*	p_{model}=0.036* S=2.31599 R^2=49.71% R^2_{adj}=37.14% S_{valid}=2.35911 R^2_{valid}=30.43%
	MH	-0.953	0.026*	
	H	4.056	0.005*	
	GI	5.621	0.048*	
50-59	Constant	78.284	<0.001*	p_{model}=0.001* S=2.00374 R^2=47.27% R^2_{adj}=42.68% S_{valid}=2.28519 R^2_{valid}=22.47%
	GI	-4.197	0.010*	
	MHR	-0.391	<0.001*	
≥ 60	Constant	107.415	<0.001*	p_{model}=0.002* S=5.82703 R^2=27.58% R^2_{adj}=23.77% S_{valid}=5.93312 R^2_{valid}=18.99%
	H	-2.372	0.025*	
	AGI	-7.491	0.001*	

Legend: *$p<0.001$. R: Pearson's correlation; R^2: Coefficient of determination; S: Standard error; Adj: Adjusted. MH: mandibular height at the mental foramen; RAR: degree of resorption of the alveolar ridge; MI: thickness of the inferior cortex of the mandible; H: distance from the lower border of the MI to the center of the mental foramen; h: distance from the inferior border of the MI to the inferior border of the mental foramen; PMI: panoramic mandibular index; AGI: antegonial index; GI: gonial index; MHR: maximum height of the ramus; GA: gonial angle.

Table 7. Regression models estimated by age group and gender, males.

Age Group	Predictor	Beta	P Value	Model statistics
20-29	Constant	32.407	<0.001*	p_{model}=0.013* S=2.15466 R^2=57.79% R^2_{adj}=47.24% S_{valid}=2.72914 R^2_{valid}=9.72%
	AGI	-3.875	0.057	
	GI	8.838	0.003*	
	MHR	-0.140	0.106	
30-39	Constant	52.172	<0.001*	p_{model}=0.090 S=1.98177 R^2=35.45% R^2_{adj}=23.72% S_{valid}=2.36466 R^2_{valid}=0.00%
	MH	-0.351	0.064	
	AGI	-3.536	0.084	
40-49	Constant	19.950	0.038*	p_{model}=0.017* S=2.31139 R^2=34.25% R^2_{adj}=29.55% S_{valid}=2.35833 R^2_{valid}=21.77%
	GA	0.198	0.017*	
50-59	Constant	37.357	0.003*	p_{model}<0.001* S=1.57321 R^2=82.85% R^2_{adj}=77.71% S_{valid}=1.85093 R^2_{valid}=67.96%
	H	1.917	<0.001*	
	MI	5.098	<0.001*	
	AGI	-5.804	<0.001*	
	GI	-3.919	0.003*	
	MHR	-0.353	0.002*	
	GA	0.145	0.026*	
≥ 60	Constant	69.029	<0.001*	p_{model}<0.001* S=2.9204 R^2=80.16% R^2_{adj}=76.08% S_{valid}=3.19386 R^2_{valid}=70.69%
	MH	-0.571	0.034*	
	H	-10.661	<0.001*	
	RAR	23.052	<0.001*	
	MI	-6.252	0.005*	
	PMI	57.017	0.007*	
	AGI	-5.098	<0.001*	
	GI	7.471	0.053	

Legend: *p˂0.001. R: Pearson's correlation; R^2: Coefficient of determination; S: Standard error; Adj: Adjusted. MH: Mandibular height at the mental foramen; RAR: Degree of resorption of the alveolar ridge; MI: Thickness of the inferior cortex of the mandible; H: distance from the lower border of the MI to the center of the mental foramen; PMI: Panoramic mandibular index; AGI: Antegonial index; GI: Gonial index; MHR: Maximum height of the ramus; GA: Gonial angle.

DISCUSSION

The mandible undergoes a series of morphological alterations during the individual's life that seem to be influenced by age, sex and the status of the dentition, [19-22] these changes have been studied in dental radiographs. [17,18] Panoramic radiographs are widely used as an initial monitoring tool for the patient, due to its wide coverage of the jaws, easy execution and low radiation dose.[10,23] In this investigation the radiographs were obtained by previous clinical indication, regardless of an "osteoporotic" or "normal" state, hoping to represent an average group of subjects within the selected age range.

In this research, the RI means tended to decrease with age for both genders. However, for women, values were generally lower than men's, and these results have also been reported in previous studies. [6,19,24]They have been attributed to the early onset of the aging process, which begins around 45-50 years for females and is related to the culmination of the menstrual cycle and the drop of sex hormones.[6,19]

Regarding the RI measured in the body and mandibular ramus, the male values for MI, PMI, AGI, GI were lower than those reported in other studies.[19,21,23,24]Women's results for MI and PMI were considered average (≥3.0 and ≥0.33 mm) [6,7,10,17,19,20]; for AGI, the mean value was lower than the standard value (≥3.2 mm). However, it was similar to those indicated by Dutra et al. [6,7] The mean value for GI was lower than the value of ≥1.2 mm, considered standard.[19,24] These results could express discrepancies in the study design, population differences, and subjects with decreased bone density in the study sample.

GA presented a gradual decrease in men with aging. The opposite was observed in women's results, reflecting the conclusions of Damera et al. [25] and Dietrichkeit et al. [26] Due to the morphological changes that the mandible undergoes from birth to adulthood, the obtuse mandible angle of infancy and childhood becomes acute in adults. Nevertheless, as aging progresses, tooth loss leads to obtuse angles because of the muscle forces and bone resorption. [21] Likewise, some studies show that the GA may be related to the size of the mandible: the smaller the ramus, the more obtuse the angle. This point would explain the higher values obtained for females.[26]

The females in the study showed lower MHR values when compared to men's, which reflects other studies [25,27]. In this sense, and according to some studies revised, the height of the ramus fluctuates between 18 and 40 years of age, with a sustained decrease towards the fifth and sixth decades of life, [28]. These results were verified for both genders.

When the regression models were built considering the gender-age group interaction, as the ANOVA indicated, the results obtained were better than the ones obtained calculated separately for these variables. In men, models for the age groups between 50-59 and 60 ≥ years managed to explain 82.85% and 80.16% of the variance between the AC and estimated age, respectively. The models for 30-39, 40-49, and 50-59 age groups showed an adjustment of around 40% in women. In contrast, the model for the group aged 60 ≥ explained 27.58% of the variance, reflecting possibly an osteoporotic condition in the sample rather than age-related changes in the RIs.

Musa et al. [29] found significant differences when separating the subjects into two age groups. Some patients in the groups were under 65 and others over 65. The researchers pointed out that in the middle sixties, the female population was about ten years into the post-menopausal process, and hormonal changes have stimulated bone resorption. The mandible seems to undergo more evident changes from 60 and over, maintaining a relatively stable morphology until 40 years of age. This result could be related to the fact that bone mass constantly increases and peaks at 40 years of age in men and around 30-35 in women. [23] Dutra et al. [6] reported that the MI and GI values decrease abruptly after 60 years of age in both genders, which was indicated by Musa et al. [29] for AGI. Knezovic et al. [24] described that MI, GI, and AGI showed a tendency to decrease with age, showing lower values in women up to 75 years of age when the indices fall abruptly.

In their study, Dietrichkeit et al. [26] assessed the possibility of estimating gender and age in dry mandibles of Brazilian individuals (0-100 years old) considering GA and the MHR values, among other variables. They reported significant differences between gender concerning the studied variables, and they could build logistic regression models to estimate gender with 90% precision. Regarding age, the authors pointed out that only MHR was worthwhile, in contrast to the results of our research, which can be mainly attributed to the studied age range and the selected indices.

From a forensic point of view, the models proposed here could be the starting point to investigate how the morphological characteristics of the mandible contribute to age diagnosis. Future research should consider the influence of the presence or absence of teeth on these indices and how it is related to the estimation of age. Likewise, it is necessary to research whether osteopenia or osteoporosis would affect age diagnosis, particularly in females.

CONCLUSIONS

Estimating age in adults through morphological features of teeth or bones is challenging since the evaluated characteristics often require extended periods to become evident, which decreases the precision in age calculation. This work studied the usefulness of radiomorphometric indices in the mandible for age determination. A decrease in index values was found as age advances, more evident in women. Regression models explained around 80% of the variance between chronological and estimated age in males, from 50 years onwards.

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