THE APPLICABILITY OF THE CARREA'S METHOD FOR HUMAN HEIGHT ESTIMATION THROUGH LOWER AND UPPER TEETH IN DENTAL MODELS

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Palavras-chave: Antropologia Forense. Odontologia Legal. Estatura. Arco Dental. Identificação Humana.

RESUMO

Objetivo: Avaliou-se a aplicabilidade do método de Carrea, original e modificado na estimativa da estatura humana. **Métodos**: Trata-se de estudo seccional, realizado com 31 pares de modelos de gesso de 33 graduandos de odontologia. Cada modelo inferior foi analisado com o emprego do Método de Carrea (1939), original, e o método modificado (LIMA et al., 2017) foi utilizado na análise dos modelos superiores. Os dados foram analisados por estatística descritiva e inferencial (α=5 %). **Resultados**: Pelo método de Carrea original, a altura estimada incluiu a altura real em 51,6% (n=16) dos casos, com concordância de 38,7% (n=12) para o quadrante 3 e de 32,3% (n=10) para o 4. A mesma concordância global foi observada para o método modificado (51,6%; n=16), com percentual de 35,5% (n=11) e 32,3% (n=10) para os quadrantes 1 e 2, respectivamente. Não houve diferença estatisticamente significante entre os sexos. A altura foi subestimada em 58,1% (n=18) dos casos quando analisados pelo método de Carrea original, independente do quadrante analisado, e superestimada em 3,2% (n=1) no quadrante 3, e 9,7% (n=3) no quadrante 4. Pelo método modificado, subestimou-se a altura em 45,2% (n=14) para o quadrante 1, e em 38,7% (n=12) para o quadrante 2. A superestimação ocorreu em 19,4% (n=6) no quadrante 1 e em 29,0% (n=9) no quadrante 2. Obtiveram-se baixos coeficientes de correlação entre os valores estimados e reais. **Conclusão**: Os métodos de Carrea, original e modificado, apresentaram aplicabilidade questionável, devendo ser utilizados de maneira complementar a outras técnicas de estimativa de estatura.

Keywords: Forensic Anthropology. Forensic Dentistry. Body height. Dental arch. Human identification.

ABSTRACT

Objective: To evaluate the applicability of the Carrea's method in its original and modified versions for human height estimation. **Methods**: This was a cross-sectional study using 31 pairs of plaster dental models from undergraduate dental students. The lower and upper models were analyzed based on the Carrea's original method (1939) and its modified version (LIMA et al., 2017), respectively. The data were analyzed by descriptive and inferential statistics (α=5%). **Results**: The original method estimated the actual height in 51.6% of the sample (n = 16), with an agreement of 38.7% (n = 12) for quadrant 3 and 32.3% (n = 10) for quadrant 4. Similar overall agreement was observed for the modified method (51.6%; n = 16), with a 35.5% (n = 11) and 32.3% (n = 10) agreement for quadrants 1 and 2, respectively. There was no significant difference between sexes. The original method underestimated human height in 58.1% of the sample (n = 18), regardless of the quadrant analyzed, while it overestimated height in 3.2% (n = 1) of the models in quadrant 3 and in 9.7% (n = 3) in quadrant 4. The modified method underestimated height by 45.2% (n = 14) in quadrant 1 and by 38.7% (n = 12) in quadrant 2. The modified method overestimated height in 19.4% (n = 6) of the models in quadrant 1 and in 29.0% (n = 9) in quadrant 2. Low correlation coefficients were obtained between actual and estimated measurements. **Conclusion**: Both the original and modified Carrea's methods presented questionable applicability and should therefore be used with caution.

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INTRODUCTION

Human identification comprises a meticulous and extremely important process in several situations which require sex, ancestry, age and height determination through specific methods developed from anthropological studies.

Human stature is considered to be a substantial element in forensic anthropology because it represents an objective feature in the search for human identification. The estimation of stature is indispensable in anthropological examinations as it can exclude or certify the identity of an individual.[1,2]

Human stature is usually estimated from long bones which, however, might be not frequently available. Under such conditions, other parameters could be analyzed in order to predict human stature, as in example of human teeth. In many cases, as only dental elements are available for investigation, the use of methods for estimating human height from specific dental measurements becomes significant.[3-5]

It is worth noting the considerable importance of the studies carried out by the Argentine mathematician Juan Ubaldo Carrea, who was responsible for the creation of methods which have significantly contributed to Forensic Dentistry, mainly in the identification processes of damaged bodies. He developed a formula to estimate height using the dimensions of the lower incisives and canines.[6]

The modification of the Carrea's formula (1939) developed by Lima et al.[2] is notable for expanding the use of the method. It makes it possible to use the method in the upper dental arch, particularly in cases when the skull is found without the mandible, therefore accomplishing height estimation when necessary.

Based on that, this study aimed to evaluate the applicability of the original and modified Carrea's methods for human height estimation. In order to achieve this objective, plaster dental models of the upper and lower dental arches were analyzed, and the results obtained were compared to the actual height previously measured in individuals composing the study sample.

MATERIALS AND METHODS

This was a cross-sectional, documentary and descriptive study using secondary data. Plaster dental models of the upper and lower teeth, made during the Forensic Dentistry discipline in a public university, were used for analysis.

This study followed the guidelines that regulate research involving human beings and was approved by the Research Ethics Committee of our institution (CAAE: 45851815.0.0000.5188; Protocol number 0307/2015).

The study population was comprised of plaster dental models from 58 undergraduate dental students regularly enrolled in two semesters of the Forensic Dentistry discipline. The convenience sample included 31 pairs of plaster dental models, which were separated by the professor responsible for the discipline and delivered, coded, to the study examiner.

We only included plaster dental models of individuals from both sexes, who presented the anterior dental elements without any morphological alterations, erupted and that did not present any fillings in their proximal faces that could make it difficult to perform tooth measurements.

The exclusion criteria considered the following: plaster dental models in which any upper or lower anterior tooth were absent; models from individuals who had used orthodontic appliances; those who had restorations on the proximal faces of their teeth or any morphological anomalies of the tooth crowns.

As part of the practical activities of the Forensic Dentistry discipline in each semester, the height of the undergraduate students is measured and registered in a standard identification form of the discipline. Measurement is performed with the individual standing erect, with arms extended close to the body, and feet standing firmly on the ground. According to the Frankfurt plan, the head is positioned parallel to the ground, with the individual in inspiratory apnea. The distance from the heel to the horizontal plane running through the head is then measured with a slider at an angle of 90° to the metric scale.

Within the same practical class, plaster dental models are obtained by dental impressions of upper and lower teeth using irreversible hydrocolloid (alginate type II for dental impression) and subsequent casted with type IV stone. Not all students perform this activity. Those who have sensitivity to irreversible hydrocolloid, vomiting sensation, or the presence of fixed orthodontic appliances, are dismissed from participation.

Plaster dental models from each semester are stored by the discipline as part of a collection, along with the human identification cards. The professor responsible for the discipline separated the students' models and records from their collection, and handed over all the material to a trained examiner, whom performed an analysis of the eligibility criteria for sample selection.

The main investigator received the coded plaster dental models and measured the mesio-distal diameter of the central incisor, lateral incisor and canine using a digital caliper in order to obtain the arch and chord measurements (Figure 1 and 2). The caliper was zet at zero after each measurement so that to prevent variability and keep high accuracy levels.

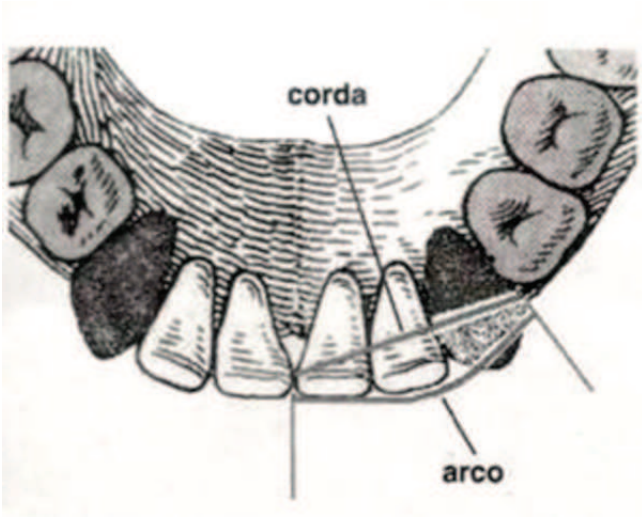


***Figure 1**: Schematic drawing of the "arch" and "chord" trace between the mesial face of the first lower incisor and the distal face of the lower canine on same quadrant. These measurements were necessary to calculate the height according to the Carrea's formula. Source: Vanrell, 2009.*



***Figure 2**: Ilustration of a plaster dental model showing the measure of the mesio-distal diameter of a canine using a digital caliper.*

With regards to the lower teeth, the arch was measured as being the tangent line through the vestibular face from the mesial limit of the central incisor until the distal limit of the canine. It means the sum of the mesio-distal diameters of the central incisor, the lateral incisor and the lower canine, measured on the vestibular face. The chord consisted of a straight lingual line between the mesial edge of the central incisor and the distal face of the canine. Maximum and minimum height was calculated using the original Carrea's formulas presented in Chart 1.

As for the upper teeth, the arch was composed by the sum of the mesio-distal diameters of the maxillary central incisor, lateral incisor and canine, measured on the vestibular face. The chord consisted of a lingual straight line from the mesial edge of the central incisor to the distal edge of the canine on the same quadrant. The maximum and minimum height was calculated using the Carrea's index modified by Lima et al.[2] as described in Chart 1.

	Carrea index	Carrea Index modified by Lima et al. (2017)
Maximum height (in milimiter)	$\frac{\text{LowerArch} \times 6 \times \pi \times 100}{2}$	$\frac{\text{UpperArch} \times 6 \times \pi \times 100}{2.55}$
Minimum height (in milimiter)	$\frac{\text{LowerChord} \times 6 \times \pi \times 100}{2}$	$\frac{\text{UpperChord} \times 6 \times \pi \times 100}{2.55}$

***Chart 1**: Maximum and minimum height calculations using the original Carrea's index and the modified Carrea's index (Lima et al, 2017).*

The data were tabulated and analyzed using the SPSS software (Statistical Package for Social Sciences), version 20.0. The data were treated and analyzed descriptively and inferentially by Pearson chi-square test and Pearson correlation coefficients, with a 5% significance level. Human height estimated by the Carrea's index (1939) and by its modified index[2] were compared to investigate the applicability of the methods.

RESULTS

From a total of 58 students regularly enrolled in the Legal Dentistry discipline, 33 pairs of plaster dental models were assigned to the discipline file and 31 of which met the eligibility criteria. Two pairs of models were excluded because of the absence of canines in the upper and/or lower arch. The participants' ages ranged from 21 to 33 years, with an average of 23.74 (±2.42) years. With regards to sex, 51.6% (n = 16) of the models belonged to females and 48.4% (n = 15) to males.

The original Carrea's method estimated the actual height in 51.6% (n = 16) of the cases, showing an agreement of 38.7% (n = 12) for quadrant 3 and 32.3% (n = 10) for quadrant 4. The same overall agreement was observed for the modified Carrea's method (51.6%; n = 16), with an agreement percentage of 35.5% (n = 11) and 32.3% (n = 10) for quadrants 1 and 2, respectively (Table 1). No statistically significant difference was observed between the sexes (p-value < 0.05, Pearson Chi-square test) (Table 2).

We also evaluated the cases in which the height was underestimated (the actual height was above the range of estimated values) or overestimated (the actual height was lower than the estimated range). Table 3 shows that the height was underestimated in 58.1% (n = 18) of the cases when analyzed by the original Carrea's method, with an average error of 10.6 cm in quadrant 3 and 5.7 cm in quadrant 4. The original method overestimated height in 3.2% (n = 1) of the cases in quadrant 3, with an average error of 4.1 cm, and in 9.7% (n = 3) of the models in quadrant 4, with an average error of 5.7 cm.

Table 1: *Minimum and Maximum values, Mean, Median, Standard Deviation (SD) and percentage of agreement (%Concordance) between the actual height and the height estimated through the original and modified Carrea's indices, per dental quadrant.*

Original Carrea method									
	Total			Quadrant 3			Quadrant 4		
	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance
Minimum	1.36	1.49		1.37	1.49		1.36	1.50	
Maximum	1.70	1.82		1.70	1.81		1.69	1.82	
Mean	1.54	1.66	51.6	1.55	1.66	38.7	1.53	1.66	32.3
Median	1.52	1.66		1.53	1.66		1.53	1.66	
SD	0.08	0.10		0.09	0.10		0.08	0.10	
Modified Carrea method									
	Total			Quadrant 1			Quadrant 2		
	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance
Minimum	1.41	1.51		1.45	1.51		1.41	1.52	
Maximum	1.86	1.94		1.86	1.90		1.80	1.94	
Mean	1.61	1.70	51.6	1.61	1.70	35.5	1.62	1.70	32.3
Median	1.60	1.71		1.61	1.70		1.60	1.72	
SD	0.08	0.08		0.08	0.08		0.09	0.08	

Table 2: *Minimum and Maximum values, Mean, Median, Standard Deviation (SD) and percentage of agreement (%Concordance) between the actual height and the height estimated through the original and modified Carrea's indices, according to sex.*

Original Carrea method									
	Total			Male			Female		
	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance
Minimun	1,36	1,49		1,39	1,50		1,36	1,49	
Maximun	1,70	1,82		1,70	1,82		1,64	1,82	
Mean	1,54	1,66	51,6	1,57	1,70	60,0[a]	1,51	1,61	43,8[a]
Median	1,52	1,66		1,56	1,71		1,51	1,60	
SD	0,08	0,10		0,09	0,08		0,07	0,09	
Modified Carrea method									
	Total			Male			Female		
	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance
Minimum	1.41	1.51		1.45	1.58		1.41	1.51	
Maximum	1.86	1.94		1.86	1.94		1.75	1.81	
Mean	1.61	1.70	51.6	1.64	1.74	46.7[b]	1.58	1.66	56.3[b]
Median	1.60	1.71		1.64	1.73		1.58	1.66	
SD	0.08	0.08		0.10	0.07		0.06	0.07	

[a]*No statistically significant difference (p=0.366; Pearson Qui-Square test).*
[b]*No statistically significant difference (p=0.594; Pearson Qui-Square test).*
SD: Standard Deviation

Height underestimation was also observed for the modified method in 45.2% (n = 14) of the models for quadrant 1, with an average error of 3.9 cm, and in 38.7% (n = 12) for quadrant 2, with an average error of 4.9 cm. Height was overestimated by the modified method by an average of 4.3 cm in 19.4% (n = 6) of the models (quadrant 1), and by 7.5 cm in 29.0% (n = 9) of the models (quadrant 2). Statistically significant differences between quadrants were observed for both lower teeth (original Carrea's method) and upper teeth (modified Carrea's method) (p-value <0.05, Pearson Chi-square test).

The results presented in Table 4 indicate significant correlations between the actual height and the minimum height estimated by the modified Carrea's method, based on quadrant 1. It is also shown a significant correlation between the actual height and the maximum height estimated by the modified Carrea's method, based on quadrant 2.

When analyzing the models, some special conditions were observed, such as the presence of crowding and/or diastema. We chose not to exclude these models in an attempt to assure a minimum sample number and also to allow analysis of the interference of such conditions in the application of the methods under study. As shown in the literature, this evaluation allowed the separation of the sample into 4 groups. Table 5 presents the estimated values and the respective agreement when the division into the groups was considered, and no statistically significant difference was observed (p-value>0.05, Pearson Chi-Square Test).

Table 3: *Absolute frequency and percentage of agreement with the actual height, and underestimation or overestimation rates obtained through the original and modified Carrea's methods, per quadrant.*

Original Carrea method	Quadrant 3[a]					Quadrant 4[a]				
			Deviation in meters					Deviation in meters		
	n	%	Min.	Max.	Mean	n	%	Min.	Max.	Mean
Concordance	12	38.7	-	-	-	10	32.3	-	-	-
Underestimation	18	58.1	0.072	0.140	0.106	18	58.1	0.003	0.111	0.057
Overestimation	1	3.2	0.052	0.030	0.041	3	9.7	0.112	0.003	0.057
Total	31	100	-	-	-	31	100			
Modified Carrea method	**Quadrant 1[b]**					**Quadrant 2[b]**				
			Deviation in meters					Deviation in meters		
	n	%	Min.	Max.	Mean	n	%	Min.	Max.	Mean
Concordance	11	35.5	-	-	-	10	32.3	-	-	-
Underestimation	14	45.2	0.025	0.054	0.039	12	38.7	0.044	0.054	0.049
Overestimation	6	19.4	0.046	0.040	0.043	9	29.0	0.096	0.055	0.075
Total	31	100	-	-	-	31	100	-	-	-

[a]*Statistically significant difference (p=0.003; Pearson Qui-Square test).*
[b]*Statistically significant difference (p=0.001; Pearson Qui-Square test).*

Table 4: *Spearman correlation coefficients and hypothesis test (nullity for absence of association between estimated height values and the actual height, in meters) for the original and modified Carrea's methods.*

Original Carrea method	Quadrant 3		Quadrant 4	
Statistics	Minimun Height (m)	Maximum Height (m)	Minimun Height (m)	Maximum Height (m)
Correlation coefficient	0.108	0.334	0.175	0.178
p-value	0.562	0.067	0.345	0.338
Number of observations	31	31	31	31
Modified Carrea method	**Quadrant 1**		**Quadrant 2**	
Statistics	Minimun Height (m)	Maximum Height (m)	Minimun Height (m)	Maximum Height (m)
Correlation coefficient	0.411	0.229	0.206	0.407
p-value	0.022[a]	0.216	0.267	0.023[a]
Number of observations	31	31	31	31

[a]*Statistically significant difference (p<0,05).*

DISCUSSION

The present study shows that the original Carrea's method resulted in 51.6% of agreement between the estimated and actual height. These findings differ from those reported by Furlan et al.[7], in which a 91.6% of agreement was observed. We highlight that in the latter study, the authors did not include crowded and/or diastema arches to their sample, and all measurements were made directly in the oral cavity of the participants. In that case, the measurements were taken through the use of dental floss and the distances between the marks were then measured with a digital caliper. Lima et al.[8] also identified higher percentages of agreement in aligned dental arches as compared to those in the present study, with 82.6% and 72.2% of agreement for the lower right and left teeth, respectively.

The percentages of agreement presented herein were similar to those identified by Silva[9], whom used digitized dental models and obtained 41.7% of agreement between the actual height and the height interval estimated by the original Carrea's method. The sample in Silva's[9] study consisted in a group of individuals who had teeth aligned and no history of orthodontic treatment, which corresponds in the present study to the data presented for group I in Table 5. The same author found a percentage of correctness of 72.3% for the group with crowded teeth and no orthodontic treatment, which is close to what we found for group II (Table 5). As in our study, the study by Sanchéz[10] included normal, crowded and diastematic lower dental teeth in the sample. However, the latter observed 45.6% of agreement between

Table 5: *Minimum and Maximum values, Mean, Median, Standard Deviation (SD) and percentage of agreement (%Concordance) between the actual height and the height estimated through the original and modified Carrea's indices, according to the special conditions.*

Original Carrea method												
	Absence of Crowding and Diastema (n=19)			Presence of Crowding (n=9)			Presence of Diastema (n=2)			Presence of Crowding and Diastema (n=1)		
	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance
Minimum	1.41	1.49		1.39	1.65		1.36	1.49		1.60	1.60	
Maximum	1.67	1.79		1.64	1.82		1.68	1.72		1.66	1.65	
Mean	1.54	1.63	42.1[a]	1.52	1.74	77.8[a]	1.52	1.60	50.0[a]	1.63	1.63	0[a]
Median	1.53	1.61		1.51	1.73		1.52	1.53		1.63	1.63	
SD	0.07	0.09		0.07	0.06		2.21	1.54		-	-	
Modified Carrea method												
	Absence of Crowding and Diastema (n=19)			Presence of Crowding (n=9)			Presence of Diastema (n=2)			Presence of Crowding and Diastema (n=1)		
	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance	Min. Height	Max. Height	% Concordance
Minimum	1.49	1.56		1.49	1.67		1.41	1.51		1.45	1.66	
Maximum	1.80	1.94		1.75	1.81		1.79	1.75		1.48	1.70	
Mean	1.61	1.70	47.4[b]	1.63	1.74	55.6[b]	1.60	1.62	50.0[b]	1.46	1.68	100.0[b]
Median	1.60	1.67		1.63	1.73		1.60	1.62		1.46	1.68	
SD	0.08	0.08		0.07	0.04		1.92	1.54		-	-	

[a]*No statistically significant difference (p=0.238; Pearson Qui-Square test).*
[b]*No statistically significant difference (p=0.769; Pearson Qui-Square test).*
SD: Standard Deviation

the actual and estimated height, which correspondes to lower rates than those observed in our study.

By using the modified Carrea's method, we found 51.6% of agreement between the estimated and actual height. This percentage is lower than that found by Lima et al.[2] when analyzing different denominators to propose the modification of the mathematical formula. Lima et al.[2] observed 63.6% of agreement, which led them to select the denominator of 2.55 for application of the formula in the upper teeth. However, in a second stage of their research in which they proposed to test the new formula, concordance percentages varied according to dental position and sex, somehow closer to what we found in our study: aligned hemiarches - 34.7% for males and 42.3% for females; and hemiarches with crowding - 65.0% for males and 51.7% for females.

Although there was a better fit for the right hemiarch when only the quadrants with normal positioning were considered, Lima et al.[8] did not find a statistically significant difference between them, which also occurred in the present study.

Silva[9] stated that Carrea did not make any reports as to which hemiarch, right or left, should be used to obtain the measurements. It means that Carrea's work was based on a study of the proportionality relation between measures of the human body, through which the two hemiarches should be equal. This confirms that there should not be an ideal hemiarch to obtain the necessary measures.

The analysis of Spearman's correlation coefficients confirmed the median results obtained in the descriptive statistics (percentage of agreement between actual and estimated height) by both methods. Despite the significant correlations between the actual values and the minimum height estimated by the modified Carrea's method based on quadrant 1, and between the actual values and the maximum height estimated by the same method from the analysis of quadrant 2, the values obtained are below the values considered to be adequate by the literature. In this correlation, values above 0.8 are considered as excellent internal consistency. According to Prieto and Muniz[11], for samples with a number below 200, values above 0.6 are already considered adequate, so that the Spearman classification can be as follows: 0.70-0.79 (adequate); 0.80-0.84 (good) and >0.85 (excellent). We did not find in the literature studies that used this statistical method to evaluate the Carrea's method, either original or modified, making it difficult to discuss these findings.

It is well known that cases with severe changes in the dental arch (tooth loss, wear, or abnormalities) should not be analyzed for estimation of body measurements. However, it is important to consider dental arches with light crowds and/or diastema, mainly in studies evaluating estimation methods such as the original and modified Carrea's indices. Under those conditions, significant percentage of agreements can be achieved and, consequently, the validity of the methods can be strengthened and extended.

It is valid to emphasize that the median values of agreement found can be attributed to the methods used in our study. As stated by Lima et al.[2], despite the high accuracy of the measurements, the use of the digital caliper can result in difficulties to measure dental dimensions due to their blunt stems, which are commonly unable to adapt adequately to dental spaces.

Cavalcanti et al.[12] used the original Carrea's height estimation technique, however using a dry-point compass and a millimeter ruler to replace the digital caliper to obtain the measurements. This resulted in 36.0% of agreement for the right lower quadrant and 48.0% for the left lower quadrant. This slight modification of the Carrea's technique may not have improved the percentage of agreement between the actual and estimated height.

Thus, it is believed as suggested by the above-mentioned authors that the dry-point compass has finer points, which would provide a more accurate measurement of the mesiodistal diameters of the dental elements. In this perspective, it is important to consider the good applicability of the technique used by Furlan et al.[7], who used dental floss to measure the dimensions and then transferred them to the digital caliper for quantification of the distances obtained, thereby achieving a great percentage of accuracy between the actual and estimated height.

Besides the possibility that the instrument used to perform the measurements interfered with the results, it is necessary to consider that this study has limitations. The main one refers to the sample size, which can be considered small, but it was what could be obtained at the study site from a non-probabilistic sampling. The difference between the study population and the sample size was mainly due to the large number of students using fixed orthodontic appliances, which may be a relatively expected and understandable feature among dental students.

The original Carrea's method and the method modified by Lima et al.[2] need further investigation with larger samples comprising heterogeneous populations in order to demonstrate their real efficacy in the estimation of human height. Thus far, both methods can be considered as complementary to other techniques recommended for height estimation during an identification process, but their sole use should be avoided.

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