Int. J. Morphol.,
40(4):883-894, 2022.

Sex Estimation by Metric Analysis of the Angle of Mandible and the Mandibular Ramus: A Systematic Review

Estimación Sexual Mediante Análisis Métrico del Ángulo de la Mandíbula y de la Rama Mandibular: Revisión Sistemática

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ALVES, N.; CEBALLOS, F.; MUÑOZ, L. & DEANA, N. F. Sex estimation by metric analysis of the angle of mandible and the mandibular ramus: A systematic review. *Int. J. Morphol., 40(4)*:883-894, 2022.

SUMMARY: Sex estimation is the first step in human identification. The mandibular ramus and the condyle have been widely used as indicators for sexual diagnosis because they are regions that undergo important morphological changes which increase sexual dimorphism. The object of the present study was to carry out a systematic review to determine the metric parameters of the mandibular ramus that present the greatest sexual dimorphism, and to sex estimation from the angle of mandible (MA). We included documents in English, Spanish and Portuguese which analysed sex estimation or sex diagnosis by metric analysis of the mandibular ramus in humans. The search was conducted in PubMed/MEDLINE, EMBASE, LILACS, up to December 2020. The risks of bias were analysed using the AQUA tool. The search identified 538 studies. After exclusion of duplicates and irrelevant articles, 39 studies were included for qualitative analysis. Of these, 18 studies were carried out on dry mandibles and 21 by imaging techniques, totalling 7270 participants of 14 different nationalities. We found 14 sex-estimation parameters in the mandibular ramus, plus the MA. Sex estimation by the MA is variable; it is a good predictor only for some populations. The height of the mandibular ramus, the angle of mandible, the bicondylar angle and the height of the coronoid process were the estimation parameters cited in the greatest number of studies. The mandibular ramus presents great sexual dimorphism and can be used as a sex predictor in different populations. Although some parameters of the mandibular ramus can present accuracy of almost 80 % when analysed in isolation, more accurate sex estimation is achieved when the parameters are analysed in conjunction.

KEY WORDS: Sex estimation; Mandibular ramus; Angle of mandible; Mandible.

INTRODUCTION

The mandible is an unpaired, symmetrical bone located in the lower third of the face. It consists of an arched body in the shape of a horseshoe and two rami which extend from the posterior ends of the body to cranial (Alves & Cândido, 2016). It starts to form during the 6th week of intrauterine development, when the first branchial arch starts to produce mandibular cartilage, indicating the location of the mandible. Its ossification is intramembranous. After birth the mandible fuses in the region of the mandibular symphysis during the first year of life, and this symphysis usually disappears by the age of 18 years (Lipski *et al*., 2013).

Estimating sex is the first step in the identification of human remains, followed by determination of other elements such as age, height and ethnic composition (Ruff, 2010; Franklin *et al*., 2014). Physical anthropology uses the morphological and metrical aspects of bone structures for estimating and determining the principal characteristics of an individual; the training and knowledge of the professional is fundamental for identifying bone remains, regardless of their condition (decomposed, burnt, dismembered) (Taylor & Kieser, 2016). In human sex identification, the pelvic and cranial bones are highly reliable; however, in the absence of

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Received: 2022-05-30 Accepted:2022-06-18

the pelvic bones, analysis of the mandible may be the best alternative due to its strong sexual dimorphism (Moore, 2013; Alves & Deana, 2019).

In modern humans, the mandible is generally smaller in female individuals than in males (Alves & Deana, 2019), the mean size being 92.4 % of that of the male mandible (Humphrey *et al*., 1999). The mandibular ramus and the condyle have been widely used as indicators for sexual diagnosis because they are regions that undergo important morphological changes which increase sexual dimorphism (Humphrey *et al*., 1999). Standards of sex differentiation which are valid for one population may not be useful for another (Vodanovic´ *et al*., 2006), since cultural and ethnic aspects may influence the development of the mandible, determining differences between populations (Iscan & Kennedy, 1989; Saini *et al*., 2011). For this reason it is important to consider not only the accuracy of sex identification in different populations, but also which parameters present the greatest dimorphism for each population. Thus the research question for this study was: Which metric parameters of the mandibular ramus present the greatest sexual dimorphism? The object of the present study was to carry out a systematic review to determine the metric parameters of the mandibular ramus that present the greatest sexual dimorphism. Furthermore, we analysed the accuracy of the angle of mandible (MA) in determining sex. A second object was to analyse the accuracy of the mandibular ramus in predicting sex in different populations.

MATERIAL AND METHOD

Eligibility criteria. We included documents in English, Spanish and Portuguese which analysed sex estimation or sex diagnosis by metric analysis of the mandibular ramus in humans (Homo sapiens). We included studies carried out in dry mandibles or by imaging methods (panoramic radiography (PR), computed tomography (CT), cone-beam computed tomography (CBCT) or spiral cone-beam computed tomography (SCBCT)). Studies were included that assessed sex estimation by analysis of metric characteristics of the mandibular ramus. Only studies that presented results for at least one variable of the mandibular ramus were included.

Studies were excluded that assessed non-metric parameters alone, sexual dimorphism alone, other metric parameters of the mandible, or that did not present results for at least one of the parameters assessed in the mandibular ramus in isolation. Literature reviews, systematic reviews, letters to the editor and conference summaries were excluded. Studies that analysed differences between the sexes only by analysis of mean differences were also excluded.

Information sources and search. We performed a systematic search of the scientific literature to identify original studies that assessed sex estimation by metric analysis of the mandibular ramus. The search was conducted in PubMed/MEDLINE, EMBASE and LILACS, up to December 2020. In addition, we examined the reference lists of the selected studies to identify other studies that met the inclusion criteria. We did not limit the search by date or publication status, however only studies in English, Spanish and Portuguese were included.

The search strategy carried out in MEDLINE was: ((((((((((((Dry skull) OR Dry mandible) OR Orthopantomography) OR Panoramic*) OR radiographic) OR ("Cone-Beam Computed Tomography"[Mesh] AND "Spiral Cone-Beam Computed Tomography"[Mesh])) OR cone beam computed tomography) OR cone beam*) OR Computed tomography*) OR CBCT*)) AND (((((((((((Coronoid*) OR condylar height) OR Gnation) OR Gonial angle) OR Bicondylar) OR mandibular ramus*) OR bigonial*) OR "Mandible"[Mesh]) OR mandible)) AND (((((((((forensic*) OR Physical anthropology) OR physical anthropology) OR sex determination) OR ("Sex Determination Processes"[Mesh] OR "Sex Determination by Skeleton"[Mesh] OR "Sex Determination Analysis"[Mesh])) OR Sex characteristics) OR Sex prediction) OR Sexual dimorphism) OR Gender estimation).

Study Selection. All references identified were extracted to an EndNote X9 database to facilitate management and delete duplicate articles. Selection by title and abstract was carried out using the Rayyan software (http://rayyan.qcri.org). Titles and/or abstracts of studies retrieved using the search strategy, and those from additional sources, were screened independently by two review authors (L.M., N.F.D.) to identify studies that potentially met the inclusion criteria. We obtained full texts of all relevant and potentially relevant studies, those appearing to meet the inclusion criteria, and those for which there were insufficient data in the title and abstract to make a clear decision. Any disagreement between the two review authors over the eligibility of particular studies was resolved through discussion with a third reviewer (N.A.).

The extraction of the descriptive data was performed independently by two researchers (L.M., F.C.) using a standardised data collection form including: Author, year, title, country, number of participants, type of study, parameters assessed, principal results.

Risk of bias. Two review authors (L.M., F.C.) independently assessed the risk of bias of the eligible works using the AQUA tool. In cases of discrepancy, consensus was obtained by consulting a third reviewer (N.F.D.). The AQUA tool consists of 20 questions and five domains, which evaluate: 1. Object(s) and subject characteristics; 2. Study design; 3. Characterization of the methodology; 4. Descriptive anatomy; and 5. Reporting of results. The signalling questions are answered as Yes, No, or Unclear. The answers to these signalling questions, Yes, No and Unclear, indicate low, high, and unclear risk of bias respectively. The risk of bias question is judged as Low, High, or Unclear: if all the signalling questions for a domain are answered Yes, then the risk of bias can be judged Low. If any signalling question is answered No, this indicates the potential for bias. The Unclear option should be used only when the reported data are insufficient to allow for a clear judgment (Henry *et al*., 2017; Evidence-Based Anatomy, 2021).

Report of quality indicators. The following quality indicators were analysed: information on randomisation; sample size calculation; approval by a scientific ethics committee; conflicts of interest and funding, and intraobserver and/or interobserver analysis. Quality indicators were classified as reported or not reported.

Synthesis of the results. A narrative synthesis of the findings was made. Tables were used to present information on the principal characteristics of the studies. The graphs were prepared with the Excel, Prisma GraphPad and RStudio software, version 1.4.1106, 2021, using the Plotly package.

RESULTS

Search results. The search identified 538 articles. After the exclusion of 14 duplicate studies and analysis of the titles and abstracts, 60 articles were selected for full text reading. Of these, 35 were excluded at this stage: 20 tested mean differences between sexes, but without assessing estimation (other outcomes), 3 did not assess sex estimation in the mandibular ramus or the angle of mandible, 12 were excluded for reasons of their design, and 1 because the study was not carried out in the population of interest. Fifteen additional studies were included after reading of the title and abstract. Finally 39 full text studies were included in the qualitative analysis (Fig. 1).

Characteristics of the studies included. Of the 39 studies included, 18 were in dry mandibles (Vodanovic *et al*., 2006; Franklin *et al*., 2006, 2008; Dayal *et al*., 2008; Saini *et al*., 2011; Carvalho *et al*., 2013; Marinescu *et al*., 2013; Pokhrel & Bhatnagar, 2013; Kranioti *et al*., 2014; Wankhede *et al*., 2015; Sharma *et al*., 2016; Álvarez Villanueva *et al*., 2017; Lopez-Capp *et al*., 2018; Vignesh *et al*., 2018; Bertsatos *et al*., 2019; Alves & Deana, 2019) and 21 in imaging studies, i.e. 10 by CBCT (Kharoshah *et al*., 2010; Ilguy *et al*., 2014; Dong *et al*., 2015; Gamba *et al*., 2016; Inci *et al*., 2016; Tunis *et al*., 2017; Lopez *et al*., 2017; Deng *et al*., 2017; Gillet *et al*., 2020; Motawei *et al*., 2020), 2 by CT (Lin *et al*., 2014; Alias *et al*., 2018), and 10 by radiography (Barthélémy *et al*., 1999; Indira *et al*., 2012; Damera *et al*., 2016; Sairam *et al*., 2016; Sambhana *et al*., 2016; Samatha *et al*., 2016; More *et al*., 2017; Maloth *et al*., 2017; Belaldavar *et al*., 2019; Ortiz *et al*., 2020) (Table I). A total of 7270 participants were included, 1981 in dry mandible studies and 5289 in imaging studies.

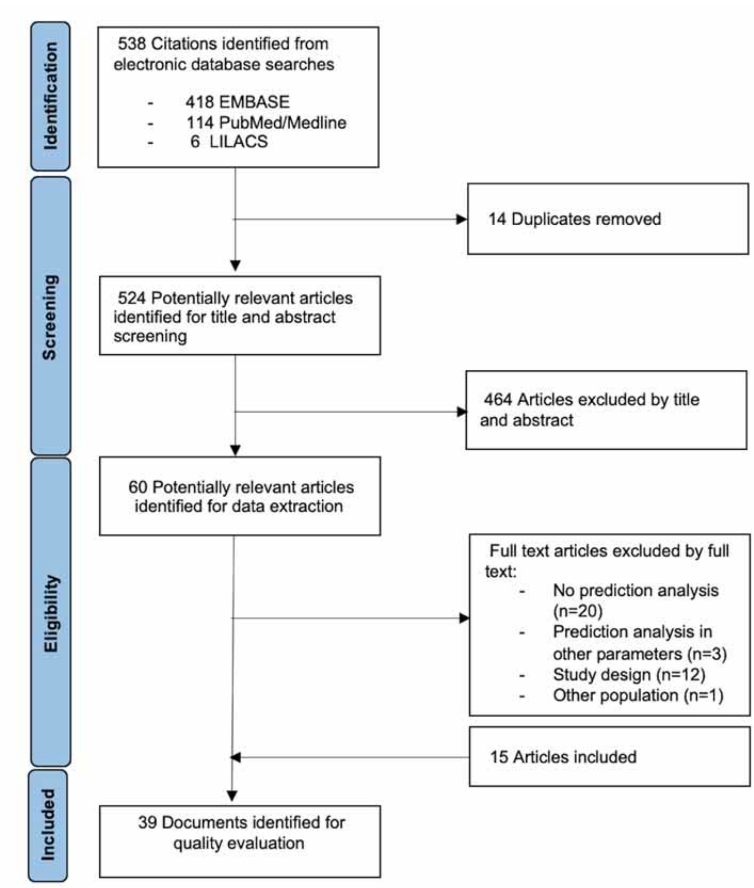

Fig. 1. Flow diagram showing the study selection process.

The definition and description of the parameters analysed are reported in Table II. The studies were carried out in different populations, 13 in India, 6 in Brazil, 4 in South Africa. Two studies each were published in China, Egypt, France, Greece and Turkey, and one each in Croatia, Israel, Korea, Malaysia, Mexico and Romania (Tables I and III).

Risk of bias. No study presented low risk of bias in all 5 domains of the AQUA tool. In the domain Study objects and characteristics, many of the studies (33/39) did not state clearly how the sample was selected or did not justify the number of participants necessary for the sample. The studies provided little information on the characteristics of the

Table I. Characteristics of the imaging studies and principal results.

Author, year	Imaging examination	Country	N Total	N Females/Males	Mean age	Variables analysed in the mandibular ramus	Principal results
Alias *et al.*, 2018	CT	Malaysia	79	31/48	18 - 74	MaRB, MiRB, RH, CoH, BC, BG	RH and BG were the best parameters for sex differentiation in the mandible. Both parameters presented accuracy of 78.5 %, sensitivity of 79.2 % and specificity of 77.4 %. The other indicators assessed could not predict sex
Barthélémy *et al.*, 1999	Teleradiography	France (South)	63	29/34	Mean 26.7 (20-34)	BG, BV, RH*	All the parameters analysed presented sexual dimorphism. Using parameters of the mandibular ramus and body, sex estimation was 87.3 %
Belaldavar *et al.*, 2019	Radiography	India	304	155/149	18 - 30	AS	The MA presented low power of sex estimation, with an accuracy of 56.3 %.
Damera *et al.*, 2016	PR	India	80	40/40	20 - 50	MaRB, MiRB, CoH, RH, MA, BG	RH was parameter with the best sex differentiation in isolation. The use of 4 indicators together (RH, PRH, CoHBG) achieved 83.3 % accuracy in s ex differentiation.
Deng *et al.*, 2017	CBCT	China	219	111/108	20-67	BC, BG*	BC was parameter with the best sex differentiation in isolation. The parameters BC, BG, biantegonial notch breadth and bi-mental foramina breadth used in conjunction presented sex estimation accuracy of 82.2 %
Dong *et al.*, 2015	CBCT	China	203	107/96	20-65	BC, BG, RH, MA, ML, MaRB*	BC, RH were the indicators with the greatest power of sex differentiation. BC, ML and RH used in conjunction presented sex rw accuracy of 84.4 %. The accuracy rose to 86.5 % when all the parameters analysed in the study were used
Gamba *et al.*, 2016	CBCT	Brazil	160	86/74	18 - 60	RH, MA, MiRB, BC, BG	The measurement values were higher in males than in females, except for the MiRB which presented no statistically significant differences between sexes. Mandibular BG, RH, MA and BC presented the greatest reliability for sex estimation
Gillet *et al.*, 2020	MSCT (multi-slice)	France	120	57/63	22-34	RH, BG, BC, MA	The mandible presented high accuracy in differentiating the sexes, with RH and BG presenting the best estimation
Inci *et al.*, 2016	MDCT (multi-detector)	Turkey	415	214/201	43 ± 16.4	MiRB, MaRB, URVH, MFUB, MRLB, MFD, MRVH, URVH, UMFA, MFA	The values for the mandibular ramus achieved accuracy rates of 51 % to 95.6 %. URVH had the highest rate at 95.6 %. The mandibular ramus gave 99 % accuracy and can provide important information for sex determination in the Turkish population
Indira *et al.*, 2012	PR	India	100	50/50	20 – 50	MaRB, MiRB, RH, PHR, CoH	All the parameters used were sex predictors; the greatest sexual dimorphism was observed in the MiRB.
Ilgüy *et al.*, 2014	CBCT	Turkey	161	95	18 – 85	MA, RH, MiRB, BG, BC	All the parameters presented sexual dimorphism, and were larger in males than in females. MA, RH and BG were the best predictors of sex, with 83.2 % accuracy
Kharoshah *et al.*, 2010	Spiral CBCT	Egypt	330	165/165	6-60	MA, RH, MiRB, BG, BC*	The estimation model presented 83.9 % accuracy; the correct predictive accuracy was 83.6 % in males and 84.2 % in females.
Lin *et al.*, 2014	CT scans	Korea	240	120/120	21-70	MiRB, MaRB, MFUB, MFLB, MFD, MRFVH, URVH, MA, UMFA, MFA	Analysis of all the parameters of the mandibular ramus flexure in conjunction presented accuracy of 88.8 %. In univariate analysis, sexual differentiation varied between 50.4 and 77.1 % (variables: upper ramus vertical height, maximum ramus vertical height, mandibular flexure upper margin, minimum ramus breadth, maximum ramus breadth). Bivariate analysis presented prediction of 81.7 % using the variables maximum ramus vertical height and upper ramus vertical height.
Lopez *et al.*, 2017	Stabiliser with CBCT	Brazil	60	28/32	17 to over 80	ML, BG, RH BC, BCB, MNB, MiRB MA, MND	The mandibular stabiliser achieved the objective of distinguishing sexual dimorphism using mandibular measurements. The BC, BCB MiRB achieved the highest coefficients of concordance; the width and depth of the notch breadth MND achieved lower rates concordance because recognition of these anatomical reference points requires greater knowledge and training
Maloth *et al.*, 2017	PR	Indian	100	50/50	Mean age 37.4 years	URB, LRB, RH, PHR, CoH	RH was the only significant value which acts as predictor for sex. The overall accuracy for diagnosing gender was 74 %, whereas for diagnosing male and female, the accuracy was 70 % and 78 %, respectively
More *et al.*, 2017	PR	India	1000	500/500	21 – 60	MaRB, MiRB, RH, PHR, CoH	Males presented higher values than females. Morphometric analysis of the mandibular ramus may allow sex to be determined in adult patients who are not totally edentulous. The 5 characteristics analysed proved to be highly significant in males, females and in general. The overall accuracy of the mandibular ramus in determining sex was 69 %.
Motawei *et al.*, 2020	CBCT	Egypt	213	114/99	26.5 ± 13.8	RH	The mandibular ramus does not present sexual dimorphism until the age of 17 years. The mandibular ramus can be used to estimate sex with 67 % accuracy in CBCT. In mandibular rami larger than 5 cm the accuracy of sex determination was 82 %, and for mandibular rami larger than 5.80 cm it was 89 %. In the age range from 7 to 17 years there was no significant difference between sexes, whereas a significant difference existed in the range 17 to 58 years.
Ortiz *et al.*, 2020	PR	Brazil	100	50/50	NR	MA*	Sex can be estimated from anatomical points visible in RP, especially using Machine Learning to support statistical methods of sex estimation
Sairam *et al.*, 2016	PR	India	200	100/100	NR	MaRB, MiRB, RH, PHR, CoH	The measurements taken in the mandibular ramus can be used to determine sex. MaRB, RH, CoH are important predictors of sex on the right side, while RH, CoH, MiRB and MaRB were good predictors on the left. The accuracy found for the left mandibular ramus was 77 % and for the right 79.5 %.
Samatha *et al.*, 2016	PR	India	120	60/60	18 – 45	MaRB, MiRB, RH, PHR, CoH	All the parameters presented sexual dimorphism, but RH was the best predictor
Sambhana *et al.*, 2016	PR	South India	384	192/192	7-75	MiRB, MaRB, BC, MA, RH, BG, CoH*	The variable that presented the best estimation in isolation was CoH with 74.7 %. All the variables analysed presented great sexual dimorphism, except the MA. When all the variables analysed (mandibular body and ramus) were used, the accuracy was 75.8 %
Tunis *et al.*, 2017	CBCT	Israel	438	224/214	Males: 53.3 ± 19.9; Females: 56.2 ± 20.6	RH, CoB, CoH, BC, BCB, CBAN* RW, MAW, MA, CoB, BANB	The more complete the mandible, the greater will be success in determining sex (up to 90.8 %). For all the characteristics analysed, except the MA, males presented higher mean values than females. The characteristics that presented the greatest sexual dimorphism were the area of the BANB, the RH, CoH, CB, width of the chin, height of the mandibular body in the region of the premolars and of the molars, area of the symphysis, height of the mandibular body at the level of the molars and premolars, and height of the symphysis

*Other measurements related with the body of the mandible were used.

individuals, so they were classified as high risk of bias for this domain. In the domain Results reporting, 37/39 studies did not assess or did not analyse the potential confusion factors, and the other studies did not state the confusion factors clearly, so they were all classified as high risk of bias. In the domain Characterization of the methodology, the studies failed to report clearly the speciality and experience of the people carrying out the study, or simply

Table II. Description and abbreviations of the parameters of the mandibular ramus.

Abbreviation	Parameter	Description
BANB	Bi-antegonial notch breadth	Distance between the two antegonial notches.
BC	Bi-condylar breadth	The straight-line distance between the most lateral points on the two mandibular condyles.
BCB	Bi-coronoid breadth	Distance between the highest points of the mandibular coronoid processes.
BG	Bigonial breadth	The straight-line distance between the two angles of mandible, measured horizontally from the right to left angle of mandible.
BLB	Bi-lingula breadth	The distance between the right and left lingula.
BNB	Bi-mandibular notch breadth	The distance between right and left mandibular notch.
CB	Condylar breadth	The distance between the most prominent points on the anterior and posterior surfaces of the mandibular condyle.
CL	Condylar length	The distance between the most prominent medial and lateral points of the mandibular condyle.
CGL	Coronion-gonion length	The distance between the coronion and gonion.
CoB	Coronoid breadth	The distance between the deepest point on the mandibular notch and the anterior margin of the coronoid process.
CoH	Coronoid height	Projective distance between the coronion and the base of the coronoid process.
LRB	Lower ramus breadth	The horizontal distance between the anterior and posterior points of the ramus of mandible at the level of the occlusal plane.
MA	Angle of mandible	The angle formed by the posterior margin of the ramus and the inferior margin of the body of mandible.
MAW	Width of Angle of mandible	The distance between the gonion and deepest point on the concavity connecting the anterior margin of the ramus with the body of mandible.
MaRB	Maximum ramus breadth	The distance between the most anterior point on the ramus of mandible and a line connecting the most posterior points on the condyles.
MFA	Mandibular flexure angle	Angle formed by the MFUB and MFLB.
MB	Mandible breadth	The distance between right and left anterior ramus.
MFUB	Mandibular flexure upper margin	Distance between posterior point of mandibular condyle and concave point of mandibular ramus flexure.
MFLB	Mandibular flexure lower margin	Distance between posterior protruding point of body of mandible and concave point of mandibular ramus flexure.
MRVH	Maximum ramus vertical height	Vertical distance between the highest point of mandibular condyle and the bottom plane of body of mandible.
ML	Mandibular length	Distance between the pogonion (pg) and the perpendicular line tangent to the posterior part of the condylar processes
MiRB	Minimum ramus breadth	Minimum breadth between the anterior and posterior margins of the ramus of mandible.
MiRH	Minimum ramus height	The description of this parameter was not reported by the author
MFD	Mandibular flexure depth	Vertical distance from concave point of mandibular ramus flexure to posterior plane of ramus of mandible.
MNB	Mandibular notch breadth	Distance between the superior point of the condylar process and the superior point of the coronoid process.
MND	Mandibular notch depth	Distance between the inferior point of the mandibular notch and the midpoint of a straight line extending from the superior point of the condylar process and the superior point of the coronoid process.
MRH	Maximum ramus height	The distance between the most superior point on the mandibular condyle of the mandibular tubercle, or most protruding point of the inferior margin of the ramus.
MRFVH	Mandibular ramus flexure vertical height	Vertical distance from concave point of mandibular ramus flexure to bottom plane of the body of mandible.
NL	Notch length	The distance between the coronion and superior condylion.
PHR	Projective height of ramus	Projective height of ramus between the highest point of the mandibular condyle and lower margin of the bone.
RH	Ramus height	Height of the ramus of the mandible from the most superior point on the mandibular condyle to the tubercle, or most protruding portion of the inferior margin of the ramus.
RW	Ramus width	The distance between the anterior and posterior indentations of the ramus of mandible.
UMFA	Upper mandibular flexure angle	The intersecting angle between mandibular flexure upper margin and the plane parallel to the bottom plane of the body of mandible.
URVH	Upper ramus vertical height	Vertical distance between mandibular ramus vertical height and mandibular ramus flexure vertical height.
URB	Upper ramus breadth	Horizontal distance between the anterior and posterior points of the ramus of mandible passing through the mandibular notch.

omitted the information. They also failed to take adequate measures to reduce interobserver (or intraobserver) variability. The majority of the studies (32/39) were therefore classified as high risk of bias for this domain. In the domain Descriptive anatomy, 12/39 studies were classified as high risk of bias because of the absence of information on the anatomical definition of the variables analysed, or lack of clarity in the illustrations showing the measurements of the predictive variables. In the domain Study design, most of the studies were classified as low risk of bias (29/39); a few were classified as high risk of bias (10/39), mainly due to poor reporting, which undermined judgment domains (Fig. 2).

Report of Quality Indicators. The majority of the studies did not report data on conflicts of interest (25/39) or approval of the study by a scientific ethics committee (23/39). In 18/39 studies the authors reported funding data; intraobserver analysis was carried out in 7/39 studies, interobserver analysis in 3/39 studies, and both in 8/39 studies (Fig. 3).

Analysis of sex determination. Fourteen sex-estimation parameters in the mandibular ramus were analysed, plus the MA, bringing the total to 15 (Fig. 4). The mandibular ramus height (RH) was reported in 23/39 studies as one of the best measurements for sex differentiation, followed by the

Table III. Characteristics of studies in dry mandibles and principal results.

Author, year	Country	N		Mean age	Variables analysed in the mandibular ramus	Principal results
		Total	Females/Males			
Álvarez-Villanueva *et al.,* 2017	Mexico	164	66/105	Males: 55.1 ± 19 and 49.2 ± 10.4; Females: 50.7 ± 18.9 and 61.7 ± 14.1	BG, BC, MaRB, MiRB, RH, RL, MA*	In both samples the most dimorphic regions are: height of the symphysis, height of the mental foramen, BG, BC, RH and length of the body. MaRB and MiRB only presented differences in the MEX sample
Alves & Deana, 2019	Brazil	113	47/66	NR	BC, BG, RH, MaRB, MiRB	The BC, BG and RH presented great accuracy in sex determination
Bertsatos et al., 2019	Greece (Athens collection)	194	89/105	9-99	BC, BG, BCB, CoH, RH, ML, MA, MaRB, MiRB, NL, BLB, MB, BNB, PHR*	The CoH, RH and ML presented accuracy up to 85.7 %
Carvalho *et al.,* 2013	Brazil	66	32/34	Over 20	RL, BG	RL and BG presented 76.47 % accuracy for males and 78.13 % for females in predicting sex.
Dayal et al. 2008	South Africa	120	60/60	20-70	BC, BG, RH, MiRB, ML*	BC, BG, RH, MiRB, ML and gonion-gnathion length presented a total accuracy of 85 % in sex determination.
Franklin et al., 2006	South Africa	40	20/20	20-45	RH, CoH, BG, BC, BCB, NL, ML*	When all the variables are used an accuracy of 95 % is achieved; with only the 4 best indicators (RH, CH, ML, BCB) the accuracy was 92.5 %
Franklin et al. 2008	South Africa	255	120/105	18-70	RH, CH, BG, BC, BCB*	The accuracy in sex estimation was 82.7 % when the best variables were used: CH, ML, coronoid height, maximum mandible length, BG. The use of all the variables for estimation gave an accuracy of 84 %. In the population analysis, better estimation was found for the Swazi, with 90.3 %, than for the Xhosa, with 77.3 %
Kranioti et al., 2014	Greece (Cretan Collection)	70	34/36	<66	BC, BG, MiRH*	All the parameters used presented sexual dimorphism. The variable BG presented 71 % accuracy, and the combination of BC and BG increased classification accuracy to 80 %.
Lopez-Capp et al., 2018	Brazil	100	53/47	18-104	BCB, BC, MN, MiRB, MaRB, RH, ML, BG, MA, MND	The variables BC and RH presented the greatest AUC. An accuracy of 83 % was achieved using variables of the mandibular ramus and body, 77.4 % for males and 89.4 % for females.
Marinescu et al., 2013	Romania	200	100/100	Mean 39 (20-86)	BC, BG*	BG breadth determined 80.5 % accuracy when used alone.
Pokhrel & Bhatnagar, 2013	India	79	26/53	NR	CL, CB, MiRB, MaRB	The predictive value produced by the condyle measurement is low; the parameters MiRB and MaRB can be used as a diagnostic tool.
Saini et al., 2011	India (Northern)	116	24/92	37.4	MaRB, MiRB, CH, RH, PHR, CoH	All the indicators assessed presented sexual dimorphism, with 80.2 % overall accuracy; CoH was the indicator that produced the greatest accuracy in isolation, with 74.1 %
Sharma et al., 2016	India	126	42/78	NR	MA, MiRB, ML	Sex estimation using the variables ML and MiRB was 60 %. Prediction was higher in adult males (63.5 %) and lower in elderly males (53.3 %). The MA presented no statistical differences between adult individuals and elderly individuals.
Vignesh *et al.,* 2018	India	80	40/40	NR	CH, PHR, MA, URB, LRB, PHR, CoH	The mandibular ramus presents great sexual dimorphism, but the RH was the only reliable indicator for predicting sex, with 78.6 % accuracy in males and 76.8 % in females.
Vodanovi_ et al., 2006	Croatia	85	26/59	NR	MA, MaRB, MiRB, RH, BG*	The length of the mandibular body, the MA and MiRB ramus are the variables producing greatest sex prediction.
Wankhede et al., 2015	India (central)	82	27/55	NR	BC, BG, MA, CoB, MiRB*	Six of the parameters analysed presented sexual dimorphism, with 81.7 % sex prediction (this analysis considered measurements of parameters of the mandibular ramus and body). The variable that presented the greatest sexual dimorphism was projection length of the corpus of the mandible, measured in the mandibular body. The BC presented good sex differentiation in 75.6 % of cases, and bigonial breadth in 70.7 %

*Other measurements related with the body of the mandible were used.

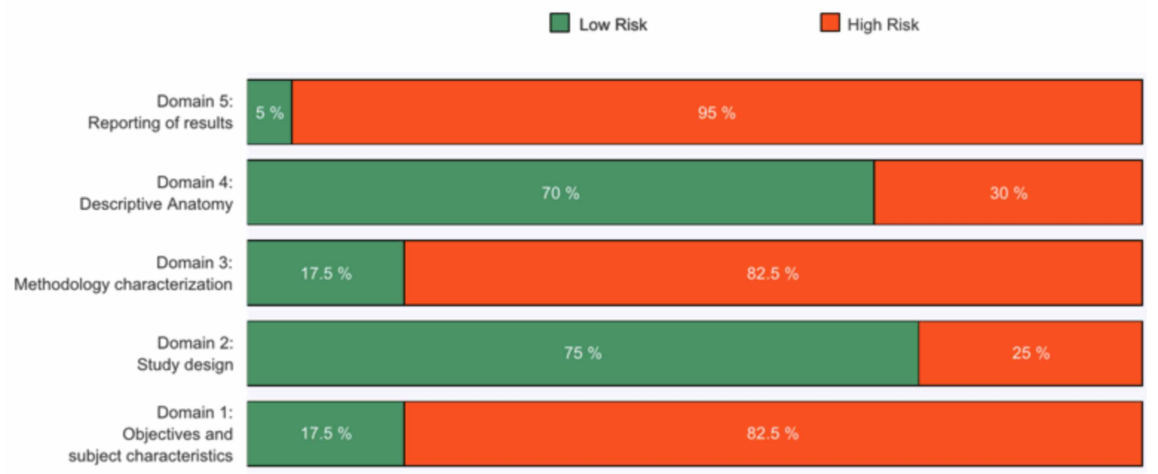

Fig. 2. Risk of bias of the studies included assessed with the AQUA tool, expressed in percentages.

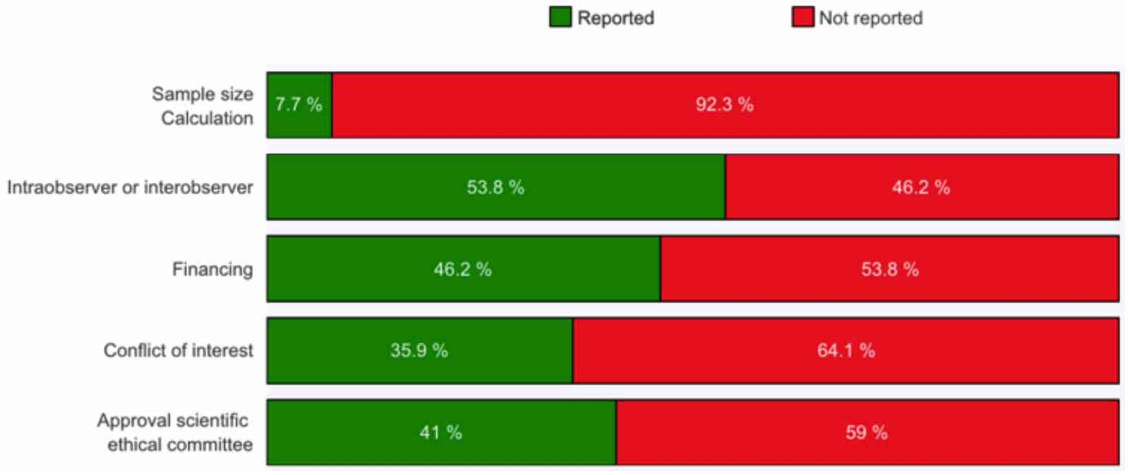

Fig. 3. Report of quality indicators.

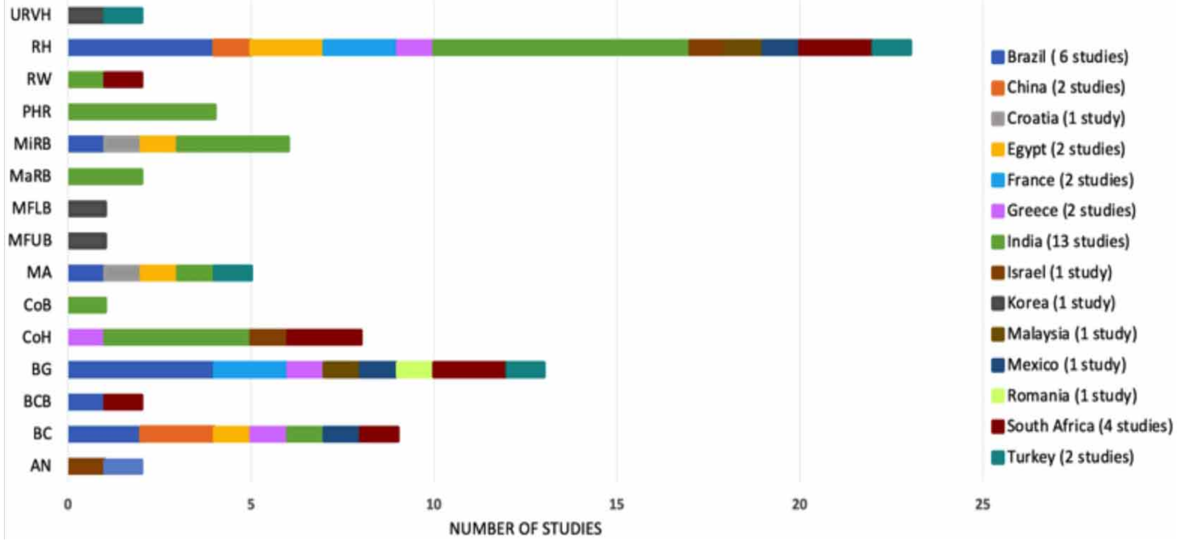

Fig. 4. Relation of parameters analysed by country.

bigonial breadth (BG), reported by 13/39 studies, and the bicondylar breadth (BC) reported by 9/39 studies as the best predictor (Fig. 4). Only two studies did not report the best parameter for sex differentiation (Carvalho *et al*., 2013); 1 study in a population in India reported that the parameter analysed did not present good differentiation (Belaldavar *et al*., 2019). RH, MiRB, MaRB, RW, PHB, MA, CoH and BC were the parameters with the greatest dimorphism in the Indian population. In Brazilian studies, RH, MiRB, MA, BG and BC proved to be good predictors for differentiating the sexes. In South-African studies, RH, RW, CoH, BG, BCB and BC were the parameters with the greatest dimorphism. The parameters with greatest dimorphism in other populations can be analysed in Figure 4.

The percentage accuracy was presented for isolated parameters or in conjunction, and was reported by 19 studies. Of these, 13 indicated accuracy higher than 80 %. Figure 5 shows the percentage accuracy by country and sample used. The highest percentage accuracy was presented by the Turkish population; MDCT was used in the analysis of parameters of the mandibular ramus, achieving 99 % accuracy (Inci *et al*., 2016). In individuals in South Africa, 92.5 % accuracy was achieved in a study in cadavers, using 4 parameters in conjunction: ramus height, coronoid height, maximum mandible length and bicoronoid breadth (Franklin *et al*., 2006). Good accuracy (88.8 %) was also found for the Korean population by CT scans, using all the parameters of the mandibular ramus flexure (Lin *et al*., 2014). The lowest percentage was found in a radiography study in an Indian population, using only the angle of mandible, which presented an accuracy of 56.3 % (Belaldavar *et al*., 2019). All the other studies presented accuracy higher than 70 % (Fig. 5, Tables I and III).

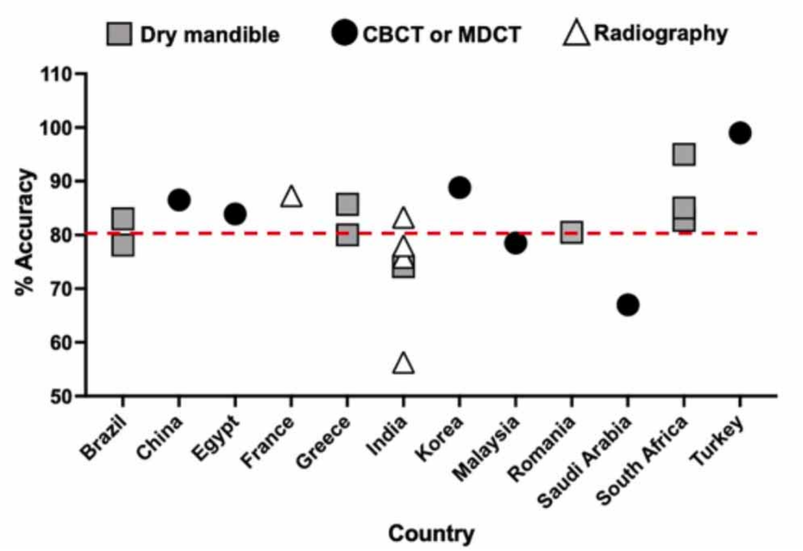

Fig. 5. Percentage accuracy found by country and type of examination (dry mandible, computed tomography or radiography).

DISCUSSION

In the present review we analysed the metric parameters of the mandibular ramus that present the greatest sexual dimorphism, considering the differences between different populations. The advantage of metric analysis is that it eliminates subjectivity in the analysis of morphological characteristics, increasing confidence in the results (Dabbs & Moore-Jansen, 2010). Morphometric methods are based on the operator's experience in observing the details of the points of reference in the bones, followed by measurements that may help construct differentiating functions and thus estimate sex. These methods can achieve an accuracy higher than 80 % in estimating sex (Dayal *et al*., 2008), without involving high costs.

Many visible sexual characteristics are absent in infancy and childhood, and develop completely at puberty, apparently due to endocrine stimulation . Other gender differences are related with the individual's activity (Slaus *et al*., 1997). Muscle size and specific relief emerge as the most diagnostic sexual characteristics (Rosas *et al*., 2002). Distinctive female muscle characteristics include small size and smooth insertions, while male muscles are larger with strongly marked insertions (Vodanovic *et al*., 2006). All the parameters presenting sexual dimorphism are influenced by the size of the mandible. This may be explained by genetically determined factors such as tooth size, or local environmental factors like muscle strength. During mastication, females exert a smaller muscular force on average, resulting in smooth muscle insertions and small mandibles. Males exert greater muscular force; they have more strongly marked muscle insertions, especially in the gonion and the coronoid process, and larger mandibles than females (Vodanovic *et al*., 2006). The sexual dimorphism found in the mandible of modern human individuals is due to differences related with musculoskeletal development, and others related with the differences in growth trajectory between males and females (Rosas *et al*., 2002). The present review included 39 studies which assessed a total of 14 sex-estimation parameters in the mandibular ramus and the MA. The expression of sexual dimorphism in the mandible shares certain characteristics in different populations (Bertsatos *et al*., 2019). In the present review, RH was indicated as a sex-estimation n parameter in 10 different populations. BG, BC and CoH were also highlighted as important sex-estimation parameters in different populations. BG, BC and RH presented over 80 % accuracy for Brazilian (Alves & Deana, 2019) and French populations (Barthélémy *et al*., 1999; Gillet *et al*., 2020). In another study, Carvalho *et al*. (2013) reported that in a Brazilian population 76.47 % accuracy was found for males and 78.13 % for females using BG and RH; while in a Greek population the combination of these two parameters achieved 80 % accuracy (Kranioti *et al*., 2014).

Although these parameters of the mandibular ramus may present good sexual dimorphism, it should be noted that they are generally less effective for sex estimation individually than when they are analysed in conjunction. Damera *et al*. (2016) report that RH was the parameter that presented the best sex differentiation in isolation, however the use of 4 indicators in conjunction produced an accuracy of 83.3 %, higher than the accuracy of any individual parameter. Deng *et al*. (2017) reported a similar finding: the parameters BC, BG, BANB and bimental foramina breadth used in conjunction presented sex estimation accuracy of 82.2 %, which was higher than the value for the best indicator, the BC with 77.6 %.

In the present review, metric analysis of the parameters of the mandibular ramus achieved accuracy higher than 80 % in the majority of the studies, regardless of the sample analysed (dry mandible, tomography or radiography). The highest accuracy was found for a Turkish population, and the lowest for an Indian population. It may be noted that in Indian populations only, the majority of the studies presented accuracy rates below 80 %. On the other hand, Damera *et al*. (2016) achieved 83.3 % accuracy by analysing 4 parameters in conjunction (RH, PHR, CoH, BG). A similar result is observed in Brazilian studies, where greater accuracy was achieved depending on the parameters analysed; it is therefore important to take into account which parameters give the best sex differentiation in each population.

The MA is located in the posteroinferior region of the mandibular ramus (Alves & Cândido, 2016), and is a valuable tool for sex differentiation (Chole *et al*., 2013). The MA was among the parameters with the greatest sexual dimorphism in Croat (Vodanovic *et al*., 2006), Brazilian (Gamba *et al*., 2016), Turkish (Ilguy *et al*., 2014) and Egyptian (Kharoshah *et al*., 2010) populations. Analysis of the angle of mandible in isolation achieved 56.3 % accuracy, however some authors report that the MA did not present sexual dimorphism, for example in Indian (Sharma *et al*., 2016; Sambhana *et al*., 2016; Vignesh *et al*., 2018) and Mexican (Álvarez Villanueva *et al*., 2017) populations. The angle of the mandible is 140º in elderly people, and less in adults (Standring, 2021); however, Sharma *et al*. (2016) reported that although elderly women presented a greater angle, no statistical differences were found in the MA between older and younger individuals of either sex. Previous studies have reported that there is no association between the MA and age, however the angle is found to increase in edentate individuals (Upadhyay *et al*., 2012). These are two important aspects that must be considered in sex estimation by analysis of the mandible. The investigator must consider these groups in the analysis to avoid reaching a false conclusion due to failure to control the confusion factors of the study.

In studies to determine sex by metric analysis of mandibular parameters, certain important points must be taken into consideration to diminish the bias and increase the quality of the evidence. Firstly, it is fundamental that the investigators should be masked when carrying out the analysis, since they may be biased by suggestion if they know the sex of the individual beforehand. Furthermore the investigators must be calibrated previously to avoid errors in the measurements. In the present review, 46.2 % of the studies did not report carrying out intra or inter-observer analysis. This is an aspect that can easily be remedied in future studies, increasing the reliability of the results. Factors that may cause confusion must also be controlled, for example: not carrying out the analysis based on age ranges, since young individuals (less than 18 years) do not present clearly marked sexual differentiation; or not adapting the analysis to the type of population, when more than one population or ethnic group may be involved. In a previous study by our team, we showed metric differences between black- and white-skinned individuals; therefore the ethnic factor must also be considered, as it may affect measurements (Alves & Deana, 2015). Another factor to consider is the method used to take the measurements, for example whether the dry mandible was stabilised to ensure that it remained in the same position throughout. In imaging studies, data on the equipment and software used to take the measurements should be included, as well as the size of voxel or window used, for example. Another important point is determination of the sample size. In the present review, the majority of authors did not show how the sample was selected or calculated; this may affect the power and degree of evidence of the study.

Limitations. We identified some limitations in our review process that deserve comment. First, limitations derived from the systematic nature of the review: despite performing the search in the most important databases in the field of health sciences, we may have failed to identify all articles. However, we believe that this limitation was minimised by the sensitive search strategy used, the additional search of references by hand, and the double independent review process followed. In addition, we only selected studies published in English, Spanish or Portuguese, being the languages the reviewers are fluent in; however no study was excluded on the basis of language. Second, no study with low risk of bias was included in our review; and many reports were far from transparent. Furthermore, our meta-analysis was limited by the high heterogeneity between the studies; however, high heterogeneity is to be expected in prevalence studies, and may be determined in large samples; it is not necessarily related with the heterogeneity of the actual studies. Another limitation is that the estimation intervals produced very wide ranges, indicating that future studies may find very diverse results. Finally, we only assessed the sex estimation indicators of the mandibular ramus, therefore other indicators that are also good predictors of sex were not assessed in the present review.

CONCLUSION

The mandibular ramus presents great sexual dimorphism in different populations, independent of the type of sample used (tomography, dry mandible or radiography). Sex estimation by MA is variable; it is a good predictor only for some populations. RH, BG, BC and CoH were cited as predictive parameters in the majority of studies; however their power of differentiation will depend on the population analysed. Depending on the population analysed, some parameters of the mandibular ramus can present accuracy of almost 80 % when analysed in isolation; however, more accurate sex estimation is achieved when the parameters are analysed in conjunction. The accuracy of sex determination by the mandibular ramus may differ between populations, and the best parameters must be chosen according to the study population.

Author Contributions. NA conceived the study. NA and NFD contributed to design this study, interpreted the results, and wrote the manuscript. FC, LM did the selection of the studies, and data extraction. NA and NFD performed the data analysis. All authors read and approved the manuscript.

ACKNOWLEDGEMENTS

ANID-Subdirección de Capital Humano/Doctorado Nacional/2021 [FOLIO21210983].

We would like to acknowledge Willie Barne for his help in editing the English version of this manuscript.

ALVES, N.; CEBALLOS, F.; MUÑOZ, L.; DEANA, N. F. Estimación sexual mediante análisis métrico del ángulo de la mandíbula y de la rama mandibular: revisión sistemática. *Int. J. Morphol., 40(4)*:883-894, 2022.

RESUMEN: La estimación sexual es el primer paso en la identificación humana. La rama mandibular y el cóndilo se han utilizado ampliamente como indicadores para el diagnóstico sexual debido a que son regiones que sufren cambios morfológicos importantes, aumentando el dimorfismo sexual. El objetivo del presente estudio fue realizar una revisión sistemática a fin de determinar los parámetros métricos de la rama mandibular que presentan mayor dimorfismo sexual, bien estimar el sexo a través del ángulo de la mandíbula (AM). Se incluyeron artículos en Inglés, Español y Portugués que analizaron la predicción sexual o el diagnóstico sexual mediante análisis métrico de la rama mandibular en humanos. La búsqueda fue realizada a través de PubMed/MEDLINE, EMBASE, LILACS, con límite hasta Diciembre 2020. El análisis de los riesgos de sesgos se realizó con la herramienta AQUA. Fueron identificados 538 estudios. Tras la exclusión de duplicados y estudios fuera del tema fueron incluidos 39 estudios para análisis cualitativa. De estos, 18 estudios fueron realizados en mandíbulas secas y 21 en exámenes de imagen, totalizando 7270 participantes de 14 nacionalidades distintas. Fueron encontrados 14 parámetros predictores del sexo en la rama mandibular más el AM. La predicción sexual a través del AM es variable, siendo un buen predictor solamente para algunas poblaciones. La altura de la rama mandibular, ángulo bigoníaco, ángulo bicondilar y la altura del proceso coronoides fueron los parámetros predictivos citados en mayor número de estudios. La rama mandibular presenta gran dimorfismo sexual y puede ser utilizada como predictor del sexo en diferentes poblaciones. A pesar que algunos parámetros de la rama mandibular pueden presentar una precisión de casi 80 % cuando analizadas de forma aislada, una mayor predicción sexual es alcanzada cuando los parámetros son analizados en conjunto.

PALABRAS CLAVE: Estimación sexual; Rama mandibular; Ángulo de la mandíbula; Mandíbula.

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