Are computed tomography images of the mandible useful in age and sex determination? A forensic science meta-analysis

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KEYWORDS

Mandible,
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ABSTRACT

Objectives. This meta-analysis addresses the use of mandibular computed tomography (CT) scans for age and/or sex determination in forensic science.
Methods. Six databases were searched until June 2023, using the keyword "mandible" combined with keywords related to "multislice computed tomography" (MCT) or "cone-beam computed tomography" (CBCT) and keywords related to "skeletal age determination" or "sex determination analysis."
Main Results. Among the 23 studies included, 11 used MCT and 12 used CBCT to perform forensic assessments. Age determination was the aim of a single study, sex and age determinations were the objective of five studies, and the other studies investigated the determination of sex only. Meta-analysis could be performed only for sex determination.
Conclusions. Mandible measurements are useful in sex determination, as the bicondylar and bigonial breadth are larger in males than in females. For the mandible angle, the meta-analysis results confirm sex dimorphism in CBCT scans but not in MCT scans. For age estimation, further studies are needed to prove that the mandible hole is a reliable parameter for age estimation. PROSPERO registration number: CRD42021260967.

INTRODUCTION

In forensic science, sex and age determination are fundamental aspects of personal identification. As the mandible is the largest and longest-lasting facial bone, it has a critical role in human identification, particularly in the absence of a complete skull or pelvis.[1] Determining individual features using the mandible comprises the use of measurements and macroscopic morphological form assessments.[1]

The integration of forensic science and medical imaging technology has contributed to considerable advances in forensic science; it is now possible to evaluate body structures in highly decomposed or contaminated bodies or in cultures with low autopsy acceptance.[2] Although plain radiographs have their value in forensic practice, technologies with 3D outputs, such as computed tomography (CT),[2] that provide accurate and reliable imaging of maxillofacial structures have been largely studied and applied in forensic science.

Multislice computed tomography (MCT) and cone-beam computed tomography (CBCT) are CT imaging techniques

that use the same imaging reconstruction principle, although they differ in radiation dose and in spatial, contrast, and temporal resolution.[3] CBCT is typically applied in cases of dental and jaw disorders; however, it is not applied in cases of neoplastic lesions where the administration of contrast agents and evaluation of soft tissues is required.[3]
For postmortem human identification, several combinations of distinct mandible landmarks and linear or angular measurements have been proposed and extensively studied. However, this process is complicated by the fact that it is difficult to access and assess complex anatomical structures or sites in mandibles covered by soft tissue. Thus, MCT and CBCT have been utilized as imaging tools in forensic investigations. Frequently, the objective of such investigations was to verify the correlation between the linear or angular measurements of mandibular anatomical sites and age or sexual dimorphism in different populations. Some of the studies also investigated the influence of age and sex on mandible shape. However, comparisons that include distinct populations have not yet been performed.
Hence, the objectives of the present systematic review were to determine 1) the mandible sites that have been studied for skeletal age and sex determination, 2) the main results and conclusions of the reviewed studies, and 3) whether mandible images are useful in the determination of age and sex for human identification. It should be noted that only studies that used MCT or CBCT for mandible-based assessment of age and/or sex were included in the review.

MATERIALS AND METHODS

Protocol and registration
This systematic review and metanalysis is registered at the National Institute for Health Research, International Prospective Register of Systematic Reviews (PROSPERO). The registration number is CRD42021260967. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was followed.[4]

Data selection
The selection of studies potentially eligible for inclusion in this was performed using the following databases: PubMed Central® (United States National Institutes of Health's National Library of Medicine), Embase® (Excerpta Medica Database), Scopus® (Elsevier), Cochrane Central Register of Controlled Trials, Web of Science® (Institute of Scientific Information – Clariative Analytics), and Google Scholar® (Google). The aforementioned databases were searched without language and time restrictions (until June, 2023). The Boolean operators "AND" or "OR" were used to combine and optimize the searches.
Itemized search strategies were established for each database based on keywords determined by "Medical subjects headings" (MESH): "Mandible" combined with keywords defining MCT as: "Multislice Computed Tomography OR Multidetector Computed Tomography OR Multidetector-Row Computed Tomography OR Multisection Computed Tomography" or keywords defining CBCT as: " Cone-Beam Computed Tomography OR CT Scan, Cone-Beam OR Cone-Beam CT OR Cone-Beam Computer-Assisted Tomography OR Cone-Beam Computerized Tomography OR Volume CT OR Volume Computed Tomography OR Volumetric CT OR Volumetric Computed TomographyCT Scan, Cone-Beam OR Cone-Beam CT OR Cone-Beam Computer-Assisted Tomography OR Cone-Beam Computerized Tomography OR Volume CT OR Volume Computed Tomography OR Volumetric CT OR Volumetric Computed Tomography".
For searches regarding age determination, the following keywords were added to the aforementioned combination: "Age Determination by Skeleton OR Bone Age Measurement OR Skeletal Age Measurement OR Skeletal Maturation Index". For searches regarding sex determination, the following keywords were added: "Sex Determination Analysis OR Sex Determination Technics OR Sex Determination Techniques".
Manual searches were also performed.

Eligibility criteria: Types of studies and Participant groups
Published research articles or technical notes were considered for inclusion. Abstracts, oral presentations, case reports and literature reviews were excluded.
Investigations with mandible measurements or morphologic classifications for age and sex determinations in forensic science, using MCT or CBCT were considered for inclusion. Investigations about development of software or equations for age or sex determination without measurements or morphologic classifications were excluded.
The articles considering the following assessments were excluded: dental status, canal mandibular,

mandibular foramen, mental foramen, alveolar bone evaluations.
MCT or CBCT scans performed in human beings were included. Studies performed in dried mandibles or that did not used MCT or CBCT were excluded. Investigations that not included mandible bone in the assessment, were not considered for inclusion.

Data extraction
Data extraction was executed by two independent reviewers, who initially screened the titles and abstracts, and then evaluated the full text of each selected study. The screening and selection of potentially included studies will be performed using Rayyan QRI (https://www.rayyan.ai/).[5]
The search results were summarized in one flow chart, according to PRISMA statement[6] (Figure 1 – data selection) and tables (Tables 1 to Table 4).

Data analysis – risk of bias
The quality of each original research were be assessed using the Cochrane risk of bias tool for non-randomized studies, [7] and demonstrated in a figure (Figure 2) using Robvis tool[8] (https://mcguinlu.shinyapps.io/robvis/).

Figure 1. PRISMA flow diagram illustrating the literature search

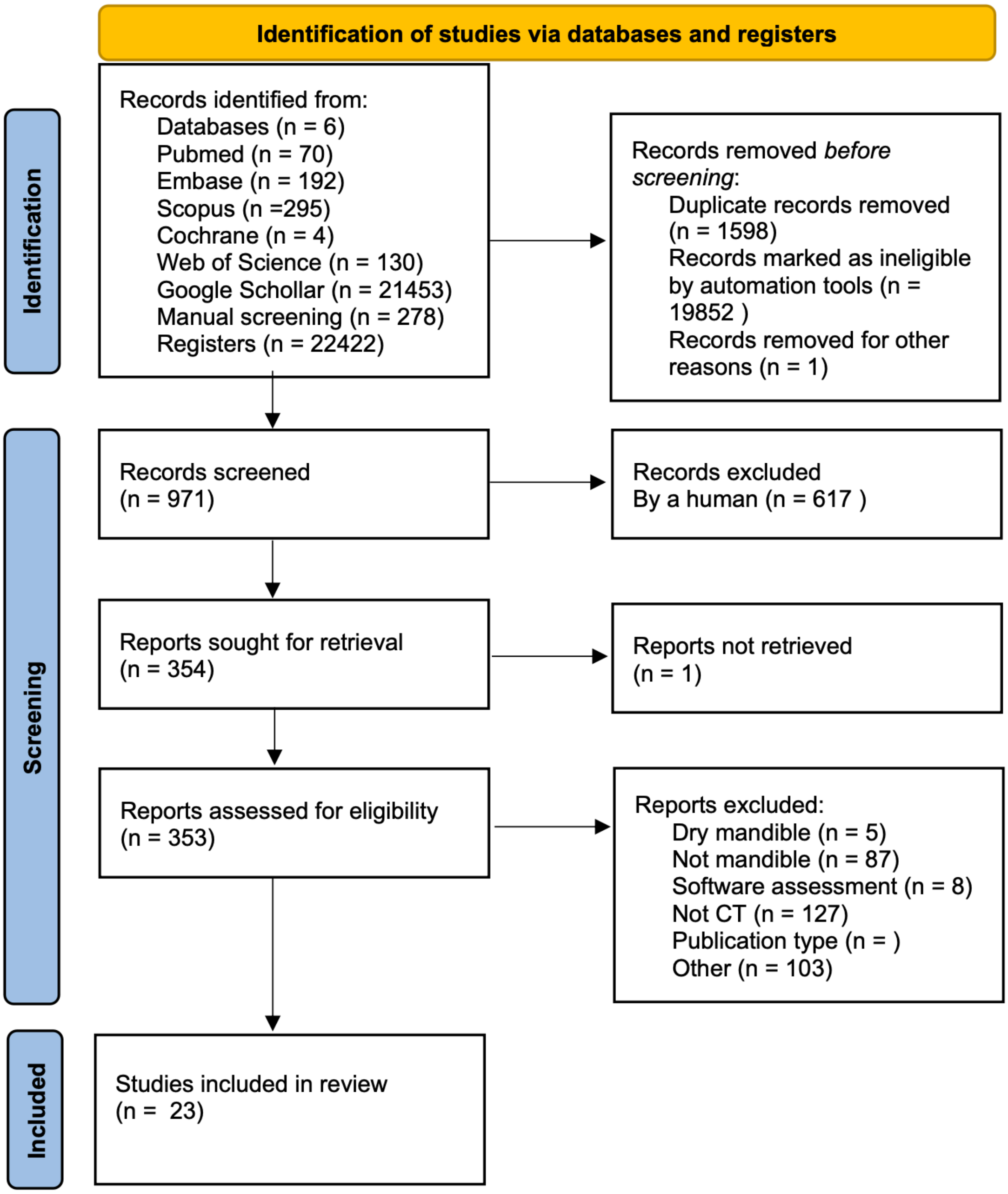


Table 1. Year of publication, main subject (skeletal age or sex determination), type of computed tomography used (Multislice computed tomography or cone beam computed tomography), sample features and ethnicity of the group studies

Author	Year	Country	Determination sex or age?	Bones included	Type of CT	Sample features	Origin of the population studied
Atef et al.[9]	2020	Libya and Egypt	Sex	Mandible	MCT	200 CT scans: minimum age 18 years; maximum age 60 years; 87 females, 113 males	Libyan Population in Tripoli
Imaizumi et al.[10]	2020	Japan	Sex	Mandible and Skull	MCT	100 CT scans: minimum age 23 years; maximum age 65 years; 114 females, 99 males	Japanese
Gillet et al.[11]	2020	France	Sex	Mandible and Skull	MCT	120 CT scans, minimum age 23; maximum age 84 years, 57 females and 63 males, divided in three groups: whole sample, over 40 years, under 40 years.	French
Motawei et al.12	2020	Egypt, Saudi Arabia, Taiwan	Age and Sex	Mandible	CBCT	213 CT scans: minimum age 7 years; maximum age 63 years; 114 females, 99 males	Egyptians
Okkesim and Erhamza[13]	2020	Turkey	Sex	Mandible	CBCT	70 CT scans: minimum age 18 years; maximum age 29 years; 35 females, 35 males	Central Anatolian Turkish
Fan et al.[14]	2019	Australia and Belgium	Sex	Mandible	CBCT	654 CT scans: minimum age 8.5 years; maximum age 19.5 years; 386 females, 268 males	Australian? (Email sent to the author)
Albalawi et al.[15]	2019	Saudi Arabia	Sex	Mandible	CBCT	200 CT scans: minimum age 18 years; maximum age 60 years; 104 females, 96 males.	Saudi Arabia
Bulut et al.[16]	2019	Germany and Turkey	Sex (according to age ranges)	Mandible	MCT	300 CT scans: minimum age 20 years; maximum age 80 years; 150 females, 150 males.	White (country of origin not specified)
Tassoker et al.[17]	2019	Turkey	Sex and age	Mandible	CBCT	121 CT scans: minimum age 10 years; maximum age 69 years; 71 females, 50 males	Turkish (from Middle Anatolia)
Alias et al.[18]	2018	Malaysia	Sex	Mandible	MCT	79 CT scans: minimum age 18 years; maximum age 74 years; 31 females, 48 males.	Malaysian
Barak et al.[19]	2018	Turkey	Age and Sex	Mandible	CBCT	433 CT scans: minimum age 8 years; maximum age 31 years; 260 females, 173 males.	Turkish
Barbieri et al.[20]	2018	Brazil	Age and Sex	Mandible	CBCT	60 CT scans: 30 females, 30 males. The scans were divided in groups according to age (5 examinations for each decade of life).	Brazilian
Zheng et al.[21]	2018	China	Sex (age as secondary objective)	Mandible and maxilla	CBCT	420 CT scans: minimum age 18 years; maximum age 70 years; 210 females, 210 males.	Han adults in Northeast China

Deng et al.[22]	2017	China	Sex	Mandible	CBCT	219 CT scans: minimum age 7 years; maximum age 20 years; 108 females, 111 males	Central Chinese
Tunis et al.[23]	2017	Israel	Sex	Mandible	MCT	438 CT scans: 214 females, 224 males; male mean age 53.3 ± 19.9; female mean age 56.2 ± 20.6 years.	Israeli
Inci et al.[24]	2016	Turkey	Sex	Mandible	MCT	415 CT scans: minimum age 18 years; maximum age 60 years; 214 females, 201 males.	Turkish
Gamba et al.[25]	2016	Brazil	Sex	Mandible	CBCT	160 CT scans: minimum age 18 years; maximum age 60 years; 86 females, 74 males.	Brazilian
Dong et al.[26]	2015	China	Sex	Mandible	CBCT	203 CT scans: minimum age 20 years; maximum age 65 years; 107 females, 96 males.	Chinese Han
Kano et al.[27]	2015	Japan	Sex	Mandible	MCT	232 CT scans from cadavers: minimum age 16 years; maximum age 100 years; 106 females, 116 males	Japanese
İlgüy et al.[28]	2014	Turkey	Sex	Mandible	CBCT	161 CT scans: minimum age 18 years; maximum age 85 years; 95 females, 66 males.	European descendants
Lin et al.[29]	2014	China and Republic of Korea	Sex	Mandible	MCT	240 CT scans: minimum age 21 years; maximum age 70 years; 120 females, 120 males.	Korean
Minier et al.[30]	2014	France	Age	Femur and mandible	MCT	167 CT scans of fetuses (74 females and 93 males), aged from 20 to 40 weeks. The mandible was missing in 16 fetuses	Not specified
Karoshah et al.[31]	2010	Egypt and Saudi Arabia	Sex	Mandible	MCT	500 CT scans: minimum age 6 years; maximum age 60 years; 250 females, 250 males.	Egyptian

Abbreviations: MCT: multislice computed tomography; CT: computed tomography; CBCT: cone beam computed tomography

Statistical Assessment

Variables were assessed only if data provided was available as "mean values" and "standard deviations" from 3 or more investigations using exactly the same measurement and the same type of CT. Data was not considered for the meta-analysis if incomplete or missing the population origin. The analysis was carried out using the standardized mean difference as the outcome measure. A random-effects model was fitted to the data. The amount of heterogeneity was estimated using the maximum-likelihood estimator. In addition to the estimate of tau^2, the I^2 statistic are reported.

Meta-analysis assessments were performed using Jamovi version 1.6 (The Jamovi Project).

Table 2. Summary of the methodology, results and conclusions of the studies included

Author	Methodology applied	Results	Conclusions
Atef et al.[9]	Quantitative assessment (measures in mandible)	There are differences between male and female in all mandibular parameters except minimal ramus breadth and gonial angle.	Mandible can be used to differentiate sex as evidenced by that female were higher than male except gonial angle.
Imaizumi et al.[10]	Morphologic studies and machine learning for shapes creation.	The validation results on actual casework skulls were less acceptable than expected; a larger sample is needed to achieve better results.	The sex estimation method developed enables to perform objective identification of skeletal remains.
Gillet et al.[11]	Metric and geometric morphometric methods to evaluate size and shape-related sexual dimorphism.	Cranium was the most dimorphic structure, regardless of which analysis method and individual's age. The assessment of mandible did not increase sex estimation accuracy for the whole skull.	Although the mandible does not appear to be the most dimorphic structure of the cephalic extremity sample, it remains a useful tool in the absence of an intact skull.
Motawei et al.[12]	The length of the ramus of the mandible was measured in lateral CT scans.	There are no sexual dimorphism of the mandible ramus length until the age of 17 years.	The mandibular ramus length is valuable in age estimation and less valuable in sex determination.
Okkesim and Erhamza[13]	Linear parameters were measured using the mouse-driven method.	It was found that all variable of mandibular ramus on CBCT models showed a statistically significant difference between males and females.	The development of standards to each population for accurate gender identification from skeletal remains is needed.
Fan et al.[14]	Growth trajectories of the mandible in males and females were modelled using a non-linear kernel regression framework.	Mandibular sexual dimorphism already exists at 9 years of age, but this is mostly in size, but not in shape. Significant dimorphism was evident by 11 years and increased through adolescence.	Growth direction in both males and females is similar but is faster, peaks later and occurs over a longer period in males than in females.
Albalawi et al.[15]	Mandibular angular measurements using 3D images.	Measurements presented differences between males and females.	The angle formed by the intersection of lines from the left and right gonion to mention helps in providing anthropological data.
Bulut et al.[16]	Measurements and comparisons of gonial angle, using 3D CT imaging. Sample divided according to sex and grouped according to age ranges.	The authors showed that the gonial angle is sexually dimorphic in senior adult ages (60 – 80 years). Females have larger gonial angles in all 3 age groups (no statistic test showed for the aforementioned information provided by authors).	The results revealed that the gonial angle is not a particularly good indicator to identify the sex from the cranium and should not be used as a sole criterion.
Tassoker et al.[17]	Authors compared panoramic radiographs with CBCT using linear and angular measurements.	According to CBCT examinations, right and left gonial angle are higher in females than males.	Panoramic radiography measurements showed significant differences from CBCT in the mandible.
Alias et al.[18]	Morphometric and morphological parameters analysis using 3D imaging	In this study, all parameters were found to be greater in male mandibles than in female. By stepwise discriminant function analysis, from the bigonial breath and condylar height were the best parameters selected in the analysis.	The mandible could be distinguished according to the sex in the Malaysian population.

Barak et al.[19]	Condyle cortication assessment using visual classification: type 1 (no cortication); type 2; type 3 (surface with similar or higher density than the surrounding cortical areas).	For Males: *Type I mean age observed: 14.14 years *Type II mean age observed: 16.11 years *Type III mean age observed: 19.39 years For Females: *Type I mean age observed: 13.01 years *Type II mean age observed: 15.52 years *Type III mean age observed: 17.95 years	Chronologic age increased as the stages of the cortication progress from Type I to Type III in male and female individuals, and all the stages of the cortication in the mandibular condyle of male occur compared to female.
Barbieri et al.[20]	3D models generated from 3D angular measuring tools.	No differences were found between mandibular incision measurements in both sexes, or age ranges groups.	The structure evaluated cannot contribute to forensic anthropology evaluations.
Zheng et al.[21]	The maxillofacial bones were measured in the median sagittal position.	Evaluation of variables using CBCT reconstruction technology provided a new theoretical basis and practical means for sex determination.	Sex determination of maxillofacial region using CBCT has a high accuracy rate and is also applicable to different countries.
Deng et al.[22]	Four linear variables were selected in the mandible 3D images.	It was demonstrated that the breadth size of the mandible is a useful in sex determination in the studied population.	Virtual measurements obtained from 3D images by CBCT may serve as a substitute for direct anatomic measurements.
Tunis et al.[23]	Linear measurements from 3D reconstructions of the mandible.	Except for mandibular angle, males have a greater mean value than females.	The method applied is not age dependent.
Inci et al.[24]	Linear distances and angle measurements.	There was no statistical difference in the mandibular flexure angle between males and females. Mandibular angle values were higher in females. Comparing the accuracy rates of sex determination, the upper ramus vertical height showed the highest dimorphism.	Morphometric measures of the upper part of the ramus, can provide valuable data to determine sex in a Turkish population.
Gamba et al.[25]	Measurements obtained from 3D sagittal views and axial views	Authors validated a formula that provided an imaging metric that can assist the dental examiner.	Bicondylar breadth, Ramus length, Bicondylar breadth, and Gonial angle showed better reliability for sex estimation.
Dong et al.[26]	Linear or angular measurements using 3D images from CBCT scans.	All of the measurements studied were sexually dimorphic, with the maximum mandibular length and bi-condylar breadth being the most dimorphic.	Mandible expresses sexual dimorphism in the contemporary adult Han Chinese population.
Kano et al.[27]	Quantitative measurements and correlation with body height as a secondary data.	Although these parameters weakly depended on the body height, the correlations were insufficient for stature estimation.	These findings suggest the efficacy of CT morphometry of the mandible for sex discrimination with quantitative assessment.
İlgüy et al.[28]	Measurements were performed using 3D imaging.	The mean values of mandibular measurements were greater for males than females except for gonial angle.	The sagittal diameter of foramen magnum seems to be useful according to the discriminant analysis test for sex determination.
Lin et al.[29]	Measurements using mandible 3D models.	Males are larger than females in all variables, except for mandibular flexure angle, mandibular flexure depth and mandibular flexure lower border and mandible angle.	The upper ramus above flexure has the larger potentials than the mandibular ramus flexure itself to discriminate sexes.

Minier et al.[30]	Linear and angular measurements of the mandible and femur.	Femoral length and mandible measurements presented correlation with age; however femoral length correlation was stronger than mandible correlation.	Mandible is a reliable indicator for estimating fetal age at death.
Karoshah et al.[31]	Measurements in 3D models	Significant differences and included: bicondylar breadth, gonial angle and minimum ramus breadth.	The overall predictive accuracy of the prediction model constructed was 83.9%

Table 3. Measurements performed, and their main values, angles or morphometric parameters reported (values or classification, if applicable) and statistical analysis results from publications that used MCT in the assessments

Authors	**Measurements in mandible**	**Mean values provided (mm)**		**Angles measured in mandible or morphometric parameters**	**Values reported for the mandible angles measured or morphologic features**		**Statistical analysis results***
		Male	**Female**		**Male**	**Female**	
Atef et al.[9]	*Ramus length[a] *Minimal ramus breadth *Coronoid height *Gonion-gnathion length *Bicondylar breadth *Bigonial length	58.2 23.3 53.7 60.1 96.3 77.7	49.1 23.4 47.1 50.3 87.9 76.7	*Gonial angle	121.51	125.0	Except for minimal ramus breadth, variables showed statistically significant differences. Mandible angle was higher in females than males.
Imaizumi et al.[10]				*Mental eminence *Gonion *Chin	Projected Everted Squared	Little/no projection Little/no eversion Oval	Virtual shapes created showed clear sexual dimorphism.
Gillet et al.[11]	*Mandibular symphyses height *Ramus height[a] *Bigonial breadth *Bicondylar breadth	Male 32.25 58.96 94.94 104.16	Female 29.43 54.34 87.52 96.77	*Gonial angle	Not reported		Male presented higher mean values than females, except for gonial angle.
Bulut et al.[16]				*Gonial angle (20 – 39 years) (40 – 59 years) (60 – 80 years)	123.73 123.38 122.99	124.03 124.16 124.69	No statistically difference was observed among the age groups in both sexes; except for the age range 60 – 80 years, with higher values for the gonial angle for females than males (p = 0.04).

Alias et al.[18]	*Maximum breadth of ramus *Minimum breath of ramus *Condylar height *Maximum height of ramus *Coronoid height *Mandibular Body Height *Symphyseal height *Bicondylar Breadth *Bigonial Breadth	Mean values not provided		*Shapes chin: Squared Pointed *Gonial flare Everted Inverted *Muscle markings More prominent Less prominent	92% 85% 90%	84% 80% 90%	The independent t-test showed significant difference between males and females.
Tunis et al.[23]	*Ramus length[b] *Ramus width *Body length *Mandibular angle Width *Coronoid width *Coronoid height *Condyle width *Chin width *Bicondylar Breadth *Bigonial breadth *Chin height[a] *Chin thickness *Chin area *Symphysis area *Symphysis Thickness *Symphysis height	66.9 31.8 79.9 34.5 23.7 19.4 20.3 28.3 122.4 94.0 21.6 4.0 52.9 322.9 15.5 33.1	58.9 30.2 75.0 31.5 22.4 17.5 18.4 23.2 115.7 87.1 21.0 3.9 50.3 283.5 14.4 30.1	*Mandibular Angle	123.5	125.6	Significant differences between males and females were found for all mandibular external measurements and for most of the internal measurements. Except for mandibular angle, males have a greater mean value than females.
Inci et al.[24]	*Minimum ramus breadth *Maximum ramus breadth *Mandibular flexure upper border Distance *Mandibular flexure lower border Distance *Mandibular flexure depth vertical distance *Mandibular ramus flexure vertical height *Maximum ramus vertical height *Upper ramus vertical height	Mean values not provided		*Mandibular angle *Upper mandibular flexure angle (Mandibular flexure upper border - posterior plane of mandibular ramus) * Mandibular flexure angle (Mandibular flexure upper border - Mandibular flexure lower border)	Mean values not provided		Mandibular flexure angle presented no statistical difference between males and females. Mandibular angle values were higher in females ($P<0.001$); all other values were higher in males ($P<0.001$).

Kano et al.[27]	*Bicondylar breadth *Bigonial width *Gnathion - Condylus	128.4 102.9 125.2	121.7 95.8 117.4	*Angle formed by bilateral gnathion and condyles *Mandibular Angle	61.5 126.0	63.3 129.8	Sex difference in virtual measurements were observed in the angle formed by bilateral gnathion and condyles. No mention about mandibular angle results.
Lin et al.[29]	*Minimum Ramus Breadth *Maximum Ramus Breadth *Mandibular Flexure Upper Border *Mandibular Flexure Lower Border *Mandibular Flexure Depth *Mandibular Ramus Flexure *Maximum Ramus Vertical Height *Upper Ramus Vertical Height	36.46 46.71 26.01 17.08 2.22 26.71 57.62 30.92	34.24 44.08 22.92 18.01 2.24 24.96 51.52 26.56	*Mandibular Angle *Upper Mandibular Flexure Angle *Mandibular Flexure Angle	122.53 52.52 165.31	124.30 50.01 164.62	Mean measurement values between male and female showed statistically significant differences, with the exception of mandibular flexure angle, mandibular flexure depth and mandibular flexure lower border. Males are larger than the females except for mandible angle ($p<0.05$).
Minier et al.[30]	*Coronoid process-Condylar process *Condylar process-Mandibular angle *Mandibular angle-Mental tubercle *Condylar process-Mental tubercle *Coronoid process-Mandibular angle *Coronoid process-Mental tubercle	Mean values not provided		*Mental Tubercule-Coronoid process-condylar process *Coronoid process-condylar process-mandibular angle *Condilar process-mandibular angle-Mental tubercule *Mandibular Angle-Mental Tubercule-Coronoid Process	Mean values not provided		Distances Coronoid process to Condylar process and Coronoid process to Mandibular angle ($R2=0.85$);Condylar process to Mental tubercle ($R2=0.72$).
Karoshah et al.[31]	*Ramus length[b] *Minimum ramus breadth *Mandibular base length (gonion–gnathion length) *Bigonial breadth *Bicondylar breadth	Male 65.1 28.7 76.2 104.8 108.9	Femal e 64.7 27.96 83.1 100.8 99.6	*Gonial angle	Male 122.8	Female 121.1	Bicondylar breadth and minimum ramus breadth were significantly higher in males than in females. Gonial angle in males was significantly greater than that in females.

[a]Distance between gonion and condilyon
[b]Distance from the highest point on the condyle to the gonion
*Pertaining to data demonstrated in this table only

Table 4. Measurements performed, and their main values, angles or morphometric parameters reported (values or classification, if applicable) and statistical analysis results from publications that used CBCT in the assessments

Authors	Measurements in mandible	Mean values provided		Angles measured in mandible or morphometric parameters	Values reported for the mandible angles measured or morphologic features		Statistical analysis Results*
		Male	Female		Male	Female	
Motawei et al.[12]	*Mandible Ramus Length (07 – 17 years) (17 – 58 years)	4.79 6.04	4.66 5.42				No significant differences between sex in age range of 7 to 17 years; significant difference between males and females for the mean length of the mandible ramus in the age range of 17–58 years.
Okkesim and Erhamza[13]	*Coronoid height *Condilar height *Mandibular ramus height *Maximum ramus breadth *Minimum ramus breadth	63.54 66.65 53.91 38.41 31.68	57.57 59.98 48.00 35.16 28.97				All measurements in mandible ramus presented significant differences.
Fan et al.[14]				*Gonial angle *Chin Females = more obtuse gonial angle and a narrower chin compared with males. These two traits become more distinct during growth.		More obtuse narrower	Females presented a more obtuse gonial angle and a narrower chin compared with males. These two traits become more distinct during growth. Considering the total sample, mandible was larger in males than in females at all ages. The size difference became greater, as the size of the mandible increased more rapidly in males than in females. The growth rate is similar at 9–10 years for both
Albalawi et al.[15]	*Linear distance from the gonion right to menton *Linear distance from the gonion left to menton *Linear distance from the gonion right to gonion left	86.8 49.5 47.7	82.6 47.7 46.6	*Angle formed by gonion right to menton to gonion left.	129.9	126.7	Statistically significant values were found for differences for all variables studied (p = 0.000)

Tassoker et al.[17]	*Right Ramus length *Left Ramus length *Right maximum ramus breadth *Bigonial width	6.51 6.35 4.11 17.42	5.92 5.83 3.84 16.38	*Right gonial angle *Left gonial angle	117.13 118.02	120.03 119.41	Males have mostly higher mandibular measurements on panoramic radiographs and CBCT except the gonial angle. Maximum ramus breadth presented statistical significance differences when comparing distinct age ranges.
Barak et al.[19]		Qualitative assessment of mandibular condyle cortication		*Type I: (no cortication) Mean age: 14.14 *Type II: Lower density in superior surface Mean age: 16.11 *Type III: Similar or higher density in superior surface Mean age: 19.39			Males with Type I and II cortication were older than females. Females presented more Type III cortication than males.
Barbieri et al.[20]				*right mandibular notch angle *left mandibular notch angle	102.01 102.70	105.25 103.55	No statistically significant differences were found between mandibular incision measurements in both sexes, and in the different age groups studied.
Zheng et al.[21]	*Area of mandibular Foramen *Bigonial breadth *Direct distance between right and left coracoid *Height of symphysis * Min-height of mandibular notch *Min-breadth of mandibular ramus *Buccal side bone thickness of Mandibular foramen * Tongue side bone thickness of Mandibular foramen *Vertical diameter of Mandibular foramen *Horizontal diameter of Mandibular foramen *Vertical from prosthion to palatal breadth	7.18 103.39 102.01 32.52 52.33 34.61 1.03 5.91 2.23 3.84 38.70 41.60	5.95 95.83 97.11 29.64 47.82 32.00 0.93 5.76 2.23 3.50 37.17 40.37	*Mandibular angle (total sample) (18 – 24 years) (25- 30 years) (31- 40 years) (41-50 years) (51- 60 years) (61 – 70 years)	121.52 122.70 120.44 122.45 120.92 121.83 120.80	125.44 125.35 124.78 126.19 125.42 125.62 125.27	Significant differences were not observed in two variables: Tongue side bone thickness of mandibular foramen and vertical diameter of mandibular foramen. Female presented higher values of Mandibular angle. Considering age ranges, mandibular angle and the other variables did not present differences when genders were compared.

Deng et al.[22]	*Bicondylar breadth *Bigonial breadth *Biantegonial notch breadth *Bimental foramina breadth	129.70 100.19 89.81 49.45	121.80 93.55 85.72 47.32				All the breadth dimensions described were significantly larger in males than in females.
Gamba et al.[25]	*Ramus length *Gonion-gnathion length *Minimum ramus breadth *Bigonial breadth *Bicondylar breadth	54.36 70.37 28.70 118.48 94.96	49.41 67.14 28.91 110.03 87.47	*Gonial angle	121.28	119.83	All variables showed differences between sex except minimum ramus breadth. Gonial angle in male was larger than in female.
Dong et al.[26]	*Bicondylar breadth *Bigonial breadth *Bi-antegonial notch breadth *Bi-mental foramina breadth *Distance between mental foramen and mandibular inferior border *Maximum mandibular ramus breadth *Maximum mandibular length *Maximum mandibular ramus height *Maximum mandibular body length	130.00 100.281 90.072 49.734 15.297 45.413 126.198 65.962 86.458	121.44 93.594 85.674 47.228 14.006 41.996 117.398 58.243 81.462	*Mandibular angle *Mental angle	123.444 72.909	126.648 71.974	Mental Angle was the only measurement that did not presented statistical significance.
İlgüy et al.[28]	*Ramus length *Min ramus breadth *Gonion–gnathion length *Bigonial breadth *Bicondylar breadth	61.67 29.89 71.86 100.33 120.79	54.72 28.09 67.73 94.77 116.23	*Gonial angle	121.14	122.31	The mean values of mandibular measurements were greater for males than females except for gonial angle.

Figure 2. Risk of bias assessment according to Robvis

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Atef et al.	+	+	+	+	+	+	+	+
Imaizumi et al	+	+	+	+	+	+	+	+
Gillet et al	+	+	+	+	+	+	+	+
Motawei et al.	+	+	+	+	+	+	+	+
Okkesim and Erhamza13	+	+	+	+	+	+	+	+
Fan et al.	+	+	+	+	+	+	+	+
Albalawi et al	+	+	+	+	+	+	+	+
Bulut et al	+	+	+	+	-	+	+	+
Tassoker et al	+	+	+	+	+	+	+	+
Alias et al	+	+	+	-	+	+	+	-
Barak et al	+	+	+	-	-	+	-	-
Barbieri et al	+	+	+	+	+	+	+	+
Zheng et al.	+	+	+	+	+	+	+	+
Deng et al	+	+	+	+	+	+	+	+
Tunis et al	+	+	+	+	+	+	+	+
Inci et al.	+	+	+	+	+	+	+	+
Gamba et al.	+	+	+	+	+	+	+	+
Dong et al.	+	+	+	+	+	+	+	+
Kano et al	+	+	+	+	+	+	+	+
İlgüy et al.	+	+	+	+	+	+	-	-
Lin et al.	+	+	+	+	+	+	+	+
Minier et al	+	+	+	+	+	+	+	+
Karoshah et al	+	+	+	+	+	+	+	+

Domains:
D1: Bias due to confounding.
D2: Bias due to selection of participants.
D3: Bias in classification of interventions.
D4: Bias due to deviations from intended interventions.
D5: Bias due to missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.

Judgement
- Moderate
+ Low

RESULTS

A total of 23 studies were included. [9-31] Eleven studies perform forensic assessments in MCT[9-11, 16, 18, 23, 24, 26, 28-30] and twelve studies in CBCT.[12-15, 17, 19-22, 25, 27, 31] Some author also evaluate other bones but mandible, such as the femur, [29] maxilla[21] and skul.l[9, 10] The number of CT scans evaluated ranged from 60[20] to 654[14] and the age of the patients that performed the CT scans ranged from 6[30] to 100[26] years old, except for a study that included fetuses.[29] The origin of the population included in the samples were highly heterogeneous and highly specific, as Libyan from Tripoli[11] or Turkish from Middle Anatolia.[17] Data about the year of publication, country of the assessments origin, bones included, type of CT and sample features are available on Table 1.

Age alone was the aim of a single study, which investigated mandibles of fetuses.[29] Sex and age determinations was the objective of five studies, [12, 16, 17, 19-21] although age determination was a secondary data in two of them. [16, 21] The other studies investigated the possibility to determine sex using mandible bone data with different methodologies.[9-11, 13-15, 17, 18, 20, 22-28, 30, 31]

In Table 2, the methodology applied in the studies, the results and the main conclusions are summarized. Most of the studies used quantitative analysis in their methodologies, with linear or angular measurements, [9, 11-18, 20-24, 26-31] although some of them used morphologic assessments[10, 14, 18, 19] or created nominal/qualitative classifications for determining age or/and sex, [14, 18, 19] or even for machine learning. [10]

The landmarks, measures and/or classifications applied by the authors that used MCT, as well as the statistical evaluations results of each investigation are available on Table 3. For CBCT is available in Table 4.

Meta-analysis assessments

The investigators used a highly heterogeneous landmarks and measures or qualitative classifications, which limited the articles included in meta-analysis. First, as it was necessary to include in each assessment the same type of CT as measurements varies between CT and CBCT.[32] Secondly, it is also needed to include measurements using the exactly the same landmarks or sites of mandible. Considering the aforementioned, it was included both for MCT and CBCT for sex comparisons: mandibular angle (gonial angle),[11, 17, 21, 23, 25, 27, 28, 30, 31] bicondylar breadth,[9, 11, 22, 23, 25, 27, 30, 31] and bigonial breadth.[9, 21-23, 25, 27, 30, 31] Thus, means comparisons were limited to some populations, as Brazilians,[25] Chinese (central or Han),[21, 22, 31] European descendants,[27] Turkish,[17] French,[9] Israeli,[23] Egyptian,[30] Lybian and[11] Korean.[28] Meta-analysis results are available on Figures 3 to 5.

Data provided by authors regarding to age was insufficient to perform statistical assessments.

a) Mandibular angle

For mandible statistical analysis, it was included in statistical model four studies[11, 23, 28, 30] which performed MCT and five that performed CBCT in separate. [17, 21, 25, 27, 31] Mandible angle presented significant differences between males and females in the CBCT model but not presented in MCT model. Figure 3A and 3B demonstrates the meta-analysis graphics.

For MCT, the observed standardized mean differences ranged from -1.70 to 3.49. The estimated average standardized mean difference based on the random-effects model was 1.40 (95% CI: -1.46 to 4.27). The average outcome did not differ significantly from zero ($z = 0.96$; $p = 0.34$). The presence of heterogeneity was observed. Results are available on Figure 3A.

For CBCT, the observed standardized mean differences ranged from -1.45 to 3.92. The estimated average standardized mean difference based on the random-effects model was 2.10 (95% CI: 0.32 to 3.87). The average outcome differed significantly from zero ($z = -2.31$, $p = 0.02$). The presence of heterogenicity was detected although studies have good scores on quality assessments. Results are available on Figure 3B.

b) Bicondylar breadth

For bicondylar statistics analysis, both MCT[9, 11, 23, 30] CBCT [22, 25, 27, 31] four studies were included and results confirmed significant differences between male and females. Graphics are available on Figure 4A and 4B.

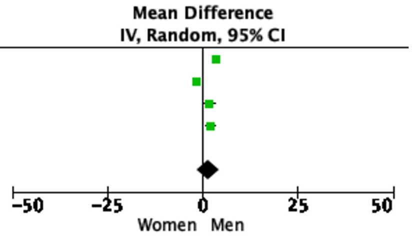
For MCT mean differences ranged from 6.70 to 9.84. The estimated average standardized mean difference based on the random-effects model was 7.97 (95% CI: 6.29 to 9.65). The average outcome differed significantly from zero ($z = 9.28$, $p < 0.0001$). Even though there may be some heterogeneity, the true outcomes of the studies are generally in the same direction as the estimated average outcome. (Figure 4A)

For CBCT, the observed standardized mean differences ranged from -8.56 to -4.91. The estimated average standardized mean difference based on the random-effects model was -7.34 (95% CI: -8.37 to -5.94). The average outcome differed significantly from zero (z = 10.32, p < 0.0001). Even though there may be some heterogeneity, the true outcomes of the studies are generally in the same direction as the estimated average outcome. (Figure 4B)

Figure 3. Mandible angle meta-analysis results for multislice computed tomography (MCT) and cone-beam computed tomography (CBCT)

Study or Subgroup	Women Mean	Women SD	Women Total	Men Mean	Men SD	Men Total	Weight	Mean Difference IV, Random, 95% CI
Atef (Lybian)	125	2.31	106	121.51	2.9	113	25.6%	3.49 [2.80, 4.18]
Kharoshah (Egyptian)	121.1	3.9	250	122.8	4.3	250	25.6%	−1.70 [−2.42, −0.98]
Lin (korean)	124.3	6.09	120	122.53	6.64	120	24.0%	1.77 [0.16, 3.38]
Tunis (Israeli)	125.6	6.44	250	123.5	7.62	224	24.7%	2.10 [0.82, 3.38]
Total (95% CI)			726			707	100.0%	1.40 [−1.46, 4.27]

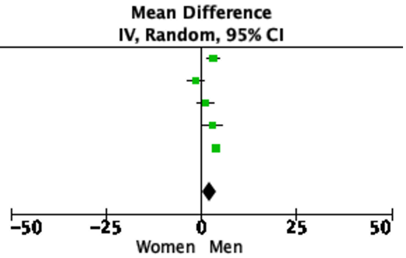
Heterogeneity: $Tau^2 = 8.19$; $Chi^2 = 106.80$, df = 3 (P < 0.00001); $I^2 = 97\%$
Test for overall effect: Z = 0.96 (P = 0.34)



A

Study or Subgroup	Women Mean	Women SD	Women Total	Men Mean	Men SD	Men Total	Weight	Mean Difference IV, Random, 95% CI
Dong (Chinese Han)	126.64	5.63	107	123.44	5.95	96	21.5%	3.20 [1.60, 4.80]
Gamba (Brazilian)	119.83	6.68	86	121.28	8.21	74	18.0%	−1.45 [−3.79, 0.89]
Ilguy (European descendant)	122.31	6.79	95	121.14	6.56	66	19.2%	1.17 [−0.92, 3.26]
Tassoker (Turkish)	120.03	6.06	71	117.13	7.38	50	17.3%	2.90 [0.42, 5.38]
Zheng (Chinese Han)	125.44	5.13	210	121.52	5.5	210	24.0%	3.92 [2.90, 4.94]
Total (95% CI)			569			496	100.0%	2.10 [0.32, 3.87]

Heterogeneity: $Tau^2 = 3.15$; $Chi^2 = 19.85$, df = 4 (P = 0.0005); $I^2 = 80\%$
Test for overall effect: Z = 2.31 (P = 0.02)

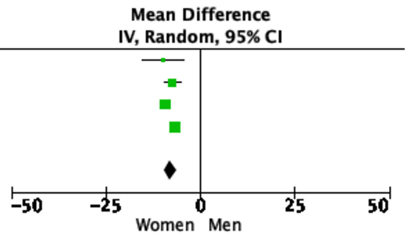


B

Figure 4. Bicondylar breadth meta-analysis results for multislice computed tomography (MCT) and cone-beam computed tomography (CBCT)

Study or Subgroup	Women Mean	Women SD	Women Total	Men Mean	Men SD	Men Total	Weight	Mean Difference IV, Random, 95% CI
Atef (Lybian)	80.79	28.9	106	90.63	4.8	113	7.5%	−9.84 [−15.41, −4.27]
Gillet (French)	96.77	6.14	57	104.16	6.29	63	23.9%	−7.39 [−9.62, −5.16]
Kharoshah (Egyptian)	99.6	6.4	250	108.9	7.7	250	33.5%	−9.30 [−10.54, −8.06]
Tunis (Israeli)	115.7	5.64	214	122.4	5.77	224	35.2%	−6.70 [−7.77, −5.63]
Total (95% CI)			627			650	100.0%	−7.97 [−9.65, −6.29]

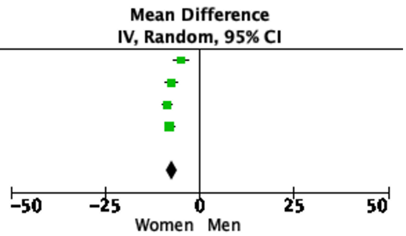
Heterogeneity: $Tau^2 = 1.80$; $Chi^2 = 10.33$, df = 3 (P = 0.02); $I^2 = 71\%$
Test for overall effect: Z = 9.28 (P < 0.00001)



A

Study or Subgroup	Women Mean	Women SD	Women Total	Men Mean	Men SD	Men Total	Weight	Mean Difference IV, Random, 95% CI
Ilguy (European descendant)	116.23	5.5	95	121.14	6.56	66	21.6%	−4.91 [−6.84, −2.98]
Gamba (Brazilian)	87.47	5.36	86	94.96	6.08	74	23.0%	−7.49 [−9.28, −5.70]
Dong (Chinese Han)	121.44	4.75	107	130	5.31	96	27.0%	−8.56 [−9.95, −7.17]
Deng (Chinese central)	121.8	4.56	108	129.7	5.02	111	28.3%	−7.90 [−9.17, −6.63]
Total (95% CI)			396			347	100.0%	−7.34 [−8.73, −5.94]

Heterogeneity: $Tau^2 = 1.37$; $Chi^2 = 9.50$, df = 3 (P = 0.02); $I^2 = 68\%$
Test for overall effect: Z = 10.32 (P < 0.00001)



B

c) Bigonial breadth

For bigonial breadth analysis, three MCT[9, 23, 30] studies and five for CBCT. [21, 22, 25, 27, 31] Both assessments confirmed the statistical significant differences between male and females, as demonstrated on Figure 5A and 5B.

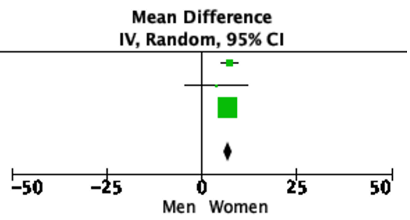
For MCT, the observed standardized mean differences ranged from 4.00 to 7.42. The estimated average standardized mean difference based on the random-effects model was 6.96 (95% CI: 5.99 to 7.93). The average outcome differed significantly from zero (z = 24.10, p = <0.00001). An examination of the studentized residuals revealed that one study (Kharoshah et al.[30]) may be a potential outlier in the context of this model. Results are available on Figure 5A.

Considering CBCT, the observed standardized mean differences ranged from 5.56 to 8.45. The estimated average standardized mean difference based on the random-effects model was 7.03 (95% CI: 6.16 to 7.89). The average outcome differed significantly from zero (z = 15.97, p < 0.00001). Results and metanalysis graph are available on Figure 5B.

Figure 5. Bigonial breadth meta-analysis results for multislice computed tomography (MCT) and cone-beam computed tomography (CBCT)

Study or Subgroup	Men Mean	Men SD	Men Total	Women Mean	Women SD	Women Total	Weight	Mean Difference IV, Random, 95% CI
Gillet (French)	94.94	7.12	63	87.52	5.25	57	18.9%	7.42 [5.20, 9.64]
Kharoshah (Egyptian)	104.8	7.5	250	100.8	66.3	250	1.4%	4.00 [−4.27, 12.27]
Tunis (Israeli)	94	5.99	224	87.1	5.58	214	79.7%	6.90 [5.82, 7.98]
Total (95% CI)			537			521	100.0%	6.96 [5.99, 7.93]

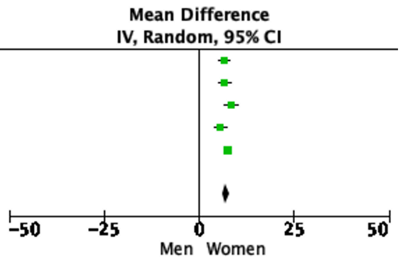
Heterogeneity: Tau² = 0.00; Chi² = 0.67, df = 2 (P = 0.72); I² = 0%
Test for overall effect: Z = 14.10 (P < 0.00001)



A

Study or Subgroup	Men Mean	Men SD	Men Total	Women Mean	Women SD	Women Total	Weight	Mean Difference IV, Random, 95% CI
Deng (Chinese central)	100.19	5.85	111	93.55	4.98	108	20.4%	6.64 [5.20, 8.08]
Dong (Chinese Han)	100.28	6.33	96	93.59	5.1	107	18.1%	6.69 [5.10, 8.28]
Gamba (Brazilian)	118.48	5.99	74	110.03	4.85	86	16.6%	8.45 [6.74, 10.16]
Ilguy (European descendant)	100.33	4.99	66	94.77	5.9	95	16.8%	5.56 [3.87, 7.25]
Zheng (Chinese Han)	103.39	5.82	210	95.83	4.88	201	28.1%	7.56 [6.52, 8.60]
Total (95% CI)			557			597	100.0%	7.03 [6.16, 7.89]

Heterogeneity: Tau² = 0.41; Chi² = 6.99, df = 4 (P = 0.14); I² = 43%
Test for overall effect: Z = 15.97 (P < 0.00001)



B

DISCUSSION

The process of identifying humans from physical features is not restricted to the identification of individuals who are declared dead. It is also used to identify asylum seekers (e.g., people without valid identification documents), unaccompanied minors,[33] and victims and perpetrators of crimes and war atrocities (e.g., in criminal prosecution).[34] Hence, because living individuals must sometimes be identified, the use of non-invasive methods, such as CT, is essential. The present review has shown that diverse methods based on MCT or CBCT have been used to determine age or sex for individual identification. Essentially, the studies selected in this review were highly heterogeneous in terms of the methodologies, measurements, evaluations, and populations included.

The minority of the studies aimed to associate a mandibular assessment of any nature with age.[12, 17, 19, 20, 29] Minier et al.[29] observed a significant correlation between age and mandible measurements in fetuses and that the coronoid process to condylar process and coronoid process to mandibular angle measurements had the highest correlations with age. Other studies estimated skeletal age based on the mandible dimorphism inherent to sex variation. On this point, all the collected information was complementary. Motawei et al.[12] reported that mandible ramus length correlates with age, particularly in the age range of 17–57 years old.

Also, Tassoker et al.[17] verified that the only mandibular bone measurement that correlated with age was the maximum ramus breadth, which has lower values in 10–19 year-olds compared to 60–69 year-olds.

When compared to the other facial bones, the mandible exhibits the greatest growth and morphological size and remodeling changes.[35] Considering that the mandible is isolated, others have concluded that the mandible ramus is the structure that best represents the remodeling changes that occur in certain age ranges and that changes in the mandible ramus strongly correlate with age.[35, 36] The findings of the included studies corroborate these conclusions.[12, 17]

Furthermore, the size and shape of the mandible are also used to predict an individual's sex.[35] Although sexual dimorphism is present at birth,[37] sex differences decrease rapidly during early life[12, 37] and only resume during the phase of puberty to adulthood[37] with the influence of sex hormones.[12] Thus, sex dimorphism is not only reflected in the size of the mandible, but also in its shape.[10, 14, 18] The mandible angle is one of the most-studied factors responsible for shape differences and more obtuse angles have been found in females.[14]

In MCT-based studies, the mandible angle was found to have higher mean values in females compared to males.[9, 11, 23, 24, 28] An exception was reported by Karoshah et al.,[30] who found that the angles were greater in males than in females in an Egyptian population. In CBCT-based studies, the results were similar,[17, 27, 31] except in Gamba et al.'s[25] study of a Brazilian population. In a study that included different age groups of males and females, Zheng et al.[21] also did not observe statistically significant differences in mandible angle between the sexes.

Hence, this meta-analysis of studies that focused on the mandible angle has shown that the results of MCT-based studies are dissimilar, with no significant differences found between males and females, and that CBCT-based studies have found significant differences between males and females. These findings raise the issue of whether this structure actually shows dimorphism or whether the imaging technique influences the final results. Considering the meta-analysis assessment method, more CBCT-based studies were included in the statistical analysis, and this may have influenced the statistical significance observed.

The bicondylar breadth was found to be greater in males than in females,[9, 11, 18, 22, 23, 25-27, 30, 31] as well as the bigonial breadth.[21-23, 25-27, 30, 31] Statistically significant differences were found in all populations studied.

In contrast to the findings of other studies included in the model, in a study with a Libyan population, Atef et al. [11] found that the bicondylar breadth had smaller mean values in females than males. The same observation was made by İlgüy et al.,[27] who studied a population of European descendants. These findings lead to the question: Do these Libyan and European-descendant populations differ from the other populations studied, or were the selected individuals not an appropriate representative sample of the populations?

In terms of sex differences, it was found that both bicondylar breadth and bigonial breadth could be used to determine sex. However, a study of an Egyptian population showed outlier results.[30] Hence, conducting larger studies that include distinct populations worldwide could answer the question of whether bicondylar breadth, bigonial breadth, and mandible angle measurements correlate with sex.

CONCLUSION

Considering the studies included in this review, we conclude that mandible measurements are useful for sex determination, as both the bicondylar and bigonial breadth have been found to have higher values in males than in females. Regarding the mandible angle, the meta-analysis results confirm that sex differences can be detected using CBCT scans but not MCT scans. In terms of age estimation, further studies are needed to prove that the hole of the mandible is a reliable parameter for age estimation.

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