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REVIEW Open Access

Applicability of the mandibular canine index for sex estimation: a systematic review

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Abstract

Background: The Mandibular Canine Index (MCI) comprises a method of sex estimation by teeth that presents controversial results in the literature.

Main body: This systematic review aims to expose whether MCI can be used as a method of reliable sex estimation. A literature search was performed using the keywords "canine," "sex," "gender," "determination," "estimation," "dimorphism," "assessment," "forensic" in the databases Pubmed, Scopus, Lilacs, Scielo, and Web of Science. In addition, manual searches were carried out on the reference lists of the selected articles to cover the largest number of articles of interest as possible. Studies that performed the measurements only on maxillary canines, scientific conferences abstract books, case reports and literature reviews were excluded. The assessment of methodological quality and risk of bias was carried out based on a checklist for cross-sectional studies and another for accuracy studies. Thus, 53 articles were selected, 13 of which were accurate and 40 were cross-sectional. All accuracy articles were assessed as low risk. Among cross-sectional articles, seven were considered to be of low risk, 31 of moderate risk, and two of high risk. The accuracy of the sex estimate by MCI was verified and, despite varying among studies, the minimum and maximum values found were, respectively, 20% and 87.5% for women and 40.6% and 94% for men.

Conclusion: The accuracy of the MCI was variable and should be used with caution and as an auxiliary method of sex estimation.

Keywords: Forensic anthropology, Forensic dentistry, Odontometry, Tooth

Background

The construction of the victim's biological profile comprises an important stage of the human identification process in which knowledge of forensic anthropology is applied in order to reduce the number of potential suspects (Francisco et al. 2013). This initial screening is performed when primary identification methods need to be applied to bodies with an advanced state of decomposition, carbonized, fragmented or skeletonized, and it prevents time and resources from being wasted (Francisco et al. 2013; Silva et al. 2015).

In extreme situations in which it is not possible to easily distinguish human remnants from non-humans (Dias et al. 2012; Oliveira et al. 2008; Silva et al. 2013), the construction of the biological profile must be initiated by determining the species so that, afterwards, parameters such as sex, age, stature and ancestry can be estimated (Silva et al. 2013). Estimating sex, in turn, is particularly important because it is an information that will guide the methods to be applied in estimating the other parameters that will form the victim's biological profile (Krishan et al. 2016; Rösing et al. 2007).

To estimate sex in adults, cranial elements can be used (Spradley and Jantz 2011) and, in forensic practice, the bones of the pelvis and skull are widely used because

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they have morphological and morphometric characteristics evidenced by pubertal hormones (Koelzer et al. 2019; Krishan et al. 2016; Rogers 2005; Rösing et al. 2007; Sinhorini et al. 2019), although the presence of youthful traits and androgenic characteristics may be present (Krishan et al. 2016; Silva et al. 2015).

In addition to the bone elements, research was carried out to ascertain or even quantify the presence of sexual dimorphism in the teeth, especially of the canine tooth in the male sex as it is evolutionarily associated with hunting activities and primate survival (Rao et al. 1989; Vijayan et al. 2019). Thus, the use of teeth in sex estimation is motivated by the resistance that these organs present, which would be particularly useful in the identification of extremely fragmented bodies or incomplete bones (Acharya et al. 2011; Azevedo et al. 2019; Vijayan et al. 2019).

Rao et al. (Rao et al. 1989) proposed a simple and practical method for sex estimation that was based on the ratio between the mesiodistal measurement of the mandibular canine tooth and the lower intercanine distance, which is why this method became known as the Mandibular Canine Index (MCI). Thus, this systematic review aims to answer the following question: the MCI can be applied as a reliable method for sex estimation of an unknown person?

Main text

Material and methods

Search strategy

The searches were conducted on September 20th, 2019. In order to find relevant studies, there were no language restrictions, a range of publication year was not used, and the search was performed in the electronic databases Pubmed, Scopus, Lilacs, Scielo, and Web of Science. The search strategy was adequate for each database and the following keywords were used: canine, sex, gender, determination, estimation, dimorphism, assessment, forensic, as shown in Table 1. Manual searches were carried out on the reference lists of the selected articles to verify whether previous searches in the databases failed to identify any studies of interest.

Article eligibility

The PICO strategy (P—Population; I—Intervention; C—Comparison; O—Outcome) is fundamental for the construction of the appropriate research question, which determines a comprehensive bibliographic search, which incorporates the best scientific data available on the studied topic (Santos et al. 2007). Thus, this systematic review included articles that submitted patients (P), who had the sex previously known by those responsible for the research (C), to certain dental measures to calculate the Mandibular Canine Index (I) in order to estimate the sex of these individuals (O). Studies that performed the measurements only on maxillary canines, abstract books of scientific congresses, case reports, and literature reviews were excluded.

Initially, the selection was made by reading the titles and abstracts of the articles found. If the abstract was not available or if any doubts persisted regarding inclusion or not, the studies were downloaded and read in full. Some full texts were not found by manual search or using the Unpaywall software. The authors were asked to provide them via ResearchGate (http://www.researchgate.net), however, to no avail. Scientific papers found in more than one database were considered only once. The search and selection of the articles were performed by two different researchers independently. Then, the selected studies were checked by both researchers. When there was doubt about include or exclude any article, a third examiner was consulted.

Assessment of quality and risk of bias

The methodological quality assessment used two checklists proposed by The Joanna Briggs Institute: (The Joanna Briggs Institute 2017, 2020) one for cross-sectional studies, named "Checklist for Analytical Cross-Sectional

Table 1 Quantity of articles found in each database according to the search strategy

Electronic databases	Research strategies	Total
Lilacs	(tw:(canine)) AND (tw:(sex OR gender)) AND (tw:(characteristics OR dimorphism OR estimation OR determination OR assessment AND forensic))	41
Pubmed	(((canine) AND (sex OR gender)) AND (determination OR estimation OR dimorphism OR assessment)) AND forensic	103
Scielo	(canine) AND (sex OR gender) AND (characteristics OR dimorphism OR determination OR estimation OR assessment) AND (forensic)	10
Scopus	(canine) AND (sex OR gender) AND (determination OR estimation OR dimorphism OR assessment) AND (forensic)	1566
Web of Science	ALL=((canine) AND (sex OR gender) AND (determination OR estimation OR dimorphism OR assessment) AND (forensic))	86
Total		**1806**

studies" (The Joanna Briggs Institute 2020), which has an observational design and participants are selected only by the inclusion and exclusion criteria (Setia 2016), and another directed to the accuracy studies, named "Checklist for Diagnostic Test Accuracy Studies" (The Joanna Briggs Institute 2017). In the analysis of cross-sectional studies (Table 2), topics were discussed on the details of the chosen samples, such as the inclusion and exclusion criteria, and demographic data; the measurements taken and the examiners (validity, reliability, training); possible confounding factors and on statistical analysis. When the information requested in each item was answered with "Yes," the score of 11.11% was applied; the value zero was assigned when the question received the answer "U" (uncertain) and when "N/R" (not/reported) was used, the value 5.5% was determined. The percentage column relates to the percentage of "Yes" that each study presents. Thus, when the percentage of "Yes" remains below 49%, the risk is considered "High"; if the percentage is between 50 and 69%, it is classified as "Moderate"; and "Low" is applied if the percentage is equal to or greater than 70%.

For the accuracy studies (Table 3), items related to the sample and the method of carrying out the measurements were verified. Regarding the samples, the surveys were evaluated according to the sampling method used and the exclusion criteria applied. For the evaluation of the measurements made, the following characteristics were observed: the blinding of the examiners, the data of the reference standard and if the time of analysis of the reference was compatible with the time of analysis of the variable of interest. In this case, when the information requested in each item was answered with "Yes," a score of 12.5% was used; the value of 6.25% was applied if the question received the answer "Unclear" and when "No" was used, the value zero was determined. The percentage column relates to the percentage of "Yes" that each study presents. Thus, when the percentage of "Yes" remains below 49%, the risk is considered "High"; if the percentage is between 50 and 69%, it is classified as "Moderate"; and "Low" is applied if the percentage is equal to or greater than 70%.

Results

From the search in the electronic databases, 1806 articles were found, of which 1590 remained eligible after the removal of duplicates. Then, reading the titles and abstracts allowed to select 61 studies and, after applying the inclusion and exclusion criteria, 53 articles were included in this systematic review, as illustrated in Fig. 1. A description of the studies involved in this work containing the year of publication, title, online journal in which they were published, and the respective Quartile is shown in Table 4.

From the analysis of the methodological quality of the accuracy studies, Table 5 explains that only Rajarathnam et al. commented on the sampling method applied (Rajarathnam et al. 2016), while all articles scored positively on the items on the precaution of using case-control and inappropriate exclusions, the performance of measures in a standardized way and the inclusion of all patients in the analysis. For questions regarding the blindness of the

Table 2 Criteria for quality assessment of cross-sectional studies (The Joanna Briggs Institute 2020)

Q1) Were the criteria for inclusion in the sample clearly defined?
Q2) Were the study subjects and the setting described in detail?
Q3) Was the exposure measured in a valid and reliable way?
Q4) Were objective, standard criteria used for measurement of the condition?
Q5) Were confounding factors identified?
Q6) Were strategies to deal with confounding factors stated?
Q7) Were the outcomes measured in a valid and reliable way?
Q8) Was appropriate statistical analysis used?

Table 3 Criteria for quality assessment of accuracy studies (The Joanna Briggs Institute 2017)

Q1) Was a consecutive or random sample of patients enrolled?
Q2) Was a case control design avoided?
Q3) Did the study avoid inappropriate exclusions?
Q4) Were the index test results interpreted without knowledge of the results of the reference standard?
Q5) If a threshold was used, was it pre-specified?
Q6) Is the reference standard likely to correctly classify the target condition?
Q7) Were the reference standard results interpreted without knowledge of the results of the index test?
Q8) Was there an appropriate interval between index test and reference standard?
Q9) Did all patients receive the same reference standard?
Q10) Were all patients included in the analysis?

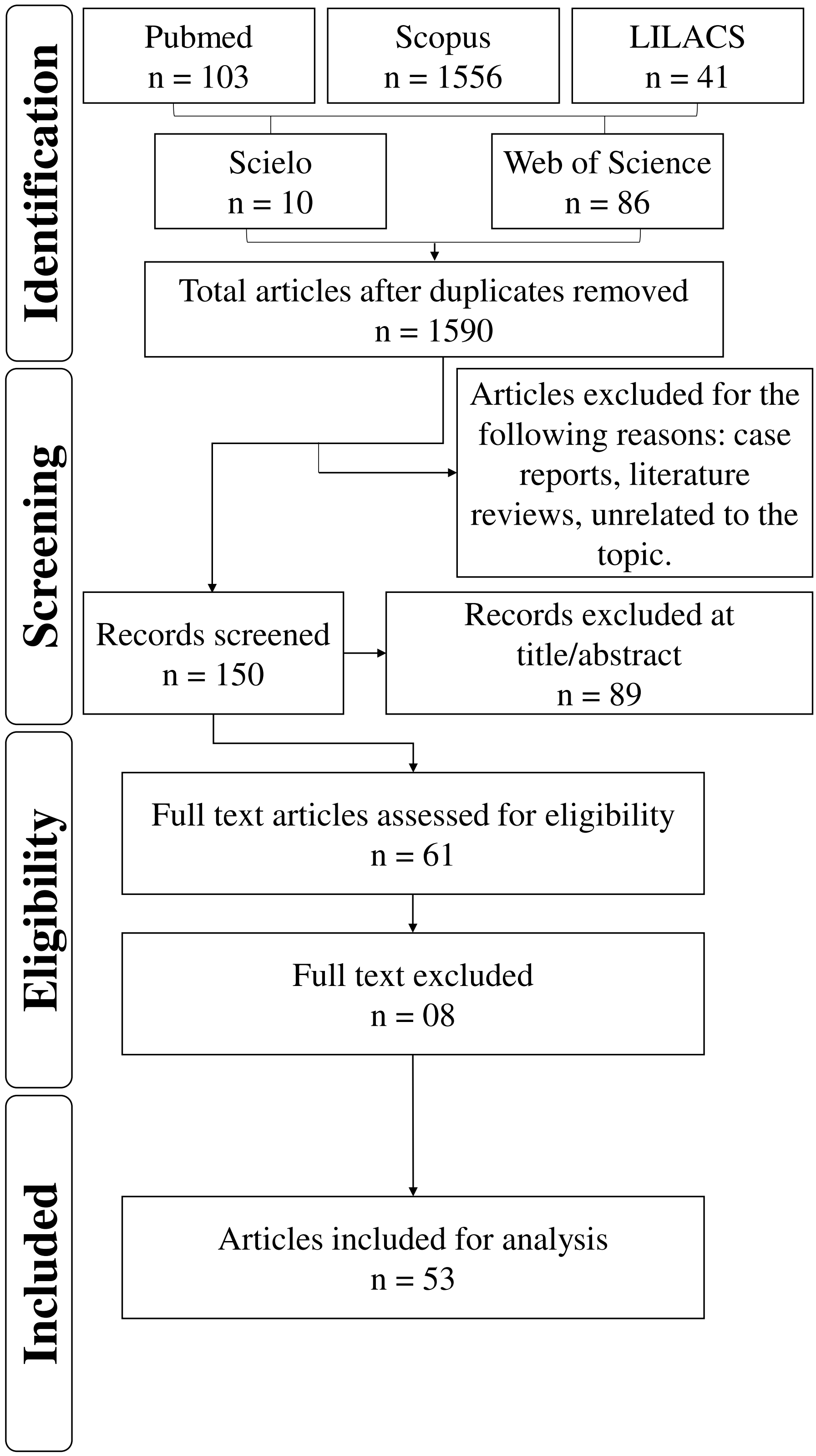

Fig. 1 Flowchart of the search results in the databases

Table 4 Title, journal and quartile of the included articles

Authors	Title	Journal	Quartile
Acharya and Mainali 2009	Limitations of the mandibular canine index in sex assessment	Journal of Forensic and Legal Medicine	Q1
Acharya et al. 2011	Validity of the mandibular canine index (MCI) in sex prediction: Reassessment in an Indian sample	Forensic Science International	Q1
Anu et al. 2018	Canine index: A tool for determination of sex	Indian Journal of Public Health Research and Development	Q4
Atreya et al. 2019	Sex predictability by using mandibular canine index	Journal of Nepal Health Research Council	Q3
Azevedo et al. 2019	Sex estimation using the mandibular canine index components	Forensic Science, Medicine, and Pathology	Q2
Bai et al. 2018	Correlative study on lip prints, fingerprints, and mandibular intercanine distance for gender determination	Journal of Forensic Dental Sciences	–a
Bakkannavar et al. 2015	Canine index - A tool for sex determination	Egyptian Journal of Forensic Sciences	Q2
Dhakar et al. 2012	Assessment of sexual dimorphism in permanent canines among different Indian ethnic groups - A comparative study	Indian Journal of Forensic Medicine and Toxicology	Q3
Divyadharsini and Kumar 2019	Analysing cheiloscopic pattern and mandibular canine index for gender determination	Research Journal of Pharmacy and Technology	Q3
Duraiswamy et al. 2009	Sex determination using mandibular canine index in optimal-fluoride and high-fluoride areas	Journal of Forensic Dental Sciences	–a
Gandhi et al. 2017	Significance of mandibular canine index in sexual dimorphism and aid in personal identification in forensic odontology.	Journal of Forensic Dental Sciences	–a
Gargano et al. 2014	¿Son los índices caninos mandibular y maxilar herramientas fidedignas para la determinación del sexo?	Actas Odontológicas	–a
Grover et al. 2013	An odontologist's key to sex determination: study analysis of mandibular canine teeth in south Indian population	Journal of Orofacial Research	–a
Gupta et al. 2014	Stature and gender determination and their correlation using odontometry and skull anthropometry	Journal of Forensic Dental Sciences	–a
Gupta and Daniel 2016	Crown size and arch width dimension as an indicator in gender determination for a Puducherry population	Journal of Forensic Dental Sciences	–a
Hosmani et al. 2013	Reliability of Mandibular Canines as Indicators for Sexual Dichotomy	Journal of International Oral Health	Q3
Ibeachu et al. 2012	Sexual dimorphism in mandibular canine width and intercanine distance of University of Port-Harcourt student, Nigeria	Asian Journal of Medical Sciences	–a
Iqbal et al. 2015	Reliability of mandibular canine and mandibular canine index in sex determination: A study using Uyghur population	Journal of Forensic and Legal Medicine	Q1
Jacob et al. 2018	Significance of using the mandibular canine index in gender determination	IIOAB Journal	Q4
Kakkar et al. 2013	Study of mandibular canine index as a sex predictor in a Punjabi population	Indian Journal of Oral Sciences	–a
Kaushal et al. 2003	Mandibular canines in sex determination	Journal of the Anatomical Society of India	Q4
Kaushal et al. 2004	Sex determination in north Indians using mandibular canine index	Journal of Indian Academy of Forensic Medicine	Q4
Krishnan et al. 2016	Gender determination: Role of lip prints, finger prints and mandibular canine index.	Experimental and Therapeutic Medicine	Q2
Kumawat et al. 2017	Mandibular canine: A tool for sex identification in forensic odontology.	Journal of Forensic Dental Sciences	–a
Lagos et al. 2016	Sensibilidad y especificidad clínica del indice mandibular canino y del ancho mesiodistal del diente canino para estimar el sexo: ajuste de un modelo predictivo	International Journal of Odontostomatology	–a

Table 4 (continued)

Authors	Title	Journal	Quartile
Latif et al. 2016	Sex determination from mandibular canine index for the age group of 17-40 years in north indian population	International Journal of Scientific Study	–a
Mohsenpour et al. 2017	Mandibular and maxillary canine as a tool for sex determination	Journal of Morphological Sciences	Q4
Muhamedagić and Sarajlić 2013	Sex determination of the Bosnian-Herzegovinian population based on odontometric characteristics of permanent lower canines	Journal of Health Sciences	Q4
Muller et al. 2001	Odontometrical method useful in determining gender and dental alignment	Forensic Science International	Q1
Muthukumar and Thenmozhi 2018	Sex determination of an individual by studying the mandibular canine index	Drug Invention Today	Q4
Nadendla et al. 2016	Identification of gender using radiomorphometric measurements of canine by discriminant function analysis	Indian Journal of Dental Research	Q3
Nagalaxmi et al. 2014	Cheiloscopy, palatoscopy and odontometrics in sex prediction and discrimination - A comparative study	Open Dentistry Journal	Q2
Narang et al. 2014	Sex determination by mandibular canine index and molar odontometrics: A comparative study	Indian Journal of Oral Sciences	–a
Otuaga and Chris-Ozoko 2012	Sex determination in Deltans using mandibular canine	Biomedical and Pharmacology Journal	Q4
Paramkusam et al. 2014	Morphometric analysis of canine in gender determination: revisited in India.	Indian Journal of Dental Research	Q3
Patel et al. 2017	Mandibular canine index: A study for gender determination in Gandhinagar population.	Journal of Forensic Dental Sciences	–a
Patil et al. 2015	To evaluate the accuracy of various dental parameters used for the gender determination in Nagpur District population	Indian Journal of Dental Research	Q3
Priyadharshini et al. 2018	Comparison of cheiloscopy, odontometric, and facial index for sex determination in forensic dentistry.	Journal of Forensic Dental Sciences	–a
Rajarathnam et al. 2016	Mandibular canine dimensions as an aid in gender estimation.	Journal of Forensic Dental Sciences	–a
Rao et al. 1989	Mandibular canine index--a clue for establishing sex identity	Forensic Science International	Q1
Reddy et al. 2008	Mandibular canine index as a sex determinant: A study on the population of western Uttar Pradesh	Journal of Oral and Maxillo Facial Pathology	Q3
Sassi et al. 2012	Sex determination in Uruguayans by odontometric analysis	Brazilian Journal of Oral Sciences	Q4
Shahid et al. 2018	Sex prediction assessment via mandibular canine index and logistic regression in Pakistani population: A digital model study	Journal of International Dental and Medical Research	Q3
Sharma and Gorea 2010	Importance of mandibular and maxillary canines in sex determination	Journal of Punjab Academy of Forensic Medicine & Toxicology	Q4
Sherfudhin et al. 1996	A cross-sectional study of canine dimorphism in establishing sex identity: comparison of two statistical methods	Journal of Oral Rehabilitation	Q1
Silva et al. 2016	A new approach to sex estimation using the mandibular canine index	Medicine, Science, and the Law	Q2
Singh et al. 2012	Sex determination using cheiloscopy and mandibular canine index as a tool in forensic dentistry	Journal of Forensic Dental Sciences	–a
Singh et al. 2015	Mandibular canine index: A reliable predictor for gender identification using study cast in Indian population	Indian Journal of Dental Research	Q3
Sreedhar et al. 2015	Dimorphic Mandibular canines in gender determination in Moradabad population of Western Uttar Pradesh	Journal of Forensic Dental Sciences	–a

Table 4 (continued)

Authors	Title	Journal	Quartile
Srivastava 2010	Correlation of odontometric measures in sex determination	Journal of Indian Academy of Forensic Medicine	Q4
Vijayan et al. 2019	Significance of mandibular canine index in sex determination	International Journal of Forensic Odontology	–a
Vishwakarma and Guha 2011	A study of sexual dimorphism in permanent mandibular canines and its implications in forensic investigations.	Nepal Medical College Journal	–a
Yadav et al. 2002	Mandibular canine index in establishing sex identity	Indian Journal of Dental Research	Q3

[a] Not found

Table 5 Outcomes of the assessment of the risk of bias within eligible accuracy studies

Authors	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	%	Risk
Acharya et al. 2011	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Azevedo et al. 2019	N/R[a]	Yes	Yes	Yes	N/A[b]	N/R[a]	YES	Yes	Yes	Yes	88.77	Low
Gupta et al. 2014	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Gupta and Daniel 2016	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Iqbal et al. 2015	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Jacob et al. 2018	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Lagos et al. 2016	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Rajarathnam et al. 2016	YES	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	83.16	Low
Sassi et al. 2012	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Shahid et al. 2018	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Sherfudhin et al. 1996	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low
Silva et al. 2016	N/R[a]	Yes	Yes	Yes	N/A[b]	N/R[a]	YES	Yes	Yes	Yes	88.77	Low
Sreedhar et al. 2015	N/R[a]	Yes	Yes	N/R[a]	N/A[b]	N/R[a]	N/R[a]	Yes	Yes	Yes	77.55	Low

[a] Not reported, [b]not applicable

survey examiners, the affirmative answer was received only by Azevedo et al. (Azevedo et al. 2019) and Silva et al. (Silva et al. 2016). Finally, no article scored positively in relation to the information on the reference data for comparison with those found by the studies.

It is clear that everyone reached a score above 70%, and classified as low risk. Azevedo et al. (Azevedo et al. 2019) and Silva et al. (Silva et al. 2016) received the maximum score in seven of the nine questions applied, adding a percentage of 88.77%. Other values received were 83.16% and 77.55% (Table 4), directed to the studies that gained the highest value in six and five items of the methodological evaluation, respectively.

The checklist for cross-sectional studies showed that only two studies did not clearly provide the inclusion and exclusion criteria. Regarding the second question, five studies did not describe the sample in detail. About the standardization of measures, all articles received a positive score; however, for the requirements on confounding factors, no article scored positively. When verifying the statistical analysis, seven studies did not clearly inform the statistical method used (Table 6).

It appears that only seven studies were considered low risk for obtaining a 75% percentage and only Muhamedagic and Sarajlic (Muhamedagić and Sarajlić 2013) and Yadav et al. (Yadav et al. 2002) reached lower percentages, being classified as high risk. The remaining studies received percentages between 50 and 68.75% and, therefore, were identified as of moderate risk.

The samples of the selected studies involved the population of some countries in Asia, Africa, Europe, and America, with the Indians being the most investigated (n = 37), and the sample size varied between 50 (Krishnan et al. 2016; Muthukumar and Thenmozhi 2018) and 1000 (Gargano et al. 2014; Jacob et al. 2018) participants. The youngest individuals analyzed were 14 years old (Dhakar et al. 2012; Duraiswamy et al. 2009; Sherfudhin et al. 1996); the most advanced age examined was 60 years old (Gargano et al. 2014; Sassi et al. 2012) and some studies (Atreya et al. 2019; Muhamedagić and Sarajlić 2013; Muller et al. 2001) did not inform the studied age group.

Table 6 Outcomes of the assessment of the risk of bias within eligible cross-sectional studies

Authors	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	%	Risk
Acharya and Mainali 2009	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Anu et al. 2018	Yes	Yes	Yes	Yes	No	No	Unclear	Yes	68.75%	Moderate
Atreya et al. 2019	Yes	No	Yes	Yes	No	No	Yes	Unclear	56.25%	Moderate
Bai et al. 2018	Yes	No	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Bakkannavar et al. 2015	Yes	Yes	Unclear	Yes	No	No	Unclear	Unclear	56.25%	Moderate
Dhakar et al. 2012	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Divyadharsini and Kumar 2019	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Duraiswamy et al. 2009	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Gandhi et al. 2017	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Gargano et al. 2014	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Grover et al. 2013 (contd.)	Yes	Yes	Yes	Yes	No	No	Yes	Unclear	68.75%	Moderate
Hosmani et al. 2013	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Ibeachu et al. 2012	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Kakkar et al. 2013	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Kaushal et al. 2003	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Kaushal et al. 2004	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Krishnan et al. 2016	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Kumawat et al. 2017	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Latif et al. 2016	Yes	Yes	Yes	Yes	No	No	Yes	Unclear	68.75%	Moderate
Mohsenpour et al. 2017	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Muhamedaglic and Sarajlic 2013	No	No	Unclear	Yes	No	No	Unclear	Yes	37.50%	High
Muller et al. 2001	Yes	No	Yes	Yes	No	No	Yes	Yes	62.50%	Moderate
Muthukumar and Thenmozhi 2018	Yes	Yes	Unclear	Yes	No	No	Unclear	Unclear	56.25%	Moderate
Nadendla et al. 2016	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Nagalaxmi et al. 2014	Yes	No	Yes	Yes	No	No	Yes	Yes	62.50%	Moderate
Narang et al. 2014	No	Yes	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Otuaga and Chris-Ozoko 2012	No	Yes	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Paramkusam et al. 2014	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Patel et al. 2017	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Patil et al. 2015	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Priyadharshini et al. 2018	Yes	Yes	Unclear	Yes	No	No	Unclear	Yes	62.50%	Moderate
Rao et al. 1989	No	Yes	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Reddy et al. 2008	No	Yes	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Sharma and Gorea 2010	No	Yes	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Singh et al. 2012	Yes	Yes	Unclear	Yes	No	No	Unclear	Unclear	56.25%	Moderate
Singh et al. 2015	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Srivastava 2010	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Vijayan et al. 2019	Yes	Yes	Yes	Yes	No	No	Yes	Yes	75%	Low
Vishwakarma and Guha 2011	No	Yes	Unclear	Yes	No	No	Unclear	Yes	50%	Moderate
Yadav et al. 2002	No	Yes	Unclear	Yes	No	No	Unclear	Unclear	43.75%	High

Most of the selected studies analyzed only the right and left mandibular canines. However, some authors have also included the evaluation of the right and left maxillary canines. The measurements were performed on plaster models, digital models, radiographs and in situ evaluation. With regard to the examiners who performed the measurements, participation ranged from zero to ten in the surveys that provided this information (Table 7).

The data obtained by the studies included in this review are shown in Table 8. The lowest values found for the average of the mandibular canine index were 0.1896 ± 0.0175 in women and 0.1921 ± 0.0185 (Kakkar et al. 2013) in men, and the largest, discovered by Vijayan, Jayarajan, and

Table 7 Description of included studies

Study	Subjects	Age (years)	Tooth	Studied material	Examiners	Origin population
Acharya and Mainali 2009	123 (M = 65 and F = 58)	19–28	33 and 43	Plaster models	–[a]	Nepal
Acharya et al. 2011	205 (M = 103 and F = 102)	19–32	33 and 43	Plaster models	–[a]	India
Anu et al. 2018	150 (M = 75 and F = 75)	18–22	13, 23, 33 and 43	In situ	–[a]	India
Atreya et al. 2019	80 (M = 40 and F = 40)	–[a]	33 and 43	Plaster models	one	Nepal
Azevedo et al. 2019	120 (M = 50 and F = 70)	16–30	33 and 43	Plaster models	–[a]	Portugal
Bai et al. 2018	300 (M = 150 and F = 150)	18–25	33 and 43	Plaster models	–[a]	–[a]
Bakkannavar et al. 2015	500 (M = 250 and F = 250)	15–25	13, 23, 33 and 43	In situ	–[a]	India
Dhakar et al. 2012	150 (M = 75 and F = 75)	14–20	33 and 43	Plaster models	–[a]	India
Divyadharsini and Kumar 2019	100 (M = 50 and F = 50)	19–26	33 and 43	In situ	–[a]	India
Duraiswamy et al. 2009	145	14–15	33 and 43	Plaster models	two	India
Gandhi et al. 2017	62 (M = 31 and F = 31)	15–25	33 and 43	Plaster models	one	India
Gargano et al. 2014	1000 (M = 501 e F = 499)	18–60	13, 23, 33 and 43	Plaster models	one	Uruguay
Grover et al. 2013	80 (M = 40 and F = 40)	18–20	33 and 43	In situ	two	India
Gupta et al. 2014	60 (M = 30 and F = 30)	15–25	33 and 43	Plaster models	–[a]	India
Gupta and Daniel 2016	106 (M = 53 and F = 53)	18–25	33 and 43	Plaster models	–[a]	India
Hosmani et al. 2013	100 (M = 50 and F = 50)	15–21	33 and 43	Plaster models	one	India
Ibeachu et al. 2012	300 (M = 150 and F = 150)	18–30	33 and 43	In situ	–[a]	Nigeria
Iqbal et al. 2015	216 (M = 107 and F = 109)	18–25	33 and 43	Plaster models	two	China
Jacob et al. 2018	1000 (M = 500 and F = 500)	18–25	33 and 43	Plaster models	two	India
Kakkar et al. 2013	250 (M = 175 and F = 175)	17–25	33 and 43	Plaster models	–[a]	India
Kaushal et al. 2003	60 (M = 30 and F = 30)	17–21	33 and 43	In situ and plaster models	–[a]	India
Kaushal et al. 2004	60 (M = 30 and F = 30)	17–21	33 and 43	In situ	–[a]	India
Krishnan et al. 2016	50 (M = 25 and F = 25)	18–25	33 and 43	Plaster models	–[a]	India
Kumawat et al. 2017	300 (M = 150 and F = 150)	17–25	33 and 43	Plaster models	one	India
Lagos et al. 2016	150 (M = 65 and F = 85)	18–24	33 and 43	Plaster models	–[a]	Chile
Latif et al. 2016	150 (M = 75 and F = 75)	17–40	33 and 43	Plaster models	–[a]	India
Mohsenpour et al. 2017	100 (M = 50 and F = 50)	18–35	13, 23, 33 and 43	In situ	–[a]	Iran
Muhamedagić and Sarajlić 2013	180 (M = 90 and F = 90)	–[a]	33 and 43	In situ	–[a]	Bosnia and Herzegovina
Muller et al. 2001	424 (M = 214 and F = 210)	–[a]	33 and 43	In situ	ten	France
Muthukumar and Thenmozhi 2018	50 (M = 25 and F = 25)	18–25	33 and 43	In situ	–[a]	India
Nadendla et al. 2016	120 (M = 60 and F = 60)	20–30	33 and 43	In situ and radiography	–[a]	India
Nagalaxmi et al. 2014	60 (M = 30 and F = 30)	20–30	33 and 43	In situ and	two	–[a]
Narang et al. 2014	410 (M = 200 and F = 210)	20–40	33 and 43	plaster models	one	India
Otuaga and Chris-Ozoko 2012	200 (M = 100 and F = 100)	17–21	33 and 43	In situ	–[a]	Nigeria
Paramkusam et al. 2014	120 (M = 60 and F = 60)	18–25	13, 23, 33 and 43	In situ and plaster models	one	India

Table 7 (continued)

Study	Subjects	Age (years)	Tooth	Studied material	Examiners	Origin population
Patel et al. 2017	400 (M = 200 and F = 200)	21–40	33 and 43	In situ and Plaster models	three	India
Patil et al. 2015	200	15–50	13, 23, 33 and 43	In situ	–[a]	India
Priyadharshini et al. 2018	100 (M = 50 and F = 50)	20–25	33 and 43	In situ	two	India
Rajarathnam et al. 2016	200 (M = 100 and F = 100)	18–25	33 and 43	In situ and Plaster models	–[a]	India
Rao et al. 1989	766 (M = 382 and F = 384)	15–21	33 and 43	In situ	two	India
Reddy et al. 2008	200 (M = 100 and F = 100)	17–25	33 and 43	Plaster models	–[a]	India
Sassi et al. 2012	112 (M = 56 and F = 56)	21–60	33 and 43	Plaster models	one	Uruguay
Shahid et al. 2018	128 (M = 64 and F = 64)	18–24	33	Plaster models	>one	Pakistan
Sharma and Gorea 2010	177	17–50	13, 23, 33 and 43	Plaster models	–[a]	India
Sherfudhin et al. 1996	301 (M = 150 and F = 151)	14–17	13, 23, 33 and 43	In situ	One	India
Silva et al. 2016	120 (M = 50 and F = 70)	16–30	33 and 43	Plaster models	Two	Portugal
Singh et al. 2012	60 (M = 30 and F = 30)	20–25	33 and 43	Plaster models	–[a]	India
Singh et al. 2015	100 (M = 45 and F = 55)	20–30	33 and 43	Plaster models	two	India
Sreedhar et al. 2015	60 (M = 30 and F = 30)	19–30	33 and 43	Plaster models	–[a]	India
Srivastava 2010	400 (M = 200 and F = 200)	17–21	33 and 43	In situ	two	India
Vijayan et al. 2019	100 (M = 50 and F = 50)	18–25	33 and 43	Plaster models	one	India
Vishwakarma and Guha 2011	180 (M = 90 and F = 90)	17–23	33 and 43	In situ	–[a]	India
Yadav et al. 2002	360 (M = 180 and F = 180)	15–21	33 and 43	Plaster models	–[a]	India

[a] Not found

Jaleel (Vijayan et al. 2019), were 0.521 ± 0.012 in women and 0.444 ± 0.010 in men for the right mandibular canine index and 0.526 ± 0.014 in women and 0.447 ± 0.012 in men for the left mandibular canine index.

Canine sexual dimorphism was analyzed, and the highest rate found was 15.24% for the right canine, and 16.74% for the left canine (Ibeachu et al. 2012). The accuracy of the sex estimation by MCI was verified and, despite varying among studies, the minimum and maximum values found were, respectively, 20% (Anu et al. 2018) and 87.5% (Rao et al. 1989) for women and 40.6% (Jacob et al. 2018) and 94% (Silva et al. 2016) for men. The results found led some studies (Acharya et al. 2011; Acharya and Mainali 2009; Atreya et al. 2019; Gargano et al. 2014; Hosmani et al. 2013) to the conclusion that the canine mandibular index is not reliable for sex estimation, while others (Bakkannavar et al. 2015; Dhakar et al. 2012; Divyadharsini and Kumar 2019; Kaushal et al. 2004; Kumawat et al. 2017) guaranteed the applicability of this index in forensic practice.

Discussion

MCI is a widely researched method of sex estimation by teeth, although its practical application remains controversial. When applying MCI in different populations, divergent levels of accuracy were found (Table 8), and information related to monomorphism and reverse dimorphism of canine teeth as a result of human evolution was also reported (Boaz and Gupta 2009; Prabhu and Acharya 2009), which makes the use of MCI in forensic practice as an even more dubious method of sex estimation.

The divergence related to the use of the canine mandibular index in sex estimation is present even in studies of the same population. The Indians were the most evaluated by the studies included in this systematic review and, while some authors stated that MCI has a statistically significant sexual dimorphism, presenting rates starting at 80% (Dhakar et al. 2012; Gandhi et al. 2017; Kaushal et al. 2004; Kumawat et al. 2017; Latif et al. 2016; Paramkusam et al. 2014; Patel et al. 2017; Rao et al. 1989; Singh et al. 2015; Sreedhar et al. 2015), others showed accuracy below 50% (Acharya et al. 2011; Anu et al. 2018; Hosmani et al. 2013; Jacob et al. 2018; Krishnan et al.

Table 8 Results found by the included studies

Study	Canine index average	Canine sexual dimorphism	Accuracy of sex estimation	Population
Acharya and Mainali 2009	Female: 0.26 Male: 0.26	–[a]	Female: 44.44% Male: 57.14%	Nepal
Acharya et al. 2011	Female: 0.24 Male: 0.24	–[a]	Female: 52% Male: 49.51%	India
Anu et al. 2018	Female: 0.22 Male: 0.22	–[a]	Female: 20.0% Male: 88.0%	India
Atreya et al. 2019	Right canine: Female: 0.22 Male: 0.23 Left canine Female: 0.22 Male: 0.22	–[a]	Right Female: 60.0% Male: 57.5% Left Female: 62.5% Male: 57.5%	Nepal
Azevedo et al. 2019	–[a]	Right canine: 85.8% Left canine: 85.8%	Right Female: 58.6% Male: 72.0% Left Female: 57.1% Male: 72.0%	Portugal
Bai et al. 2018	Right canine Female: 0.25 Male: 0.26 Left canine Female: 0.25 Male: 0.26	–[a]	Female: not mentioned Male: 89%	–[a]
Bakkannavar et al. 2015	Right canine Female: 0.27 Male: 0.28 Left canine Female: 0.27 Male: 0.28	–[a]	Right Female: 75.6% Male: 73.2% Left Female: 76.8% Male: 73.2%	India
Dhakar et al. 2012	Right canine Rajasthan (Female: 0.24/Male: 0.27) Gujarat (Female: 0.25/Male: 0.27) Karnataka (Female: 0.24/Male: 0.27) Left canine Rajasthan (Female: 0.23/Male: 0.26) Gujarat (Female: 0.24/Male: 0.27) Karnataka (Female: 0.23/Male: 0.27)	–[a]	Rajasthan: 78% Gujarat: 76% Karnataka: 82%	India
Divyadharsini and Kumar 2019	Female: 0.26 Male: 0.27	–[a]	–[a]	India
Duraiswamy et al. 2009	Right canine Optimal-fluoride (Female: 18.46/Male: 20.46) High-fluoride (Female: 19.34/ Male: 18.73) Left canine Optimal-fluoride (Female: 19.14/Male: 21.07) High-fluoride (Female: 19.34/ Male: 20.10)	–[a]	–[a]	India
Gandhi et al. 2017	Female: 0.25036 Male: 0.24808	Right canine: 6.85% Left canine: 7.62%	Female: 83.8% Male: 74.19%	India

Table 8 (continued)

Study	Canine index average	Canine sexual dimorphism	Accuracy of sex estimation	Population
Gargano et al. 2014	Right canine Female: 0.2658 Male: 0.2712 Left canine Female: 0.2658 Male: 0.2714	–[a]	Female: 43.67% Male: 48.1%	Uruguay
Grover et al. 2013	Right canine Female: 0.22 Male: 0.25 Left canine Female: 0.21 Male: 0.23	Right canine: 10.11% Left canine: 4.44%	Right canine: 9.43% Left canine: 11.81%	India
Gupta et al. 2014	Right canine Female: 0.22494 Male: 0.21669 CANINE Female: 0.23410 Male: 0.22041	–[a]	–[a]	India
Gupta and Daniel 2016	Right canine Female: 24.57 Male: 26.23 Left canine Female: 24.77 Male: 26.32	–[a]	Right Female: 77.36% Male: 73.58% Left Female: 66.04% Male: 67.92%	India
Hosmani et al. 2013	Female: 0.26406 Male: 0.26574	–[a]	Female: 50% Male: 40%	India
Ibeachu et al. 2012	Right canine Female: 0.208 Male: 0.228 Left canine Female: 0.207 Male: 0.230	Right canine: 15.24% Left canine: 16.74%	–[a]	Nigeria
Iqbal et al. 2015	Female: 0.2368 Male: 0.2572	–[a]	Female: 70–97% Male: 8–73%	China
Jacob et al. 2018	Female: 0.279 Male: 0.284	–[a]	Female: 70.2% Male: 40.6%	India
Kakkar et al. 2013	Female: 0.1896 Male: 0.1921	–[a]	Female: 55.03% Male: 53.54%	India
Kaushal et al. 2003	Right canine Casts (Female: 0.267/Male: 0.278) Intraoral (Female: 0.267/Male: 0.280) Left canine Casts (Female: 0.268/Male: 0.283) Intraoral (Female: 0.267/Male: 0.282)	Casts Right canine: 7.96% Left canine: 9.79% Intraoral Right canine: 7.95% Left canine: 8.89%	–[a]	India
Kaushal et al. 2004	Right canine Female: 0.26 Male: 0.28 Left canine Female: 0.26 Male: 0.28	Right canine: 7.954% Left canine: 8.891%	Right Female: 80% Male: 70% Left Female: 83.33% Male: 66.67%	India
Krishnan et al. 2016	–[a]	–[a]	Female: 24% Male: 84%	India
Kumawat et al. 2017	Right canine Female: 0.24 Male: 0.25 Left canine Female: 0.24 Male: 0.25	Right canine: 5.53% Left canine: 5.42%	Female: 78% Male: 81.33%	India

Table 8 (continued)

Study	Canine index average	Canine sexual dimorphism	Accuracy of sex estimation	Population
Lagos et al. 2016	–[a]	–[a]	75.29%	Chile
Latif et al. 2016	Female: 0.253 Male: 0.269	–[a]	Female: 76% Male: 80%	India
Mohsenpour et al. 2017	Right canine Female: 0.2545 Male: 0.2677 Left canine Female: 0.2567 Male: 0.2704	–[a]	Right Female: 62% Male: 44% Left Female: 64% Male: 54%	Iran
Muhamedagić and Sarajlić 2013	Right canine Female: 0.247 Male: 0.259 Left canine Female: 0.238 Male: 0.250	–[a]	Right: 68.89% Left: 68.54%	Bosnia and Herzegovina
Muller et al. 2001	Female: 0.261 Male: 0.275	–[a]	–[a]	France
Muthukumar and Thenmozhi 2018	Right canine Female: 0.2784 Male: 0.2855 Left canine Female: 0.2784 Male: 0.2878	–[a]	Right Female: 75.6% Male: 73.2% Left Female: 76.8% Male: 73.2%	India
Nadendla et al. 2016	Clinical Female: 0.2630 Male: 0.2614 Occlusal Female: 0.2765 Male: 0.2625	–[a]	Clinical Female: 31.70% Male: 76.70% Occlusal Female: 58.30% Male: 71.70%	India
Nagalaxmi et al. 2014	Right canine Female: 0.2497 Male: 0.2501 Left canine Female: 0.2540 Male: 0.2524	Right canine: 3.73% Left canine: 3.06%	Right Female: 70.0% Male: 73.3% LEFT Female: 56.7% Male: 66.7%	–[a]
Narang et al. 2014	Right canine Female: 0.248 Male: 0.255 Left canine Female: 0.241 Male: 0.255	–[a]	Female: 67.6% Male: 68.0%	India
Otuaga and Chris-Ozoko 2012	Right canine Female: 0.26 Male: 0.27 Left canine Female: 0.26 Male: 0.27	Right canine: 8.58% Left canine: 8.54%	RIGHT Female: 49.06% Male: 50.94% LEFT Female: 49.06% Male: 50.94%	Nigeria
Paramkusam et al. 2014	Female: 0.26 Male: 0.25	Right canine: 8.0% Left canine: 8.4%	Female: 76.66% Male: 80.00%	India
Patel et al. 2017	Right canine Female: 0.249 Male: 0.263 Left canine Female: 0.249 Male: 0.263	Right canine: 8.42% Left canine: 8.40%	Female: 80.00% Male: 77.50%	India
Patil et al. 2015	Female: 0.319 Male: 0.344	–[a]	–[a]	India

Table 8 (continued)

Study	Canine index average	Canine sexual dimorphism	Accuracy of sex estimation	Population
Priyadharshini et al. 2018	Right canine Female: 0.25 Male: 0.25 Left canine Female: 0.25 Male: 0.25	–[a]	–[a]	India
Rajarathnam et al. 2016	Right canine Casts (Female: 0.25/Male: 0.26) Intraoral (Female: 0.25/Male: 0.26) Left canine Casts (Female: 0.25/Male: 0.26) Intraoral (Female: 0.25/Male: 0.26)	Right canine: 6.90% Left canine: 6.96%	73%	India
Rao et al. 1989	Female: 0.254 Male: 0.296	–[a]	Female: 87.5% Male: 84.3%	India
Reddy et al. 2008	Right canine Female: 0.246 Male: 0.259 Left canine Female: 0.247 Male: 0.261	Left canine: 9.058%	Female: 66% Male: 78%	India
Sassi et al. 2012	Standard value: 0.267	–[a]	Female: 29% Male: 54%	Uruguay
Shahid et al. 2018	Female: 0.26 Male: 0.26	–[a]	Female: 43.70% Male: 51.30%	Pakistan
Sharma and Gorea 2010	Right canine 17–30 years (Female: 0.259/Male: 0.265) 30–50 years (Female: 0.252/Male: 0.256) Left canine 17–30 years (Female: 0.257/Male: 0.265) 30–50 years (Female: 0.252/Male: 0.254)	RIGHT 17–30 years: 5.616% 30–50 years: 4.687% LEFT 17–30 years: 6.103% 3050 years: 3.882%	–[a]	India
Sherfudhin et al. 1996	–[a]	–[a]	Female: 50.17% Male: 49.83%	India
Silva et al. 2016	Female: 0.30 Male: 0.31	–[a]	Female: 25.7% Male: 94%	Portugal
Singh et al. 2012	Right canine Female: 0.21 Male: 0.21 Left canine Female: 0.21 Male: 0.21	Right canine: 6.926% Left canine: 5.498%	–[a]	India
Singh et al. 2012	Right canine Female: 0.21 Male: 0.21 Left canine Female: 0.21 Male: 0.21	Right canine: 6.926% Left canine: 5.498%	–[a]	India
Singh et al. 2015	Right canine Female: 0.25 Male: 0.26 Left canine Female: 0.25 Male: 0.26	Right canine: 14.1% Left canine: 15.2%	Female: 87.2% Male: 83.8%	India

Table 8 (continued)

Study	Canine index average	Canine sexual dimorphism	Accuracy of sex estimation	Population
Sreedhar et al. 2015	Right canine Female: 0.27 Male: 0.25 Left canine Female: 0.28 Male: 0.27	–[a]	Right MCI: 84.3% Left MCI: 75.8%	India
Srivastava 2010	Right canine Female: 0.255 Male: 0.256 Left canine Female: 0.256 Male: 0.257	Right canine: 2.804% Left canine: 2.326%	Female: 51% Male: 48%	India
Vijayan et al. 2019	Right canine Female: 0.521 Male: 0.444 Left canine Female: 0.526 Male: 0.447	–[a]	–[a]	India
Vishwakarma and Guha 2011	Right canine Female: 0.2569 Male: 0.2864 Left canine Female: 0.2645 Male: 0.2888	Right canine: 12.51% Left canine: 10.15%	–[a]	India
Yadav et al. 2002	Female: 0.288 Male: 0.310	–[a]	Female: 81.1% Male: 83.3%	India

[a] Not found

2016; Srivastava 2010) supporting the idea that MCI is not a significant sex estimation method.

Research carried out in Nepal (Acharya and Mainali 2009; Atreya et al. 2019), Portugal (Azevedo et al. 2019; Silva et al. 2016) and Uruguay (Gargano et al. 2014; Sassi et al. 2012) showed that the mandibular canine index showed insufficient capacity to estimate sex and should be used with caution. However, MuhamedagIic and Sarajlic tried to find out if mandibular canines could provide elements that estimate sex in the population of Bosnia and Herzegovina and reported that the right MCI indicated greater accuracy in relation to other measures (Muhamedagić and Sarajlić 2013).

This contrast can be explained by the fact that both genetic and structural formation are different between individuals, even though they are part of the same population (Jacob et al. 2018). In addition, the results for the MCI can be diverse depending on the geographic area in which each individual lives, being necessary to carry out a random sampling in each region to obtain results with greater accuracy (Singh et al. 2015).

On the other hand, the mesiodistal distance of both mandibular canine teeth, one of the components of the MCI formula, was able to estimate sex with an 85.8% level of general accuracy (78% for males and 91.4% for the female sex), while the intercanine distance presented a level of 71.7% (74% for the male sex and 70% for the female sex) of accuracy in the research by Azevedo et al. (Azevedo et al. 2019). When in the form of MCI, Azevedo et al. found levels of general accuracy of 63.3 and 64.2% for left and right canine teeth, respectively (Azevedo et al. 2019). Other studies (Acharya et al. 2011; Divyadharsini and Kumar 2019; Ibeachu et al. 2012; Paramkusam et al. 2014; Patil et al. 2015) also confirm the results found by Azevedo et al. when evidencing that the mesiodistal length of the canines revealed a greater degree of accuracy for sex estimation than the MCI (Azevedo et al. 2019). Questions about the influence of the intercanine distance on the accuracy of the MCI can be raised, especially if factors such as the shape of the lower dental arch, the presence of dental crowding or diastemas, or even dental movement resulting from dental absences are considered.

When thinking about the sexual dimorphism of canine, there is a disagreement about which tooth would be able to more accurately predict sex. The left canine showed a higher degree of dimorphism for some authors (Gandhi et al. 2017; Kaushal et al. 2004; Kaushal et al. 2003; Paramkusam et al. 2014; Rajarathnam et al. 2016; Reddy et al. 2008; Sharma and Gorea 2010; Singh et al. 2015) and the value of 16.74% was found by Ibeachu, Didia, and Orish for that parameter (Ibeachu, Didia and Orish et al. 2012). However, there is also evidence in the literature that the right canine provides higher rates of sexual dimorphism.

Vishwakarma and Guha found that the right canine was more dimorphic than the left, with levels of 12.51 and 10.15%, respectively (Vishwakarma and Guha 2011).

The applicability of the canine to differ men from women is related to the action of the Y chromosome, which regulates the thickness of the dentin, influencing the size of the tooth (Garn et al. 1967). However, in addition to genetic factors, the performance of ethnic, environmental, nutritional, and cultural factors can attribute to teeth's different rates of sexual dimorphism in different studies and populations (Nagalaxmi et al. 2014).

In addition, the different applied methodologies may have played an important role in the variability of the results obtained by the studies. Patel et al. performed measurements of dental dimensions in plaster models and in the individual's oral cavity in an Indian population and, when comparing them, found that plaster models contributed to a better analysis, providing a high degree of accuracy (Patel et al. 2017). On the other hand, other studies also carried out in India identified that the measurements made intraorally and in the plaster models did not differ from each other and showed to be similar and accurate (Kaushal et al. 2003; Rajarathnam et al. 2016).

The use of plaster models to perform dental measurements has advantages over intraoral analysis, since conditions such as the existence of spacing, inclined teeth, rotations, interproximal contacts, and anatomical variations can intervene in the accuracy and repeatability of measurements of teeth in the cavity oral (Zilberman et al. 2003). Thus, in addition to facilitating the analysis of measurements when the elements mentioned above are present, plaster models allow them to be examined at another time to reduce errors during measurements due to fatigue (Patel et al. 2017).

Thus, from a methodological point of view, the use of plaster models allows studies to approach the forensic routine in which the expertise teams have skeletonized or fragmented human remains. However, since the plaster model production process may suffer environmental and operator interference, it is possible that research using skeletonized human remnants of known sex may elucidate the role of MCI in estimating sex between different populations.

Conclusions

The accuracy of the MCI was shown to vary among different populations and even within the same population. Because of this, MCI must be considered an auxiliary method in estimating sex, but its application must be viewed with great caution. On the other hand, the mesiodistal length of the canine showed a high degree of sexual dimorphism.

Abbreviation

MCI: Mandibular Canine Index.

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Authors' contributions

MFNR participated in the acquisition, analysis, and interpretation of data and contributed to the writing of the manuscript. PHVP also participated in the acquisition, analysis, and interpretation of data and contributed to the writing of the manuscript. AF was responsible for the conception and design of the study, supervision, and revision of the final manuscript. RHAS participated in the conception and design of the study, guidance, and review of the final manuscript, in addition to being responsible for the administration of the project. All authors mentioned above have read and approved the manuscript.

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References

Acharya AB, Angadi PV, Prabhu S, Nagnur S (2011) Validity of the mandibular canine index (MCI) in sex prediction: reassessment in an Indian sample. Forensic Sci Int 204:207.e1–207.e4. https://doi.org/10.1016/j.forsciint.2010.08.002

Acharya AB, Mainali S (2009) Limitations of the mandibular canine index in sex assessment. J Forensic Legal Med 16:67–69. https://doi.org/10.1016/j.jflm.2008.08.005

Anu V, Vijayakumar A, Roy JR, Pavan VR, Kiran RR, Jas RSB, Abinaya S (2018) Canine index: a tool for determination of sex. Indian J Public Heal Res Dev 9(9):143–147. https://doi.org/10.5958/0976-5506.2018.00984.1

Atreya A, Shrestha R, Tuladhar LR, Nepal S, Shrestha R, Sah SK (2019) Sex predictability by using mandibular canine index. J Nepal Health Res Counc 17(45):501–505. https://doi.org/10.33314/jnhrc.v17i4.2187

Azevedo A, Pereira ML, Gouveia S, Tavares JN, Caldas IM (2019) Sex estimation using the mandibular canine index components. Forensic Sci Med Pathol 15:191–197. https://doi.org/10.1007/s12024-018-0051-2

Bai JKS, Prakash AR, Reddy AVS, Rajinikanth M, Sreenath S, Reddy KVKK (2018) Correlative study on lip prints, fingerprints, and mandibular intercanine distance for gender determination. J Forensic Dent Sci 10:143–150. https://doi.org/10.4103/jfo.jfds_22_16

Bakkannavar SM, Manjunath S, Nayak VC, Kumar GP (2015) Canine index - a tool for sex determination. Egypt J Forensic Sci 5:157–161. https://doi.org/10.1016/j.ejfs.2014.08.008

Boaz K, Gupta C (2009) Dimorphism in human maxillary and madibular canines in establishment of gender. J Forensic Dent Sci 1(1):42–44. https://doi.org/10.4103/0974-2948.50889

Dhakar N, Jain M, Saawarn S, Saawarn N, Madhusudan AS (2012) Assessment of sexual dimorphism in permanent canines among different Indian ethnic groups - a comparative study. Indian J Forensic Med Toxicol 6(2):123–126

Dias PEM, Beaini TL, Melani RFH (2012) Identification of a tooth-like foreign body in swine sausage. J Forensic Sci 57(5):1361–1364. https://doi.org/10.1111/j.1556-4029.2012.02225.x

Divyadharsini V, Kumar VJ (2019) Analysing cheiloscopic pattern and mandibular canine index for gender determination. Res J Pharm Technol 12(1):254–258. https://doi.org/10.5958/0974-360X.2019.00048.9

Duraiswamy P, Tibdewal H, Patel K, Kumar S, Dhanni C, Kulkarni S (2009) Sex determination using mandibular canine index in optimal-fluoride and high-fluoride areas. J Forensic Dent Sci 1(2):99–103. https://doi.org/10.4103/0974-2948.60382

Francisco RA, Silva RHA, Pereira JM, Soares EG, Matheucci E Jr, Iwamura ESM, Guimarães MA (2013) Forensic anthropology screening for analyses of forensic genetics. Saúde, Ética & Justiça 18(1):128–133. https://doi.org/10.11606/issn.2317-2770.v18i1p128-133

Gandhi N, Jain S, Kahlon H, Singh A, Gambhir RS, Gaur A (2017) Significance of mandibular canine index in sexual dimorphism and aid in personal identification in forensic odontology. J Forensic Dent Sci 9:56–60. https://doi.org/10.4103/jfo.jfds_15_16

Gargano V, Picapedra A, Sassi C, Lima LNC, Alvarez R, Francesquini Júnior L, Daruge Júnior E (2014) Are mandibular and maxillary canine indexes reliable tools for sex determination? Acta Odontol 11(2):22–34

Garn SM, Lewis AB, Swindler DR, Kerewsky RS (1967) Genetic control of sexual dimorphism in tooth size. J Dent Res 46(5):963–972. https://doi.org/10.1177/00220345670460055801

Grover M, Bai RG, Ram T, Puri PM, Ghodke KR (2013) An Odontologist's key to sex determination: study analysis of mandibular canine teeth in south Indian population. J Orofac Res 3(3):157–160. https://doi.org/10.5005/jp-journals-10026-1087

Gupta A, Kumar K, Shetty DC, Wadhwan V, Jain A, Khanna KS (2014) Stature and gender determination and their correlation using odontometry and skull anthropometry. J Forensic Dent Sci 6(2):101–106. https://doi.org/10.4103/0975-1475.132536

Gupta J, Daniel MJ (2016) Crown size and arch width dimension as an indicator in gender determination for a Puducherry population. J Forensic Dent Sci 8:120–125. https://doi.org/10.4103/0975-1475.195105

Hosmani JV, Nayak RS, Kotrashetti VS, Pradeep S, Babji D (2013) Reliability of mandibular canines as indicators for sexual dichotomy. J Int Oral Health 5(1):1–7

Ibeachu PC, Didia BC, Orish C (2012) Sexual dimorphism in mandibular canine width and intercanine distance of University of Port-Harcourt student, Nigeria. Asian J Med Sci 2(5):166–169

Iqbal R, Zhang S, Mi C (2015) Reliability of mandibular canine and mandibular canine index in sex determination: a study using Uyghur population. J Forensic Legal Med 33:9–13. https://doi.org/10.1016/j.jflm.2015.03.007

Jacob C, Izadpanahian E, Jadhav M, Patil A (2018) Significance of using the mandibular canine index in gender determination. IIOAB J 9(5):9–12

Kakkar T, Sandhu S, Sekhon A, Singla K, Bector K, Sandhu J (2013) Study of mandibular canine index as a sex predictor in a Punjabi population. Indian J Oral Sci 4(1):23–26. https://doi.org/10.4103/0976-6944.118518

Kaushal S, Patnaik VVG, Agnihotri G (2003) Mandibular canines in sex determination. J Anat Soc India 52(2):119–124

Kaushal S, Patnaik VG, Sood V, Agnihotri G (2004) Sex determination in north Indians using mandibular canine index. J Indian Acad Forensic Med 26(2):45–49

Koelzer SC, Kuemmel IV, Koelzer JT, Ramsthaler F, Holz F, Gehl A, Verhoff MA (2019) Definitions of frontal bone inclination: applicability and quantification. Forensic Sci Int 303:109929. https://doi.org/10.1016/j.forsciint.2019.109929

Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh RK (2016) A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Sci Int 261:165.e1–165.e8. https://doi.org/10.1016/j.forsciint.2016.02.007

Krishnan RP, Thangavelu R, Rathnavelu V, Narasimhan M (2016) Gender determination: role of lip prints, finger prints and mandibular canine index. Exp Ther Med 11(6):2329–2332. https://doi.org/10.3892/etm.2016.3245

Kumawat RM, Dindgire SL, Gadhari M, Khobragade PG, Kadoo PS, Yadav P (2017) Mandibular canine: a tool for sex identification in forensic odontology. J Forensic Dent Sci 9(2):109. https://doi.org/10.4103/jfo.jfds_41_16

Lagos D, Ciocca L, Cáceres D (2016) Sensibilidad y especificidad clínica del indice mandibular canino y del ancho mesiodistal del diente canino Para estimar el sexo: ajuste de un Modelo predictivo. Int J Odontostomat 10(2):177–183. https://doi.org/10.4067/S0718-381X2016000200001

Latif M, Rashid W, Kaur B, Aggarwal A, Rashid A (2016) Sex determination from mandibular canine index for the age group of 17-40 years in north Indian population. Int J Sci Study 4(2):141–147. https://doi.org/10.17354/ijss/2016/271

Mohsenpour K, Gangadhar MR, Samehsalari S (2017) Mandibular and maxillary canine as a tool for sex determination. J Morphol Sci 34(4):247–250. https://doi.org/10.4322/jms.114217

Muhamedagić B, Sarajlić N (2013) Sex determination of the Bosnian-Herzegovinian population based on odontometric characteristics of permanent lower canines. J Health Sci 3(2):164–169. https://doi.org/10.17532/jhsci.2013.82

Muller M, Lupi-Pegurier L, Quatrehomme G, Bolla M (2001) Odontometrical method useful in determining gender and dental alignment. Forensic Sci Int 121(3):194–197. https://doi.org/10.1016/s0379-0738(01)00399-1

Muthukumar A, Thenmozhi MS (2018) Sex determination of an individual by studying the mandibular canine index. Drug Invent Today 10(Special Issue 1):2622–2625

Nadendla L, Paramkusam G, Pokala A, Devulapalli R (2016) Identification of gender using radiomorphometric measurements of canine by discriminant function analysis. Indian J Dental Res 27(1):27–31. https://doi.org/10.4103/0970-9290.179810

Nagalaxmi V, Sridevi U, Jyothi MN, Lalitha C, Naik MK, Srikanth K (2014) Cheiloscopy, palatoscopy and odontometrics in sex prediction and discrimination - a comparative study. Open Dent J 8(1):269–279. https://doi.org/10.2174/1874210601408010269

Narang R, Manchanda A, Bhatia H, Malhotra R (2014) Sex determination by mandibular canine index and molar odontometrics: a comparative study. Indian J Oral Sci 5(1):16–20. https://doi.org/10.4103/0976-6944.129944

Oliveira RN, Silva RHA, Boldrini SC (2008) Pericial analysis of a dental element found inside food used for human consumption. J Forensic Legal Med 15:269–273. https://doi.org/10.1016/j.jflm.2007.10.007
Otuaga PO, Chris-Ozoko LE (2012) Sex determination in Deltans using mandibular canine. Biomed Pharmacol J 5(1):111–115. https://doi.org/10.13005/bpj/329
Paramkusam G, Nadendla LK, Devulapalli RV, Pokala A (2014) Morphometric analysis of canine in gender determination: revisited in India. Indian J Dent Res 25(4):425–429. https://doi.org/10.4103/0970-9290.142514
Patel RA, Chaudhary AR, Dudhia BB, Macwan ZS, Patel PS, Jani YV (2017) Mandibular canine index: a study for gender determination in Gandhinagar population. J Forensic Dent Sci 9(3):135–143. https://doi.org/10.4103/jfo.jfds_64_16
Patil SN, Naik SB, Kamble SD, Kokane VB (2015) To evaluate the accuracy of various dental parameters used for the gender determination in Nagpur District population. Indian J Dent Res 26(6):576–581. https://doi.org/10.4103/0970-9290.176918
Prabhu S, Acharya AB (2009) Odontometric sex assessment in Indians. Forensic Sci Int 192(1–3):129.e1–129.e5. https://doi.org/10.1016/j.forsciint.2009.08.008
Priyadharshini KI, Ambika M, Sekar B, Mohanbabu V, Sabarinath B, Pavithra I (2018) Comparison of cheiloscopy, odontometric, and facial index for sex determination in forensic dentistry. J Forensic Dent Sci 10(2):88–91. https://doi.org/10.4103/jfo.jfds_102_17
Rajarathnam BN, David MP, Indira AP (2016) Mandibular canine dimensions as an aid in gender estimation. J Forensic Dent Sci 8(2):83–89. https://doi.org/10.4103/0975-1475.186364
Rao NG, Rao NN, Pai ML, Kotian MS (1989) Mandibular canine index--a clue for establishing sex identity. Forensic Sci Int 42:249–254. https://doi.org/10.1016/0379-0738(89)90092-3
Reddy V, Saxena S, Bansal P (2008) Mandibular canine index as a sex determinant: a study on the population of western Uttar Pradesh. J Oral Maxillofac Pathol 12(2):56–59. https://doi.org/10.4103/0973-029x.44577
Rogers TL (2005) Determining the sex of human remains through cranial morphology. J Forensic Sci 50(3):493–500
Rösing FW, Graw M, Marré B, Ritz-Timme S, Rothschild MA, Rötzscher K, Schmeling A, Schröder I, Geserick G (2007) Recommendations for the forensic diagnosis of sex and age from skeletons. HOMO 58:75–89. https://doi.org/10.1016/j.jchb.2005.07.002
Santos C, Pimenta C, Nobre M (2007) The PICO strategy for the research question construction and evidence search. Rev Lat Am Enfermagem 15(3):508–511. https://doi.org/10.1590/S0104-11692007000300023
Sassi C, Picapedra A, Lima LNC, Francesquini Júnior L, Daruge E, Daruge Júnior E (2012) Sex determination in Uruguayans byodontometric analysis. Braz J Oral Sci 11(3):381–386
Setia MS (2016) Methodology series module 3: cross-sectional studies. Indian J Dermatol 61:261–264. https://doi.org/10.4103/0019-5154.182410
Shahid F, Khamis MF, Alam MK (2018) Sex prediction assessment via mandibular canine index and logistic regression in Pakistani population: a digital model study. J Int Dent Medical Res 11(2):503–509
Sharma M, Gorea R (2010) Importance of mandibular and maxillary canines in sex determination. J Punjab Acad Forensic Med Toxicol 10(1):27–30
Sherfudhin H, Abdullah MA, Khan N (1996) A cross-sectional study of canine dimorphism in establishing sex identity: comparison of two statistical methods. J Oral Rehabil 23(9):627–631. https://doi.org/10.1046/j.1365-2842.1996.00406.x
Silva AM, Pereira ML, Gouveia S, Tavares JN, Azevedo A, Caldas IM (2016) A new approach to sex estimation using the mandibular canine index. Med Sci Law 56(1):7–12. https://doi.org/10.1177/0025802415575415
Silva RF, Dias PEM, Picoli FF, Rodrigues LG, Mundim MBV, Franco A (2015) Anthropological discrepancies detected in putrefied bodyidentified with dental records –a case report. RBOL 2(1):125–136. https://doi.org/10.21117/rbol.v2i1.25
Silva RF, Mendes SDSC, Marinho DEA, Rosário Júnior AF, Guimarães MA (2013) Importance of the comparative anatomy in forensic anthropology – case report. RSBO 10(2):193–197
Singh J, Gupta KD, Sardana V, Balappanavar AY, Malhotra G (2012) Sex determination using cheiloscopy and mandibular canine index as a tool in forensic dentistry. J Forensic Dent Sci 4(2):70–74. https://doi.org/10.4103/0975-1475.109889
Singh SK, Gupta A, Padmavathi BN, Kumar S, Roy S, Kumar A (2015) Mandibular canine index: a reliable predictor for gender identification using study cast in Indian population. Indian J Dent Res 26(4):396–399. https://doi.org/10.4103/0970-9290.167632
Sinhorini PA, Costa IAP, Lopez-Capp TT, Biazevic MGH, Paiva LAS (2019) Comparative analysis of four morphometric methods for sex estimation: a study conducted on human skulls. Legal Med 39:29–34. https://doi.org/10.1016/j.legalmed.2019.06.001
Spradley MK, Jantz RL (2011) Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci 56(2):289–296. https://doi.org/10.1111/j.1556-4029.2010.01635.x
Sreedhar G, Sumalatha MN, Ramesh G, Nagarajappa R, Murari A, Agrawal A (2015) Dimorphic mandibular canines in gender determination in Moradabad population of Western Uttar Pradesh. J Forensic Dent Sci 7(1):32–36. https://doi.org/10.4103/0975-1475.150302
Srivastava P (2010) Correlation of odontometric measures in sex determination. J Indian Acad Forensic Med 32(1):56–61
The Joanna Briggs Institute (2017) Checklist for diagnostic test accuracy studies. Available from: https://joannabriggs.org/critical-appraisal-tools (Accessed 23 Apr 2020).
The Joanna Briggs Institute (2020) Checklist for analytical cross sectional studies. Available from: https://joannabriggs.org/critical-appraisal-tools (Accessed 23 Apr 2020).
Vijayan A, Jayarajan J, Jaleel BNF (2019) Significance of mandibular canine index in sex determination. Int J Forensic Odontol 4:54–58. https://doi.org/10.4103/ijfo.ijfo_13_19
Vishwakarma N, Guha R (2011) A study of sexual dimorphism in permanent mandibular canines and its implications in forensic investigations. Nepal Med Coll J 13(2):96–99
Yadav S, Nagabhushana D, Rao BB, Mamatha GP (2002) Mandibular canine index in establishing sex identity. Indian J Dent Res 13(3–4):143–146
Zilberman O, Huggare JÅV, Parikakis KA (2003) Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 73(3):301–306 (https://doi.org/10.1043/0003-3219(2003)073<0301:EOTVOT>2.0.CO;2)

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