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REVIEW ARTICLE

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Prediction methods of maxillary canine impaction: a systematic review

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ABSTRACT

Objective: To describe and assess the available evidence of prediction methods of maxillary canine impaction (MCI).

Material and methods: A systematic search was conducted through PubMed, Cochrane Library, Embase, EBSCOhost, Scopus, ScienceDirect, Bireme and Scielo until December 2020. This systematic review was conducted according to the PRISMA statement. The methodology of the selected studies was assessed using the Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS-2).

Results: A total of 2391 articles were identified in the first approach and after a 2-phase selection, 11 studies were included in qualitative analysis. Prediction methods were constructed using equation-based models, geometric measurements and computational methods from clinical and imaging data to predict palatal/buccal MCI. The quality of evidence was low to moderate due to the presence of risk of bias in most of the studies included. Three cohort studies with the best methodological quality proposed prediction models based on geometric measurements, canine position and facial growth pattern that would allow predicting MCI from CBCT, lateral and panoramic radiographs.

Conclusions: The evidence is limited and most of the studies present a low methodological quality. However, it is possible to suggest that some prediction methods based on the position of the canine and facial growth pattern could predict palatal/buccal MCI in mixed dentition. Cohort studies with better methodological quality and long-term follow-up are needed to better validate a prediction model.

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Introduction

The impaction of maxillary permanent canine is a common problem in orthodontics. The presence of an impacted tooth is considered when its eruption is obstructed by other teeth, bone or soft tissue [1]. The prevalence of MCI varies widely, according to some studies in a range between 1 and 3% [2–4] and 1.1 and 13% of the population [5], being the second most frequent type of impaction after the third molars. A higher prevalence of MCI would be observed in the female gender [5], in patients with class II division 2 malocclusion, deep bite, hypodivergent profile [6] and commonly more unilateral than bilateral [7,8].

Buccally impacted canines (BIC) could be considered a form of crowding, where the lack of space in the maxillary arch would generate their impaction [9,10]. Palatine canine impaction (PCI) occurs 2 to 3 times more than buccal impaction [2–4] and unlike BIC, it is observed in patients who do not have crowding or even show an excess of space in the canine area [2,9–11].

In general, the diagnosis of MCI is based on the analysis of periapical and/or panoramic radiographs, despite the limitation of representing a three-dimensional object in a two-dimensional image. Currently, dentists use the Cone-Beam Computed Tomography (CBCT) to diagnose canine impaction, as it is more accurate in determining the position of the impacted canine and assessing the condition of adjacent roots [8,12]. However, at an early stage of development, it would be impossible to establish exactly the buccal–palatal location of the malpositioned dental germ [13].

The aetiology of MCI is still unclear [10]. It is suggested that BIC could be associated with the presence of dental crowding and/or deficiency in maxillary width [9,14]. In contrast, the causes of PCI are still unknown. Two theories try to explain it: the guidance theory and the genetic theory. The guidance theory suggests that the root of the lateral incisor would be an eruption guide. If the root is abnormal or absent, the canine will not erupt or be impacted [15,16]. The genetic theory attributes a hereditary component to PCI. It would be associated with other dental anomalies such as agenesis of permanent teeth and anomalies in the shape of the lateral incisors, enamel hypoplasia, mandibular molar aplasia [2,17–20].

An early diagnosis of MCI would be important to avoid adverse consequences in the patient since a late intervention could generate canine ankylosis, different degrees of resorption of the adjacent teeth [21,22] and long treatment times compared to patients without MCI [23]. The current evidence is not conclusive regarding the indicators of a possible

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canine impaction when the analysis of predictive factors has been carried out using conventional univariate statistics [6]. The angle formed between the canine axis and the midline and the overlap with the lateral incisor would be considered as a good indicator of impaction [24,25] while there is also evidence that would indicate that linear and angular measurements would not be good indicators to consider the success of interceptive orthodontic treatment and its duration [26,27].

Since there is no consensus regarding a model to predict MCI, the objective of this systematic review was to answer the research question according to the PICO (Population, Intervention, Control groups and Outcome) scheme: 'What are the prediction methods (I) to accurately determine maxillary canine impaction (O) in subjects with primary and mixed dentition (P) compared to those patients with erupted permanent canines (C)?'.

Material and methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement [28]. It was not registered upfront. An electronic search was conducted until 23 February 2020 and updated on 4 January 2021. The databases used were PubMed, Cochrane Library, Embase, Scopus, EbscoHost, Science-Direct, Bireme y Scielo.

Study selection

Inclusion criteria for this systematic review are given in the following sections.

Type of studies

Observational analytical studies (cohort or case-control) with the aim of designing and/or validating prediction methods to predict MCI.

Language studies

The search was conducted without the limitation of language. Studies included for analysis were in Spanish, English and Portuguese.

Types of participants

Selected studies included subjects in the primary and mixed dentition of both genders. The included participants did not undergo any previous surgical (except for the extraction of primary canines and other adjacent teeth to promote eruption guidance), orthodontic or orthopaedic procedure. Furthermore, they did not present any malformation or alteration of craniofacial growth and development.

Intervention types

Non-intervention studies, with the aim of designing and/or validating predictive models of MCI.

Type of results

Primary outcomes: Analyze studies that design and/or validate prediction models for MCI. In addition, establish the methodological quality of these studies to determine the precision of the prediction model.

Data collection

For maxillary canine impaction

Imaging methods based on CBCT, panoramic radiography or other radiographic methods by means of observation and/or cephalometric tracing (we did not establish a minimum follow-up interval to study MCI); Clinical methods: models obtained from patients or direct clinical observation; Digitisation of models or photos that allow measurements and other analyses.

Predictor construction

Multivariate or univariate statistical analysis; computational methods; mathematical modelling (equations, probabilistic models), among others.

Search strategy

For the identification and selection of the number of potentially eligible studies for this systematic review, a specific and individualized search strategy for each database was developed. A semantic field was determined for the term 'maxillary canine impaction (MCI)' and another semantic field related to the term 'predictors' (Table 1).

Study selection

In a first screening, the title and abstract of all potentially eligible articles were listed and evaluated by two researchers independently (J.A., C.R.). In a second stage, the full text of articles that potentially met eligibility criteria based on the first screening was assessed independently by the same two researchers (J.A., C.R.) according to inclusion criteria (study design: observational and diagnostic studies; objective: determine available methods to accurately predict MCI; type of participants: patients in primary or mixed dentition). When no agreement was found, the inclusion of the article within the sample was discussed with a third researcher (P.H) who acted as an arbiter. Articles that met inclusion criteria were included in the review for the final analysis. The reasons why some studies were excluded were recorded in an adjacent column and presented in the results (Table 2). To determine the quality and methodological validity regarding the design of predictors of the selected studies, the QUADAS-2 tool (Quality assessment of studies of diagnostic accuracy included in Systematic Reviews) was used (V.S. and T.J.).

Extracting data from studies

The PICO format (Population, Intervention, Control groups and Outcome) was used to make the tables of the articles

Table 1. Search strategy and terms used for the search.

Database and limits	Search strategy and terms
PubMed ($n = 1039$) Limits: Publication date: to 2020-12-31 Species: Humans	predictor [tiab] OR panoramic radiograph predictor OR radiographic predictors [tiab] OR clinical predictors [tiab] OR imagenologic predictors [tiab] OR CBCT predictors [tiab] OR prediction model [tiab] AND palatally displaced canine [tiab] OR maxillary canine impaction [tiab] OR buccally impacted canine [tiab] OR palatal canine impacted [tiab] OR buccal canine impaction [tiab] OR impacted maxillary canine [tiab] OR impacted canines [tiab] OR canine impaction [tiab] OR displaced permanent canine [tiab] OR displaced canine [tiab] OR palatal displaced canine [tiab] OR buccally displaced canine [tiab]
Cochrane Library ($n = 280$) Limits: Database: trials/methods studies Publication year: until 2020	(Risk OR determinants OR potencial determinants OR predict OR model prediction OR predictor OR prediction OR predicting OR clinical predictor OR radiographic predictor OR panoramic radiographic OR predictor CBCT predictor) AND (displaced canine OR canine impaction OR impacted canines OR maxillary canine impaction OR impacted maxillary canine OR palatally displaced canine OR PDC OR palatal canine impaction OR palatal displacement canine OR buccally impacted canine OR buccal canine impaction OR BIC)
EBSCOhost ($n = 260$) Publication date: until 2020-12-31	predictors OR panoramic radiograph predictor OR prediction OR prediction model OR imagenologic predictor OR radiographic predictors OR clinical predictors OR indicators OR clinical indicators OR radiographic indicators OR imagenologic indicators AND palatally displaced canines OR PDC OR maxillary canine impaction OR palatal impaction OR buccally impacted canines OR palatal canine impaction OR buccal canine impaction OR impacted maxillary canines OR impacted canines OR canine impaction OR displaced permanent canine OR displaced canine OR palatal displaced canine OR buccally displaced canines OR impaction of adyacent canine
Scopus ($n = 262$) Publication date: until 2020 Document type: article	predictors OR prediction OR prediction model OR clinical predictors OR imagenologic predictors OR radiographic predictors OR CBCT predictors AND canine impaction OR impacted canines OR displaced canines OR PDC OR IMC OR MIC
Embase – Medline ($n = 194$) Publication years: 1966–2020	predictors OR prediction OR prediction model OR indicators OR clinical predictors OR imagenologic predictors AND palatally displaced canines OR maxillary canine impaction OR palatal displaced canine OR displaced canine OR canine impaction OR upper canine impaction OR PDC
BIREME ($n = 103$) Limits: No limits	(tw:(predictor OR prediction OR prediction model OR imagenologic predictor OR radiographic predictor OR clinical predictor OR CBCT predictor OR clinical indicator OR imagenologic indicator OR radiographic indicator OR CBCT indicator OR predictores OR indicadores)) AND (tw:(palatally displaced canine OR PDC))
Scielo ($n = 90$) Publication date: until 2020	(determinants OR predictor OR indicator OR prediction model OR prediction OR radiographic predictor OR predictores OR indicadores) AND (PDC OR canine impaction OR displaced canine OR caninos impactados OR impactacion canina)
Science Direct ($n = 163$) Publication date: until 2020 Article type: research articles	potencial determinants OR predictors tiab OR radiographic predictors tiab OR clinical predictors tiab AND palatally displaced canines OR PDC tiab OR impaction of adyacent canine OR buccally displaced canine OR maxillary canine impaction

Table 2. Studies retrieved in full text and excluded from the review.

First author and year	Reason for exclusion
Alejos, 2019 [29]	Compare between different prediction methods.
Şenişik, 2019 [30]	Compare the reliability of prediction methods used for detecting the sagittal location of MCI with a single orthopantomography.
Cacciatore, 2018 [31]	Relationship between impacted maxillary canines, early diagnosed by using panoramic radiographs and the morphology of the maxilla.
Upegui, 2009 [32]	Compare between different prediction methods.

analyzed. Population (sample size, distribution by gender, age range and standard deviation); Intervention (an instrument for measuring, diagnostic protocol and design of predictor); Comparison criteria or control: (subjects with and without MCI, erupted permanent canines) and Outcomes (including the answer to the hypothesis, statistical analysis. Finding overall).

Quality assessment and grading the body of the evidence

Two authors independently assessed the quality of the evidence and the strength of the recommendations according to the risk of bias. The methodological quality of the selected studies was evaluated with the QUADAS-2 tool [33], used to assess the accuracy of the model of prediction of the studies analyzed. Two authors independently rated each item as 'yes', 'no', 'unclear', 'low' or 'high' (V.S., T.J.). Disagreements between the two reviewers were resolved by a consensus. When they did not reach a consensus, a third author (A.P.) made the final decision about each question.

Synthesis of results

The results collected from the included studies were based on levels of prediction of measurements made on clinical and radiographic data. The studies were clustered according to the type of maxillary canine impaction (palatal/buccal) and the predictor's models (equation-based, geometric measurements and computational).

A summary of the overall strength of available evidence was performed using the Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS-2).

Studies were considered heterogeneous and quantitative data were not comparable, so a meta-analysis was not considered appropriate.

Results

The initial search retrieved 2391 articles from the electronic databases. The studies were exported to an Excel table, and from these articles, 326 were eliminated because they were duplicates. The remaining 2065 studies were evaluated by the authors in a first screening and 2050 of these were eliminated because they were not relevant for this study. Of the remaining 15 studies, 4 were eliminated in a second

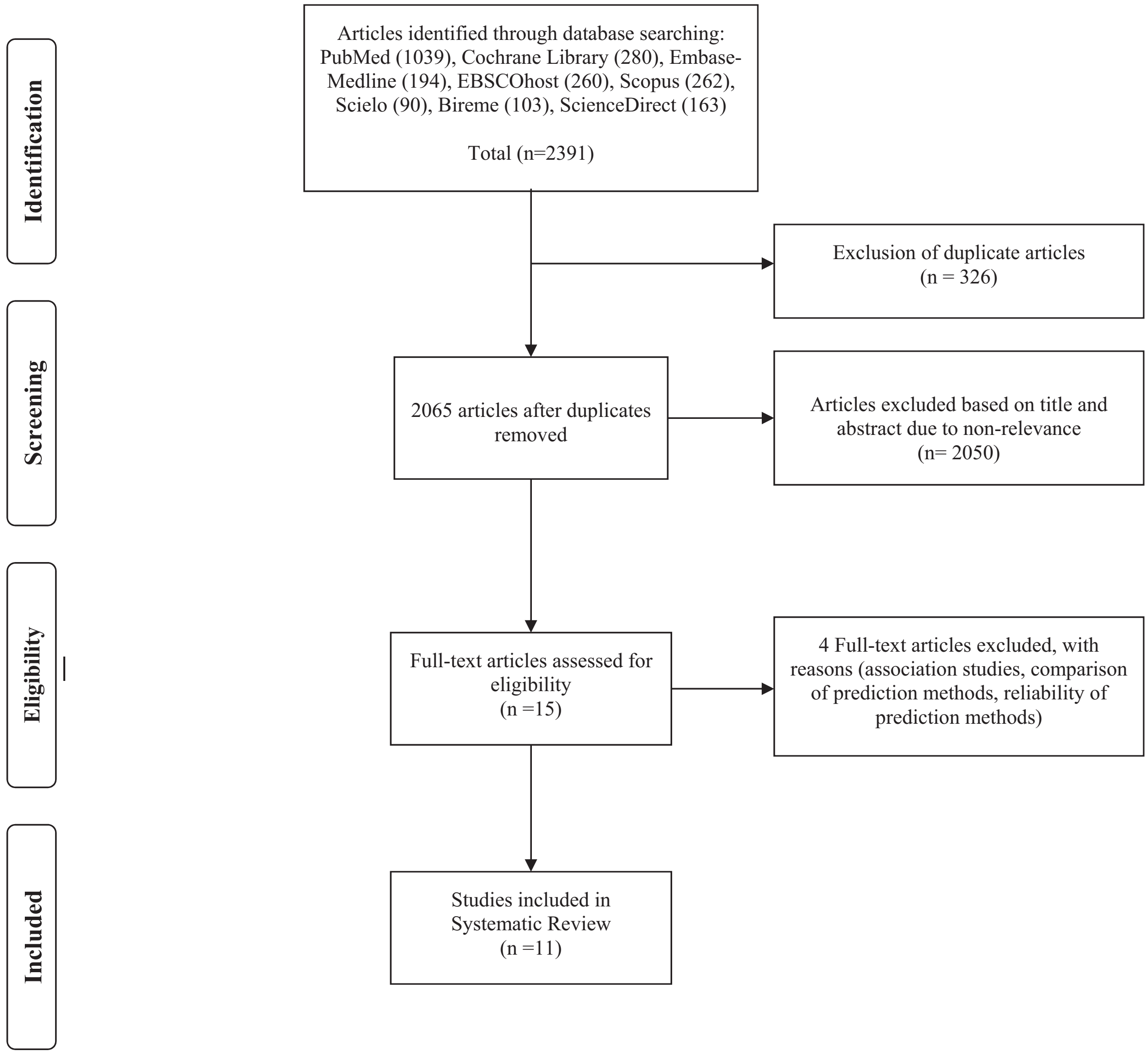

Figure 1. Search method, identification, selection and inclusion of articles. PRISMA flow chart.

screening when the full text of the articles was analyzed, and the reasons for exclusion are shown in Table 2. Finally, 11 studies were selected for data extraction and qualitative analysis. The search results are presented in Table 1 and the flowchart of the literature search is presented in Figure 1.

Study characteristics

Characteristics of participants

Based on the articles analyzed (Tables 3 and 4), 932 subjects with an age range between 3 and 21 years, of both genders and who included subjects in primary, mixed and permanent dentition were investigated. The studies included were published between 1992 and 2019. Only three articles did not detail the distribution of the sample according to gender [22,39,42]. According to the type of impaction presented, PCI was observed ($n = 4$), palatal/buccal MCI ($n = 2$) and studies that did not specify the type of impaction ($n = 5$). Regarding the presence of impacted canines, four studies included unilateral MCI [34,36,41,42], three unilateral/bilateral MCI [37–39] and four did not specify it [6,22,35,40] (Table 5).

Characteristics of predictors

The predictors were designed from data obtained from the analysis of panoramic radiographs [22,34,35,37–39,42], CBCT [41], frontal radiographs [36], panoramic radiographs in conjunction with clinical variables [6] and panoramic/lateral head radiographs [40].

Prediction models were constructed using: mathematical equations ($n = 4$) [6,29,30,32]; geometric measurements (using univariate and multivariate statistical analysis) ($n = 5$) [22,37,39,41,42] and computational methods (machine learning, random forest, discriminant analysis) ($n = 2$) [36,40]. The findings are summarised in Table 5.

Models of predictions based on mathematical equations.

In general, these studies used logistic regression models or multivariate analysis to evaluate the factors that influenced the MCI and that led to the use of an equation and model for predicting the probability of canine impaction. Four articles were analyzed, one of them did not propose any model, as no correlation was found between the clinical-radiographic variables with MCI [6]. Most of the studies proposed predictors for PCI based on equations designed

Table 3. Summary of studies that analyzed prediction methods for palatal maxillary canine impaction ($N = 4$).

	Population		Intervention		Comparison		Outcome		
First author and year	Sample (size, age, gender)	Characteristics of participants	Instrument for diagnosing canine impaction	Design and type of predictor	Study group (impaction group)	Control group	Statistical analysis or mathematical model	Findings overall	Conclusions
Malik, 2019 [34]	33 14 boys, 19 girls. 11-15 years.	Unilateral PCI Late mixed to early permanent dentition stage.	Palatal by anterior occlusal films or CBCT	Orthopantomograms: Angle A, angle B and angle C. Distance D. References planes: ML and MOP Equation to predict PIC.	PCI ($n = 33$).	Normally erupting ($n = 33$)	Mann–Whitney U test and Spearman's correlation coefficient. Logistic regression.	Equation predicts that the odds of PCI increase by 1.78 times with an increase of 10° in both angle B and angle C.	Increase angle C: more horizontal position of the tooth and can be used to identify impacted canines. Every 10° increase in angle B and angle C of a tooth when compared to its erupted counterpart increases the likelihood of its impaction by 1.78 times
Arnautska H, 2015 [35]	No data included	PCI in late mixed dentition	Anamnesis, clinical examination and panoramic radiographs	Radiographic predictor composed of angular measurements	No data included		PR (probability for canine impaction) $= 1/(1 + e - z)$, whereas $z = -7.346 + 0.116 \times b + 0.329 \times \alpha 1$ $e = 2.71828$ (Neper's constant)	If the value of PR >0.05, the probability of impaction is greater than 50%, while in the case of PR of up to 0.1, the probability of impaction approximates 100%.	In the case of existing temporary canine, we will use the value of angle β1 only. If the temporary canine is missing, we will use the equation with angle β and angle α1. Other radiographic parameters are similar to those in phase 2 of the late mixed dentition.
Sambataro, 2005 [36]	43 1st observation: m.a. 8 years 5 months. 2nd observation: m.a. 14 years, 3 months. 22 males, 21 females.	Unilateral CI Different malocclusions. Mixed dentition. CVS1	Frontal headfilms and clinical criteria.	Discriminant analysis from cephalometrics variables (skeletal and dental landkmarks).	Impacted canine group (12 subjects)	Nonimpacted canine group (31 subjects)	Discriminant analysis	Distance between the centre of the canine crown and the midsagittal plane (A3cc to Cg Vertical). Distance between the jugal process and the midsagittal plane (J to Cg Vertical). Power of the model for the prediction of canine impaction is 95.3%.	2 predictive measurements: Distance from the centre of the crown of the upper permanent canine to the midsagittal plane and the transverse width of the maxilla on the same side of the evaluated canine. The closer the canine crowns to the midsagittal plane and the larger the posterior portion of the hemimaxilla, the

(*continued*)

Table 3. Continued.

	Population		Intervention		Comparison		Outcome		
First author and year	Sample (size, age, gender)	Characteristics of participants	Instrument for diagnosing canine impaction	Design and type of predictor	Study group (impaction group)	Control group	Statistical analysis or mathematical model	Findings overall	Conclusions
									higher the probability of canine impaction.
Lindauer, 1992 [37]	56 patients. 26 girls and 30 boys.	Unilateral or bilateral palatally impacted canines. Late mixed dentition.	Panoramic radiographs and clinical criteria.	Radiographic predictor. Unerupted canine cusp tip relative to the lateral incisor root in one of four sectors using a modified method of Ericson and Kurol's (sector I, II, III and IV).	28 patients. 15 girls and 13 boys 12 years, 1 month ± 11 months.	28 chronologically and dentally age-matched. 11 girls and 17 boys whose 56 canines had erupted normally. 11 years, 8 months ± 19 months.	X2 analysis	Location of the mixed dentition canine cusp tip was significantly different for the impaction group compared with the non-impaction control group ($p < .001$). Significant difference between the impacted and non-impacted sides ($p < .005$).	When the canine cusp tip overlaid the distal half of the lateral incisor root, a canine palatal impaction was usually present.

CI: canine impaction; ML: maxillary dental midline; MOP: maxillary occlusal plane; PCI: palatal canine impaction.

considering the position of the canine, linear and angular measurements plotted on panoramic radiographs. Malik et al. developed a prediction model based on an equation for unilateral PCI considering the increase in angles B (angle between the long axis of canine adjacent lateral incisor) and C (angle between the long axis of canine maxillary occlusal plane) [34], in addition to other radiographic variables (perpendicular distance D). Arnautska et al. proposed an equation to determine the probability of impaction based on angles β1 and α1 (angles between the axis of the canine and the axis of the central and lateral incisor) [35], but without considering unilateral or bilateral impaction. Margot et al. [38] proposed a model based on parameters such as canine to midline angle, canine to first premolar angle, canine cusp to midline distance, canine cusp to maxillary plane distance and sector. The model was applied to calculate the probability of impaction with the area under the curve of 0.783 (95% CI [0.742–0.823]) with a cut-off point set at 0.342 (sensitivity of 0.800 and specificity of 0.598).

Models of prediction based on geometric measures. The studies included in the qualitative analysis prediction models were based on radiographic variables which were subjected to statistical, regression analysis to estimate the probability of impaction according to the location of the sector and canine angulation. Five studies were identified, four designed models based on the analysis of panoramic radiographs [22,37,39,42] and one based on CBCT [41]. Three studies predicted PCI, one palatal/buccal impaction, while another article did not report the position of the impacted canines. All studies validated their prediction models based on canine position (based on linear and angular measurements). The study by Lindauer et al. proposed their model based only on the location of the canine in 4 sectors in the analysis of a panoramic radiograph [37]. The other articles proposed models for use in panoramic radiographs and CBCT considering the position of the canine [22,39,41,42], also analyzing the angulation or superposition of the canine with respect to the lateral incisor [22,39,41] and determining the angulation of the canine [39,41,42]. Warford et al. concluded that the best predictor factor would be the canine location sector [22] where angulation would not provide a greater predictive value.

Models of prediction based on computational methods. Two studies constructed their predictors from the analysis of cephalometric variables from frontal, panoramic and lateral head radiographs. One determined the prediction of unilateral PCI based on discriminant analysis (DA) with a prediction model of 95.3% [36]. Another study by Laurenziello et al. [40] proposed a predictor without specifying its location using machine learning (random forest method), establishing that cephalometric data such as SN-GoMe Angle, Distance *d*, Angle α and Interincisal angle could be used as predictive values for MCI with an accuracy of 88.3%.

Assessment quality of included studies

In general, the studies analyzed were methodologically heterogeneous due to the differences in the designs and the

Table 4. Summary of studies that analyzed prediction methods for palatal/buccal maxillary canine impaction ($N = 7$).

	Population		Intervention		Comparison		Outcome		
First author and year	Sample (size, age, gender)	Characteristics of participants	Instrument for diagnosing canine impaction	Design and type of predictor	Study group (impaction group)	Control group	Statistical analysis or mathematical model	Findings overall	Conclusions
Margot, 2019 [38]	306 152 girls and 154 boys. Aa: 7-13 years	Uni/bilaterally impacted canine	Modified EK (sector) and angular methods on panoramic radiographs	Radiographic predictor composed of sector and angular measurements	Patients with at least two panoramic radiographs taken with an interval of minimum 1 year and maximum 3 years (T1 and T2)		Logistic regression Analysis. PI, the weighted sum of the predictor values (=μ) must be determined from the multiple logistic regression model.	Cut-off point was fixed at 0.342 with a sensitivity of 0.800 and a specificity of 0.598. The cross-validated area under the curve was equal to 0.750 (95% CI [0.700, 0.799]).	The prediction model based on parameters measured in panoramic radiographs is a valuable tool to decide between early intervention and regular follow-up of impacted canines
Almahdy, 2018 [39]	37 8-14 years. 51% males and 49% females T1: 8.3 to 13.2 years. m.a 9.6(SD1.26)	Unilateral or bilateral.	Clinical and radiographic criteria	Panoramic radiograph variables (longitudinal evaluation at T1 to T2).	Impacted canine	Non impacted canine	*t*-Test	Mean canine-lateral incisor angle was found to have increased significantly ($p < .01$) in CI, in T1 and T2. 95th percentile of non-impacted canine-lateral incisor angle was 31.72° and 54.1° of canine angulation in relation to the midline.	If any canine is located at a higher vertical position than the adjacent teeth and is overlapped by the lateral incisor, it has a higher chance of being impacted. Magnitude of the canine-lateral incisor angle and canine to midline angulation should be less than 30° and 54°, respectively to avoid canine impaction.
Laurenziello, 2017 [40]	109 44 males, 67 females. m.a. 9.34 years.	Physiologic canines retention first evaluation.	Clinical and radiographic criteria. .	PCA/Machine learning methods (random forest method). Determinants: Pattern of vertical facial growth (SN-GoMe angle). Interincisal angle. Angle α. Distance d.	109 patients (9–10 years). Two-year follow up period of the eruption state of each canine (erupted or impacted)		Univariate and multivariate statistical analyses.	Best performance: Random forest method, with an overall accuracy in predicting canine eruption of 88.3%	SN-GoMe Angle, Distance d, Angle α and Interincisal angle seem independently related to canine impaction and have reliable accuracy in predicting maxillary canine eruption eruption/impaction.
Uribe, 2017 [6]	90 subjects. 11–17 years.	Maxillary canine impaction.	Panoramic radiograph and clinical criteria.	Prediction model based on: PCA score and MVDA. Regression model based on OPLS-DA Prediction variables: Panoramic radiograph: Angulation of IMC = α and σ angle; d1 and d2 distance and sector location according to Ericson and Kurol.	45 subjects (58 maxillary impacted canine)/19 female, 39 males; m.a. = 14.2 years. a.r = 11–17 years.	Age- and gender-matched orthodontic patients ($n = 45$; normally erupting permanent maxillary canines)	Multivariate data analysis (MVDA). PCA was applied.	None of the parameters evaluated with either profile radiography or casts were positively correlated with impacted maxillary canines.	No correlation between clinical variables and impaction could be found using the comprehensive MVDA analysis. Therefore, these variables could not be used as predictors of impaction.

(*continued*)

Table 4. Continued.

	Population		Intervention		Comparison		Outcome		
First author and year	Sample (size, age, gender)	Characteristics of participants	Instrument for diagnosing canine impaction	Design and type of predictor	Study group (impaction group)	Control group	Statistical analysis or mathematical model	Findings overall	Conclusions
				Cephalograms: Bjork and Bergen's cephalograms norms. Study casts: arch length (anterior and posterior) and circumference dental arch; width dental arch (anterior/ posterior). Dental age: Demirjian and Goldstein criteria.					
Alqerban, 2015 [41]	65. 43 girls; 22 boys. Aa: 9.6–13.8 years	Unilaterally impacted canine	Patient dental records and CBCTs	Radiographic predictor composed of canine-related variables, linear and angular measurements.	Unilateral canine impaction side.	Normal eruption (Contralateral site).	Intraclass correlation coefficient to select 6 variables for multivariable logistic regression model Predictor $\exp(\mu)/(1+\exp(\mu))$, where $\mu = -5.66 + 2.11 \times x1 + 3.28 \times x2 + 0.27 \times x3 + 0.11 \times x4$	Prediction model using CBCT for CI (area under the curve, 0.965; 95% CI, 0.936–0.995). Canine crown position, canine cusp tip to the occlusal plane, and canine angulation to the lateral incisor were the relevant predictors in this model	Prediction of canine impaction based on CBCT was excellent. The probability of canine impaction obtained from the prediction model can help orthodontists to define the optimal intervention method.
Sajnani, 2012 [42]	111 3–21 years.	Unilaterally MIC	Clinical and radiographic (panoramic, occlusal and periapical).	Panoramic radiograph. Geometric measurements adapted from Erikson and Kurol.	Unilaterally impacted maxillary canine (group I)	Unaffected antimere (group II).	Paired *t*-test	At the age of 8 and beyond between the mean distance of the tip of IC and OC ($p = .05$). Significant difference at the age of 9 according to the position in different sectors and to the mean angle made with the midline ($p = .05$).	Diagnosis of maxillary canine impaction is possible at 8 years of age by using geometric measurements in panoramic radiographs.
Warford, 2003 [22]	82 Age: $<$12 years	Maxillary first molars and incisors fully erupted, with canines and premolars unerupted	Panoramic radiographs	Radiographic predictor consisting of angular and sector measurements	Impacted canine group	Non-impacted canine group	Logistic regression applied on sector location and angulation measurements of canines	Logistic regression analysis also determined that once the canine overlaps the midline of the lateral incisor, there is a chance of impaction greater than 0.87.	Sector location of the cusp tip of the unerupted canine is the most important predictor of eventual impaction. Sector was found to be the better predictor of impaction, with angulation adding little supplementary predictive value

a.r.: age range; CBCT: cone beam computed tomography; CI: confidence interval; m.a.: mean age; MIC: maxillary impacted canine; OC: occlusal plane; PCA: principal component analysis.

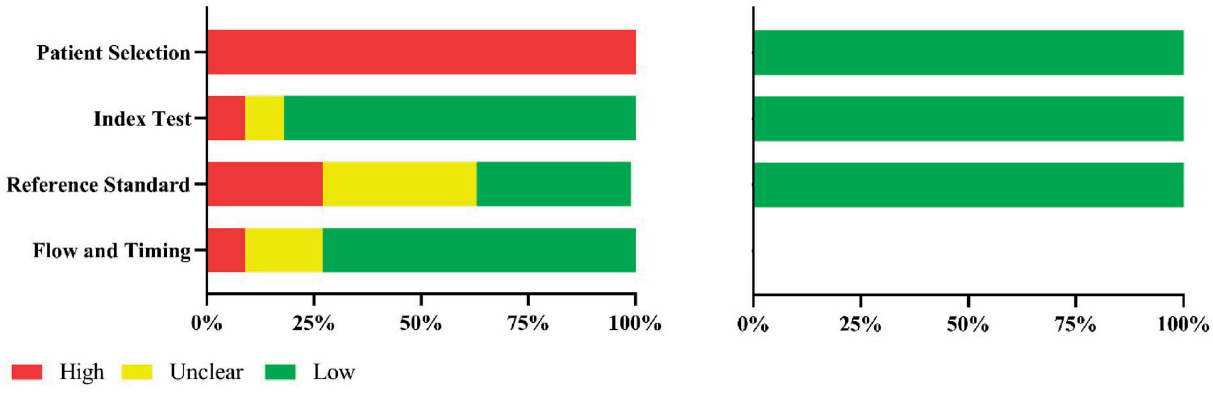

Figure 2. Criteria met, according to the QUADAS-2 tool.

prediction models. Most were composed of cohort studies ($n = 7$) and in their minority by case-control studies ($n = 4$). The methodological quality based on the QUADAS-2 tool (Table 5, Figure 2) indicates that in general, the studies would present a risk of bias in the patient selection and reference standard domains and unclear risk of bias in the index test domain. The high risk for the patient selection domain is based on the fact that 4 studies included case-control designs [6,22,34,37]. Furthermore, in all studies included, there was no randomization of the sample. The reference standard domain presented a high and unclear risk of bias in relation to its interpretation, in addition to the blinding of the researchers, which was not detailed in most of the studies, as in the index test domain, where it was unclear.

Discussion

Summary of evidence

Applying an MCI prediction model at an early age is of paramount importance in the clinical practice of orthodontics, allowing to prevent adverse consequences such as canine ankylosis, root resorption of adjacent teeth, ectopic eruption and avoiding therapeutic management of greater time and complexity. The objective of this systematic review was to describe and assess the validity of methods to predict MCI by analyzing the evidence available until December 2020.

Eleven articles were included according to the selection criteria. This systematic review showed great variability in the methods for diagnosing and predicting MCI, as well as for establishing the location of the canine (palatal, buccal, bilateral or unilateral). Most of the analyzed studies validated the prediction models in (a) mathematical models based on equations; (b) geometric measurements (based on statistical analysis) and (c) computational methods. In general, all models were built from clinical and imaging data from panoramic, lateral head, frontal and CBCT radiographs, which would allow an easy replication in clinical practice, complementing the diagnosis and planning of orthodontic treatment.

Quality of the evidence

This systematic review is supported by studies with low to moderate quality based on the analysis of the risk of bias with the QUADAS-2 tool (Table 6, Figure 2). In general, the domains that presented a high risk of bias were those related to patient selection and the reference standard.

When the methodological quality of the studies included was analyzed, we found some gaps in a few signalling questions for the QUADAS-2 tool (Table 6). None obtained a consecutive sample or randomized when selecting the patients, which constitutes a weakness in the design of these articles. On the contrary, the studies based on randomized clinical trials would generally provide stronger evidence than observational studies [43], which would be an inherent characteristic of the design of these studies. Another weakness was in the reference standard domain, where approximately 70% of the studies had a high or imprecise risk of bias given by the interpretation of the results of the reference index [22,34–36,38,40,42]. or by the lack of blinding of the researchers [6,34–37,40–42]. This limitation could be explained by the fact that most of the studies carried out diagnoses for palatal or buccal MCI based on the analysis of two-dimensional radiographic examinations or with low sensitivity diagnostic methods of MCI.

Three studies presented a lower risk of bias in the index test, reference standard, and flow and timing domains. All were cohort studies that proposed prediction models based on variables obtained from the panoramic, lateral head, and CBCT radiographs. The studies by Almahdy et al. [39] and Alqerban et al. [41] considered the position of the canine in their prediction model, as well as the analysis of linear and angular measurements. Laurenziello et al. proposed a prediction model using machine learning (random forest) where they determined the growth pattern of the face and the location of the canine [40].

Potential biases in the review process

For the development of this systematic review, every effort was made to limit the presence of biases in the article selection process using the largest number of electronic databases available, carrying out the selection process independently among researchers. In addition, articles

Table 5. Summary of articles included in the analysis according to study design, location of MCI, predictive model, and quality of evidence.

First author and year	Study design	Type of impaction (buccal and/or palatal)	Unilateral/bilateral canine impaction	Type of predictor (clinic, imagenologic, laboratory, mathematical models)	Predictive model for maxillary impaction	Quality of evidence (QUADAS-2)
Malik, 2019 [34]	Cases and controls	Palatal	Unilateral	Orthopantomograms variables: Angle A Angle B Angle C Distance D	$g(X) = \beta_0 + \beta_1$ (Angle B) $+ \beta_2$ (Angle C) $g(X) = 1.829 + 0.165$(Angle B) -0.092 (Angle B)	Low
Margot, 2019 [38]	Cohort	Maxillary canine impaction	Unilateral/bilateral	Radiographic predictor composed of sector and angular measurements	A canine would be classified as impacted when the predicted probability of impaction (PI) exceeded 0.342. To calculate the PI, the weighted sum of the predictor values ($=\mu$) must be determined from the multiple logistic regression model.	Low
Almahdy, 2018 [39]	Cohort	Maxillary canine impaction	Unilateral/bilateral	Panoramic radiograph variables (T1 vs T2).	Vertical canine crown tip height. Degree of canine overlap on the adjacent teeth. Magnitude of the canine-midline angle ($<54°$). Magnitude of the canine-lateral incisor angle ($<30°$).	Moderate
Laurenziello, 2017 [40]	Cohort	Maxillary canine impaction	Not specified	Machine learning method (Cephalometric variables)	Learning machine (random forest method) with 88.3% accuracy prediction (SN-GoMe Angle, Distance d, Angle α and Interincisal angle)	Moderate
Uribe, 2017 [6]	Cases and controls	Maxillary canine impaction	Not specified	Predictor variables: study casts, panoramic radiographs and profile radiographs	Prediction model based on PCA score and MVDA. Regression model based on OPLS-DA.	Low
Arnautska H, 2015 [35]	Cohort	Palatal	Not specified	Radiographic predictor composed of angular measurements	PR (probability for canine impaction) $= 1/(1 + e - z)$, whereas $z = -7.346 + 0.116 \times b + 0.329 \times \alpha 1$ $e = 2.71828$ (Neper's constant)	Low
Alqerban, 2015 [41]	Cohort	Palatal and buccal	Unilateral	Radiographic predictor (canine-related variables, linear and angular measurements). Does not discriminate between buccal and palatal impaction.	Predictor:exp(μ)/(1 + exp(μ)), where $\mu = -5.66 + 2.11 \times x1 + 3.28 \times x2 + 0.27 \times x3 + 0.11 \times x4$	Moderate
Sajnani, 2012 [42]	Cohort	Palatal and buccal CI	Unilateral	Panoramic radiograph (Geometric measurements).	Alpha angle: formed by the long axis of the impacted maxillary canine with the midline D1: perpendicular line was then drawn from the incisal tip of the impacted canine to the occlusal plane.	Low
Sambataro, 2005 [36]	Cohort	Palatal	Unilateral	Discriminant analysis from cephalometric variables.	Unstandardized discriminant function coefficients of the selected variables: Individual score = 5 [A3cc to Cg Vertical (0.883)] – [J to Cg Vertical (0.345)] 2 1.039.	Low
Warford, 2003 [22]	Cases and controls	Maxillary canine impaction	Not specified	Panoramic radiograph	Predictability of canine impaction as a function of sector location and angulation (logistic regression).	Low
Lindauer, 1992 [37]	Cases and controls	Palatal	Unilateral/bilateral	Panoramic radiograph	Modified method of Ericson and Kurol's: Locate unerupted canine cusp tip relative to the lateral incisor root. Sector I, II, III and IV.	Low

Table 6. QUADAS-2 criteria fulfilled.

	Item	Malik, 2019 [34]	Margot, 2019 [38]	Almahdy, 2018 [39]	Laurenziello, 2017 [40]	Uribe, 2017 [6]	Alqerban, 2015 [41]	Arnautska H, 2015 [35]	Sajnani, 2012 [42]	Sambataro, 2005 [36]	Warford, 2003 [22]	Lindauer, 1992 [37]
Domain 1: Patient Selection	Was a consecutive or random sample of patient enrolled? (Y,N,U)	N	N	N	N	N	N	U	N	N	N	N
	Was a case control design avoided? (Y,N,U)	N	Y	Y	Y	N	Y	Y	Y	Y	N	N
	Did the study avoid inappropriate exclusions? (Y,N,U)	Y	Y	Y	Y	Y	U	U	U	U	U	U
	Could the selection of patients have introduced bias? (H,L,U).	H	H	H	H	H	H	H	H	H	H	H
	Concerns regarding applicability: Is there any concern that the included patients do not match the review question? (H,L,U).	L	L	L	L	L	L	L	L	L	L	L
Domain 2: Index Test	Were the index test results interpreted without knowledge of the results of the reference standard? (Y,N,U).	U	U	U	Y	U	U	U	U	Y	U	U
	If a threshold was used, was it pre-specified? (Y,N,U)	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y
	Could the conduct or interpretation of the index test have introduced bias? (H,L,U)	L	L	L	L	L	L	H	L	L	L	U
	Concerns regarding applicability: Is there any concern that the index test, its conduct or interpretation differ from the review question? (H, L, U).	L	L	L	L	L	L	L	L	L	L	L
Domain 3: Reference Standard	Is the reference standard likely to correctly classify the target condition? (Y, N, U)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
	Were the reference standard results interpreted without knowledge of the results of the index test? (Y, N, U)	U	Y	Y	U	U	U	U	U	U	Y	U
	Could the reference standard, its conduct, or its interpretation have introduced bias? (H, L, U)	U	U	L	H	L	L	U	H	H	U	L
	Concerns regarding applicability: Is there any concern that the target condition as defined by the reference standard does not match the review question? (H,L,U)	L	L	L	L	L	L	L	L	L	L	L
Domain 4: Flow and Timing	Was there an appropriate interval between index test(s) and reference standard? (Y,N,U)	U	Y	Y	Y	Y	Y	U	Y	Y	Y	Y
	Did all patients receive a reference standard? (Y,N,U)	Y	Y	Y	Y	Y	Y	U	Y	Y	Y	Y
	Did all patients receive the same reference standard? (Y,N,U)	N	Y	Y	Y	Y	Y	U	Y	Y	Y	Y
	Were all patients included in the analysis? (Y,N,U)	Y	Y	Y	Y	Y	Y	U	Y	Y	N	Y
	Could the patient flow have introduced bias? (H,L,U)	U	L	L	L	L	L	U	L	L	H	L

Note. Y: yes; N: no; U: unclear. Risk. L: low; H: high; U: unclear.

published until December 2020 in English, Spanish and Portuguese were selected. Most studies had a male and female population (only three did not report it), which could limit the general interpretation of the results in the general population.

Prediction models based on geometric measurements

Of the five studies that established prediction models for MCI, two carried out by Almahdy et al. and Alqerban et al. presented the lower risk of bias in the index test, reference standard and flow and timing domains [39,41].

Almahdy et al. [39] proposed a prediction model for unilateral/bilateral MCI based on the position of the canine, angular and linear measurements of panoramic radiographs of growing patients between 8 and 14 years, evaluated with a 1-year interval. The proposed prediction model was based on 4 characteristics: vertical canine crown tip height, degree of canine overlap on adjacent teeth, the magnitude of canine midline angle ($<54°$), and magnitude of canine lateral incisor angle ($<30°$). Of these variables, the horizontal overlap of the canine over the lateral incisor would be considered the highest predictor and would be in agreement with previous studies [22,42]. Although the measurement and evaluation of panoramic radiographs allow a simple application in clinical practice, the use of CBCT is suggested to establish better precision in the diagnosis, monitoring and evaluation of possible root resorption of adjacent teeth [44] and determination in the buccal/palatal position. Despite the above, there is new evidence that would suggest an adequate prediction in the buccal–palatal position of impacted canines, as well as root resorption of the permanent incisors by analyzing the sectors on panoramic radiographs [30,45].

Alqerban et al. [41] designed a model based on 1-year follow-ups of patients between 9.6 and 13.8 years to predict unilateral palatal/oral impaction (area under the curve 0.965; 95% CI: 0.936–0.995) with variables of a CBCT (canine position, linear and angular measurements). Using a multivariable logistic regression method, the model was designed, and relevant predictors were established, such as canine crown position, canine cusp tip to the occlusal plane and canine angulation to the lateral incisor. Despite the use of CBCT, the authors suggest external validation, testing the reliability and reproducibility of the proposed method.

The studies performed by Lindauer et al., Warford et al. and Sajnani et al. were based on case-control [22,37] and cohort [42] designs. All presented a high risk of bias in the domains: patient selection (absence of randomization), index test (imprecision regarding the blinding of the investigators or their interpretation) [37], reference standard (for the imprecision to determine the blinding) [37,42] and the presence of bias in the interpretation of the diagnostic test for MCI [22,42] and finally in the flow and timing domain [22]. In general, all these studies built their models from the analysis of panoramic radiographs considering variables based on the position of the canine (location in sectors), angular and linear measurements. As in the case of previous studies, they analyzed similar radiographic factors that allow easy replication and precision, However, the presence of a high risk of bias constitutes a limitation for these studies.

Predictors built from computational methods

Considering the analysis of predictors based on the use of computational resources, the proposed models were analyzed by machine learning and discriminant analysis using cephalometric variables from panoramic, frontal, and lateral head radiographs. The study by Laurenziello et al. [40] presented a low risk of bias in the index test, reference standard and timing and flow domains and therefore a better methodological quality compared to the study carried out by Sambataro et al. [36]. The latter study showed a high risk of bias in the selection of patients and reference standard as it presents a possible weakness in the classification or diagnosis for MCI with the use of frontal radiographs.

Laurenziello et al. established determinants based on the facial growth pattern and the position of the canine to predict the eruption in 9 to 10-year-old patients with an accuracy of 88.3% using the random forest method [40]. The determinants SN-GoMe angle, distance *d*, angle α and interincisal angle would allow measurements on a panoramic and lateral head radiograph with reliable precision. According to the authors, the determinant SN-GoMe angle would be the most important to predict MCI. This could indicate that a vertical growth pattern could be considered a significant variable for MCI risk. Regarding the above, the available evidence is not conclusive and in turn contradictory, since it would indicate that there would be no relationship between skeletal characteristics and the presence of MCI [46,47]. On the other hand, a higher prevalence of MCI in hyperdivergent women and hypodivergent men has also been observed [48].

Predictors based on mathematical models

Predictors based on equations or mathematical models were built from imaging and clinical data for palatal or palatal/buccal MCI. In general, the quality of the evidence from the studies analyzed was low due to the presence of a high risk of bias in the selection of patients (none presented randomization). Two studies presented a case-control design [6,34] and all presented uncertainties regarding the blinding of the researchers (index test or reference standard). The presence of a high risk of bias was observed in the interpretation for the diagnosis of MCI (reference standard) as well as uncertainties in the flow and timing domain [34,35]. Only one article studied the correlation of clinical variables and MCI using multivariate data analysis (MVDA). However, we were unable to establish a model based on clinical variables to predict MCI [6]. The other studies used radiographic variables to build the models from linear and/or angular measurements, establishing an equation to determine the probability of palatal/buccal MCI [34,35,38].

Limitations

The limited available evidence and the presence of a large percentage of studies with a high risk of bias were a limitation of this systematic review. All the predictors were built from the radiological and clinical analysis of patients in primary, mixed, and permanent dentition. According to the study design, most of them were cohort studies ($n = 7$) and, to a lesser extent, of cases and controls ($n = 4$), with high heterogeneity in the construction of the prediction models that do not allow comparisons to be made among them. Most of the included studies presented the risk of bias in the patient selection domain of the QUADAS-2 tool, observing an absence of randomization of the sample and blinding of the researchers, together with the presence of biases in the interpretation of the reference standard (Table 6, Figure 2).

The CBCT is considered a highly relevant tool for the three-dimensional evaluation of craniofacial structures. Their contribution to clinical practice in orthodontics includes the study of impacted teeth, their relationship with adjacent structures, root resorption, among other indications for diagnosis, treatment planning, and follow-up in orthodontics [12]. Most of the studies proposed MCI prediction models based on the analysis of two-dimensional radiographs and without the inclusion of clinical variables, which would be a limitation. Despite this, there is evidence that would indicate that the use of panoramic radiographs could be considered a reliable resource to locate the presence of canine palatal/buccal impaction with results similar to the use of CBCT [30,45]. Panoramic radiograph is a widely used examination for the evaluation of teeth and maxillary bones by dentists [49], and considering the prediction models analyzed in this systematic review, they would be very useful because of their lower exposure to radiation dose compared to CBCT [50] and their lower cost.

Given the heterogeneity in the design of the included studies and the proposed prediction models, it was not possible to perform a meta-analysis.

Conclusions

Based on studies with a moderate level of evidence, it is possible to suggest the use of prediction models based on CBCT, panoramic and lateral head X-rays that consider the position of the canine with respect to the adjacent teeth and the pattern of facial growth to predict the palatal/buccal MCI in early stages. This systematic review highlighted the need for more studies to validate these and other prediction models, considering the performance of cohort studies, with better methodological quality and greater follow-up in the long term.

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Data availability statement

All data generated or analyzed during this study are included in this article.

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