Interventions for impacted maxillary canines: A systematic review on the relationship between initial canine position and treatment outcome.

Running title: Initial canine position and outcome.

Authors' affiliations:

K. Grisar¹, J. Luyten¹, F. Preda¹, C. Martin¹, T. Hoppenreijns³, C. Politis¹, R. Jacobs^{1,2}

¹ OMFS IMPATH Research Group, Department of Imaging & Pathology, Faculty of Medicine, University Leuven, Department of Oral & Maxillofacial Surgery, University Hospitals Leuven, Leuven, Belgium

² Department of Dental Medicine, Karolinska Institutet, Stockholm, Sweden

³ Department of Oral and Maxillofacial Surgery, Rijnstate Hospital, Arnhem

Correspondence to:

Dr. Koenraad Grisar

Department of Oral and Maxillofacial Surgery University Hospitals Leuven

Kapucijnenvoer 33, 3000, Leuven

e-mail: koenraadgrisar@gmail.com

Tel +32 16 33 24 80

Authors:

jonathanluyten2@gmail.com

catamartint@gmail.com

thoppenreijns@rijnstate.nl

flavia@opdebeeckorthodontie.be

constantinus.politis@uzleuven.be

reinilde.jacobs@uzleuven.be

ORCID

Koenraad Grisar: <https://orcid.org/0000-0001-5224-5323>

Reinilde Jacobs: <https://orcid.org/0000-0003-2123-5848>

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Constantinus Politis: <https://orcid.org/0000-0003-4772-9897>

Jonathan Luyten: <https://orcid.org/0000-0003-4524-786X>

Flavia Preda: <https://orcid.org/0000-0002-3332-4656>

Accepted Article

Background

The objective of this review was to critically assess the existing literature on the relationship between the initial position of impacted canines and treatment outcomes.

Methods

We performed a systematic review of the available literature until February 2020 using the Medline, Cochrane Central, Web of Science and PubMed databases. Prospective and retrospective studies (randomized controlled trials [RCTs], cohort studies, longitudinal follow-up studies) considering impacted maxillary canines that were orthodontically and/or surgically treated, and clearly reporting the initial position using 2D and/or 3D classifications, were included if they assessed at least one of the following: treatment success, treatment duration, number of treatment visits, radiographic outcome, periodontal health, esthetics, and/or treatment complications. The included studies were assessed for risk of bias according to the Cochrane guidelines.

Results

Seventeen studies were reviewed (2 RCTs and 15 non-RCTs). The included studies enrolled a total of 1247 patients with an average age of 14.1 years and a total of 1597 impacted canines. Various causal relationships were detected between the success of treatment modalities and the initial state of the impacted canine (bucco-palatal position, vertical position, canine angulation, root development).

Discussion

Evidence, though limited, suggests that a higher alpha angle, higher vertical position, and more mesial sector of the impacted canine are related to less successful interceptive and active treatment solutions, prolonged treatment time, and inferior outcomes.

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DR KOENRAAD GRISAR (Orcid ID : 0000-0001-5224-5323)

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**Interventions for impacted maxillary canines: A systematic review of the relationship
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INTRODUCTION

Impaction is defined as the failure of tooth eruption at its predetermined site in the dental arch within its normal period of growth due to an obstacle in the eruption path or ectopic position of the tooth germ. Impacted maxillary canines may present a wide three-dimensional range of variations with a corresponding difference in treatment difficulty.¹⁻⁴ In addition to esthetic and functional problems, untreated partially erupted or impacted canines can result in various complications, including displacement and loss of vitality of the adjacent teeth, arch length discrepancy, dental midline shift, formation of follicular cysts, ankylosis, recurrent infections, pain, caries decay, internal resorption, external resorption of the canine and adjacent teeth, or combinations of thereof.³ Therefore, a definitive diagnosis of impacted canine is often directly followed by further treatment.

A detailed assessment of the impacted maxillary canine's location, angulation, and orientation is essential for planning treatment. A variety of radiographic assessment tools have been used for evaluation and classification. Two-dimensional (2D) panoramic radiography has limitations, but three-dimensional (3D) cone beam computed tomography (CBCT) allows detailed localization of impacted canines and their relation to adjacent teeth in the horizontal, vertical, and sagittal axes.¹⁻¹¹ Treatment options for impacted canines are early interceptive treatment, such as removal of the deciduous canine, headgear treatment, and/or rapid maxillary expansion; surgical exposure with or without orthodontic traction to align the malpositioned tooth; transplantation of impacted canines in the dental arch or removal of the permanent canine, followed by closure of the diastema with orthodontic appliance, prosthetic, or restorative treatment with reinforced resin-bonded bridge or implant; or no treatment and preservation of the deciduous canine. The success of treatment is related to the complexity, duration, and complications, as well as functional and esthetic outcomes. Evaluation of the burden of care and treatment outcomes is paramount to the process of case selection for certain interventions, with the ultimate goal of improving the overall predictability and quality of treatment of impacted maxillary canines.

Impacted canines form an elaborate research field in orthodontics and oral surgery. Therefore, several systematic reviews have been conducted in the past. Special interest has been given to the periodontal outcomes of impacted canines and to the differences between open and closed surgical exposure.¹²⁻¹⁴ Interceptive treatment and root resorption have also been investigated.¹⁵⁻¹⁸ In recent years, the importance of 2D and 3D imaging with regards to this

treatment has been reviewed.^{19,20} All of these are high quality and interesting reviews, but none of them investigated the effect of the initial position of the canine on treatment outcome. Prior knowledge of treatment outcome for impacted canines is crucial in orthodontic decision-making. Therefore, a review on this subject is highly recommended to assist physicians in their clinical practice.

This systematic review aimed to critically assess the existing clinical evidence and determine whether considerable differences in treatment outcomes exist with regard to the initial position of the impacted canine and the treatment modalities used.

METHODS

Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed to ensure transparency and comprehensiveness in this systematic review.²¹ A search protocol was specified and registered at International Prospective Register of Systematic Reviews (PROSPERO nr. CRD42019133926) and all post hoc changes noted appropriately.²²

Search strategy

The search strategy was developed for EMBASE and appropriately adjusted for Cochrane Central, Web of Science, and PubMed. The electronic databases were searched for articles published up until February 2020. The search strategy used a combination of controlled vocabulary and free text terms and was run with the recommended EMBASE and MEDLINE filters.²³ The full search protocol for the different databases is given in Supplemental Table 1. No date restrictions were applied when searching the electronic databases. All references of the selected full-text articles were manually screened for potentially useful articles. Eligibility criteria were determined a priori according to the PICOS scheme (Table 1).

Study selection

The titles and abstracts of relevant studies identified through the electronic searches were screened by three authors (KG, CM, and JL). The full-text articles were obtained for the studies that fulfilled the inclusion criteria: prospective or retrospective studies (randomized controlled trials [RCTs], cohort studies, longitudinal follow-up studies) considering impacted maxillary canines that were orthodontically and/or surgically treated and clearly reported the initial position using 2D and/or 3D classifications. The studies also had to report at least one

of the following: treatment success, treatment duration, number of treatment visits, radiographic outcome, periodontal health, esthetics, or treatment complications. The full-text articles, together with full-text articles found through the manual search of the reference lists of included articles, were independently assessed by the authors to determine if they were in line with the inclusion and exclusion criteria. Studies reporting impacted maxillary canines in patients with systemic diseases, syndromes, or cleft lip and palate; not reporting the radiographic pre-treatment position of the impacted maxillary canines using 2D and/or 3D classifications; case reports, abstracts, author debates, summary articles, and (systematic) reviews; and studies in languages other than English were excluded. Disagreements were resolved through discussion. After selection, data extraction and a risk-of-bias assessment were performed.

Data extraction and management

Data were extracted by three reviewers (KG, CM, and JL) according to a modified version of the Cochrane data extraction form.²³ Data extraction forms were subsequently compared and any differences between the reviewers resolved by discussion. Authors of potentially eligible articles were contacted for clarification in case of doubts or missing data. A summary of study characteristics and outcomes can be found in Table 2.

The following data were recorded: methods (level of evidence, study design), participants (inclusion and exclusion criteria, demographics, number of participants, and number of impacted maxillary canines), diagnosis (assessment of initial canine position and classification system used for description), details regarding type of intervention, and outcomes, including success of treatment (esthetic outcome, periodontal outcome, resorption of neighboring teeth, ankylosis), number of treatment visits, and treatment time.

Risk of bias assessment

The risk of bias was assessed by two reviewers (JL and KG) using specific study forms designed by the Cochrane Collaboration.²³ Both observers independently examined the included articles based on the recommended approach for assessing the risk of bias in Cochrane reviews (Tables 3 and 4). RCTs and prospective studies were evaluated using the ROB 2.0 Cochrane tool.²⁴ The retrospective cohort studies were evaluated using the ROBINS-I tool for retrospective cohort studies following the guidelines of the latest update of the Cochrane handbook.²⁵ A more detailed description of the risk of bias analysis is given in supplemental Tables 2 and 3.

Evaluation of the level evidence (risk of bias across studies)

The level of evidence was assessed using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE).²⁶ For each outcome examined, the GRADE assesses the number of studies included, the study design, risk of bias, inconsistency, indirectness, imprecision, and other considerations, such as publication bias. Depending on the seriousness of the limitation in each of these domains, the evidence can be downgraded by one or two levels. Based on this assessment, the certainty of the outcome evaluation can be 'very low', 'low', 'moderate', or 'high'.

Summary measures and approach to synthesis

Due to small sample sizes and heterogeneity among the studies included in this systematic review, a meta-analysis was not possible. A narrative synthesis was performed by illustrating the results from individual studies according to the group evaluated.

RESULTS

Study selection

After screening the titles and abstracts of 3127 unique papers, 72 potentially eligible articles were selected (Figure 1). Study characteristics and outcomes are summarized in Table 2. A detailed description of the outcomes as reported by the included studies can be found in Supplemental Table 4. Of the 72 potentially eligible articles, 55 were excluded for not meeting the inclusion criteria, resulting in the final inclusion of 17 articles (Figure 1).^{11,27-41} Reasons for exclusion were not describing the initial position of the canines or not reporting the relationship between the initial position and outcome.^{21,27} Four studies were case series. For two studies, it was not possible to retrieve the full-text in English. One study only compared two indices without reporting the outcome (Figure 1).

Study characteristics

Characteristics of the participants

The included studies enrolled a total of 1247 patients and counted 1579 impacted canines. The mean age of the participants ranged from 9.5 to 18.2 years (mean age 14.1 ± 2.8 years). The distribution of men and women was described in all but two of the studies (306 males and 590 females).^{31,41} Two articles mentioned age restrictions: one study excluded patients

>20 years, and the other study only included patients between 12 and 16 years old at the start of treatment.^{31,40}

Position of the impacted canine

All but one study defined the impacted maxillary canine position using a 2D classification system.³⁶ Twelve studies used the classification system described by Ericson and Kurol.^{11,27,28,30-34,38-42} One study used the classification system described by Ericson and Kurol with the Lindauer modification.³⁵ Three other studies used their own classification system.^{29,30,37} One study used a 3D classification system of their own.³⁶ Twelve studies only included palatally displaced canines (PDCs).^{11,28,30,31,33,35-40} One study only considered canines with buccal impaction.³⁴ Four studies comprised palatal, buccal, and midcrestal impacted canines.^{27,29,41,42}

Three studies failed to include or mentioned the exclusion of more severely impacted maxillary canines (sector 5 Kurol and Ericson, transposition, cases with obstacles along the traction pathway, adults with deep impactions) or controversial cases.^{31,40,42} One article excluded six patients due to a lack of movement rather than reporting them as failures.⁴² This same study also excluded cases of submucosal buccal impaction.⁴²

Treatment complexity

Only one study explicitly illustrated the complexity of the impacted maxillary canine treatment. Arriola-Guillén et al. divided the patients into two groups based on complexity.²⁷ Complexity was defined based on the impaction sector, eruption inclination angle, and canine position (palatal, buccal, or midcrestal). The high complexity group included sectors 3 (alpha angle > 40°), 4, or 5 according to the Ericson and Kurol classification and bicortically impacted maxillary canines.²⁷ Although there was 60% initial root resorption in the high complexity group (compared to 15% in the low complexity group), root resorption after traction was similar in both groups.²⁷

Sample size calculation

In the RCTs, all of the studies reported a sample size calculation. Among the prospective studies, only Koutzoglou et al. failed to mention a sample size calculation.²⁹ In the retrospec-

tive sample, the studies by Arriola-Guillen et al., Caprioglio et al., and Potrubacz et al. made use of a sample size calculation.^{27,31,33}

Characteristics of the interventions

Pre-operative assessment

In most of the studies, pre-treatment assessment was performed as clinical and radiological examinations, such as 2D panoramic radiographs, most frequently by an Ericson and Kuroil analysis or an adapted version of this analysis. Some studies mentioned using CBCT, more specifically when confronted with more challenging cases or when ankylosis of the canine was suspected.^{29,33,36} One study mentioned a 3D classification system.³⁶

Treatment protocol

Different treatment modalities were reported. Five articles described interceptive approaches^{28,32,36,37,39} Eleven articles described surgical exposure and orthodontic traction of the im-

acted canine.^{11,27,30,31,33-35,38,40-42} One article described both interceptive approaches, as well as surgical exposure and orthodontic traction.²⁹ Interceptive interventions comprised deciduous canine extraction, rapid palatal expansion, and prevention of lateral sector mesialization using a transpalatal bar. Deciduous canine extraction was performed in cases in which the authors had diagnosed a palatal displacement of the permanent canine germ.^{28,32,36,37,39}

Koutzoglou et al. added palatal expansion to their protocol.²⁹ Baccetti et al. and Sigler et al. added rapid palatal expansion and a trans-palatal bar in the interceptive phase of their treatment.^{28,39}

Considering the studies describing surgical exposure and orthodontic traction, seven of the included studies offered a detailed description of the surgical technique.^{29,33-35,40-42} The reported surgical techniques varied between open^{33,35} and closed approaches^{34,40,42} or a combination of both^{29,41}. In another five studies, the details for the surgical approach were not mentioned.^{11,27,30,31,38} The applied orthodontic techniques varied from conventional mechanics with elastic traction^{30,35,40} to specific devices, including a rigid temporary anchorage device sustained on an anterior palate and previously aligned teeth²⁷; “easy cuspid” device-, a combination of modified Jonas Jig and modified ballista spring³¹; double arch technique³²; and

traction with cantilever soldered on transpalatal bar.³³ Five studies did not expand on the orthodontic modalities used.^{11,29,34,38,41}

Post-operative assessment

Post-treatment follow-up was performed with clinical examination or combined clinical and radiographic examination, including panoramic radiography, cephalogram, and/or CBCT.

Only two studies reported the use of CBCT in treatment follow-up.^{27,36}

Characteristics of outcome measures

The success of treatment, defined as a complete eruption of the canine's crown sufficient to allow for orthodontic alignment, or improvement in position compared to the initial situation was reported in nine of the included studies.^{28,29,32,33,35-37,39,42} Two studies reported ankylosis.^{29,35} One study reported root resorption of the maxillary incisors.²⁷ Six studies reported treatment duration.^{11,30,33-35,41} One study reported the number of visits.³⁹ Four studies reported periodontal outcome.^{31,34,40,42}

Treatment time and duration of mean follow-up

Mean follow-up varied between the different studies. Six studies reported results after debonding without specifying the study period.^{11,29-31,41,42} Ten studies reported results after observation periods ranging from 1 month to 48 months.^{28,32-40} One study did not specify the mean follow-up duration.²⁷ Treatment time in regards to surgical exposure and orthodontic traction interventions was divided into the traction time of the impacted tooth after exposure^{33,34,35,41,42} or was presented as the total orthodontic time^{11,30,31,38}. Three studies did not mention the duration of treatment.^{27,29,40} The initial traction of the impacted tooth has been reported to take as little as 3.5 months or as much as 12.7 ± 7.7 .^{33,34} Total treatment time ranged between 19.6 ± 7.8 months and 30.3 ± 10.8 months.^{34,41}

Risk of bias in included studies

According to the ROB 2.0 tool of the Cochrane handbook, two RCTs were rated as having a low risk of bias and one study as high risk (Table 3). The RCTs from Naoumova et al. and Bazargani et al. presented clear and elaborate descriptions of the baseline characteristics of the impacted canines.^{32,36} For the retrospective cohort studies, 10 obtained a moderate score overall and 2 were considered to have a serious risk of bias (Table 4). None of the included

cohort studies had a low risk of bias according to the ROBINS-I tool. The prospective cohort studies were of decent quality and obtained moderate overall scores (Table 4). Two retrospective studies had a serious risk of bias. Motamedi et al. lacked appropriate statistical analysis and methods to control for bias.³⁵ In addition, they offered no clear description of how the subgroup analysis was performed. Therefore, a serious risk was noted when it comes to select reporting. Zasciurinskiene et al. also had statistical issues and did not use methods to adjust for time-related confounding variables.⁴⁰

Assessment of the certainty of evidence

The certainty of evidence was evaluated according to the GRADE approach. Reasons for downgrading the evidence are detailed in Table 5. For all outcomes, the certainty levels were graded as very low due to the clinical heterogeneity of the included studies, inconsistencies in the outcomes, and the inclusion of non-randomized studies and their high risk of bias.

Qualitative synthesis

Supplemental Figures 1 and 2 provide an overview of the studies that examined buccal and palatal impaction of canines, the interventions applied, and the results examined. Six articles described interceptive approaches: removal of the deciduous canine, headgear treatment, and/or rapid maxillary expansion.^{28,29,32,36,37,39} However, only Koutzoglou et al. included canines with buccal impaction.²⁹ Naoumova et al., Baccetti et al., and Bazargani et al. found a significant increase in the spontaneous eruption of the permanent maxillary canines after extraction of the deciduous canine.^{28,32,36} Power et al. and Sigler et al. reported that the outcome was dependent on the sector position of the canine.^{37,39} Baccetti et al. and Bazargani et al. confirmed the influence of a more severe sector of displacement, together with an increased alpha angle.^{28,32} Koutzoglou et al. concluded that the severity of impaction may be associated with the development of ankylosis and treatment failure.²⁹

Though 12 articles described outcomes after surgical exposure and orthodontic traction, only four of these articles included canines with buccal impaction.^{27,29,34,41} Several authors investigated the link between canine position and periodontal outcomes after surgical exposure and orthodontic traction. The conclusions of these studies are not in agreement. Lee et al. found, on one hand, a significant correlation between the initial vertical position and the alpha angle and, on the other hand, the periodontal outcome of buccally impacted maxillary canines after

closed eruption techniques.³⁴ In contrast, Crescini et al. found 100% treatment success with excellent periodontal outcomes and relatively short treatment times ($\pm$ 21 months) for closed surgical-orthodontic treatment of buccally and palatally displaced maxillary canines.⁴² However, they applied strict exclusion criteria (only Ericson and Kuroi sectors 1, 2, and 3; six cases were retrospectively excluded due to the lack of movement of the impacted canine, transposition of the canine, obstacles along the traction pathway/roots of adjacent teeth, and submucosal buccal impactions).⁴² Zasciurinskiene et al. reported that periodontal conditions of the PDC and adjacent teeth after surgical-orthodontic treatment depend on the initial vertical and horizontal position. The more severe the impaction, the deeper the post-treatment pocket depth.⁴⁰ In contrast, Caprioglio et al. concluded that radiological variables, such as alpha angle and d-distance do not seem to influence periodontal outcomes of PDC, whereas the sector may play a significant role.³¹

Concerning the relationship between treatment duration and initial position, there is more uniformity among the different studies concerning buccal and palatal impaction.^{11,30,38,41} The mesiodistal and vertical location of the impacted canine (buccal and palatal) seems to impact treatment duration, with increasing treatment times for high impaction of PDC (31 vs. 25 months).^{11,30,41}

Koutzoglou et al. reported that surgical exposure technique, age, and severity of impaction appear to be significant predictors of ankylosis for buccal and palatal impaction of the canine.²⁹ Motamedi et al. confirmed the significant relationship between canine angulation, mesiodistal position, presence of root anomalies, and the outcome of palatally impacted canines. Remarkably, almost one-third of the impacted maxillary canines in this study population were removed due to ankylosis.³⁵

Though some studies describe treatment duration as the traction time, other studies defined this as the entire duration of orthodontic treatment with a fixed appliance after the surgical exposure. A clear definition of the forced eruption phase with regards to the canine intermediate position at the end of this phase is rather difficult to identify, so comparisons between studies are not obvious. In addition, the wide variety of orthodontic traction methods used (from simple elastic traction to specific devices for anchorage and applying cantilevers) weakens the power of such comparisons of treatment length.

DISCUSSION

This systematic review aimed to critically assess the existing clinical evidence and determine whether considerable differences exist in treatment outcomes depending on the initial position of the impacted canine and the treatment modalities used. The large heterogeneity among studies did not allow a quantitative synthesis and solid evaluation of the relationship between the initial canine position and treatment outcome. However, the present results are useful for future controlled clinical trials on this important topic.

Among the reviewed studies, the method of choice for initial assessment and localization of the impacted canine was the panoramic radiograph. Although more precise 3D imaging is available, it has yet to become routine clinical practice. A recent systematic review comparing CBCT and conventional radiography for localization of maxillary impacted canines concluded, though without strong evidence, that CBCT imaging is more effective in depicting the precise position of the impacted tooth in cases in which 2D imaging is insufficient.²⁰ De Grauwe et al. and Kapetanovic et al. agreed that the use of CBCT is justified only in cases in which conventional radiography fails to provide accurate diagnosis of pathology.^{43,44} However, one should also consider that, in more than half of the cases, CBCT is not used for mere diagnosis. In relation to canine impaction, CBCT is used more to assess complications (canine ankylosis and root resorption of neighboring teeth) and allow for minimally invasive surgery.^{43,44}

Interceptive treatment for impacted canines refers to early extraction of deciduous canines, rapid palatal expansion, and/or headgear traction in an attempt to gain space for the developing canine. Interception may decrease the chance of developing malocclusion and the need for further orthodontic treatment. A recent systematic review by Alyammahi et al. concluded that extraction of the primary canines in the mixed dentition may, in the long-term, increase the probability of subsequent successful eruption of palatally displaced canines.¹⁷ In the RCT by Naoumova et al., in the case of severe palatal displacement (alpha angle > 30 degrees, sector 4), interceptive treatment was prone to failure. In these cases, early combination treatment is advised (i.e., interceptive treatment, surgical exposure, and traction) to decrease the risk of the canine becoming more impacted and to minimize the risk of root resorption in the adjacent teeth.³⁶ A positive effect of headgear and rapid palatal expansion on improvements in the initial position of the canine with palatal impaction has been stated in multiple studies.^{28,39,45,46} A greater mesial sector and higher alpha angle have been identified as negative predictors of successful interceptive treatment.^{28,32,36,37,39} All of the above-mentioned studies

support the interceptive treatment of palatally displaced canines and even demonstrate a relationship between the initial position of the palatally impacted maxillary canine and the outcome. Interceptive treatment actions and space gain will change the environmental conditions and cause a spontaneous change in the eruption path. It is not surprising that buccally displaced canines, which are often associated with arch length discrepancy, can also benefit from these interceptive procedures, as most of them increase arch length, or at least prevent reduction of the arch length, during occlusal development.⁴⁵ However, only Koutzoglou et al. included canines with buccal impaction in their study.²⁹ Koutzoglou et al. concluded that the severity of impaction may be associated with the development of ankylosis and treatment failure.²⁹

Surgical exposure with or without orthodontic traction includes a selection of various techniques that can be differentiated into open and closed techniques according to the surgical approach. The open technique refers to removal of the overlying soft tissue and bone to expose the canine crown or, in the case of a buccal position, is an apically repositioned gingival flap. The canine can be either left to spontaneously erupt or directly bonded to an orthodontic attachment to directly apply traction. The closed technique involves raising a full mucoperiosteal flap, exposing the canine crown, and bonding an attachment. Multiple studies have investigated the influence of surgical technique on treatment outcome. A recent systematic review concluded that open surgical exposure of impacted canines seems to be superior to the closed approach in terms of reduced duration of initial alignment and decreased risk of ankylosis.¹⁴ In the included studies, the surgical technique varied between open^{33,35} and closed approaches^{34,40,42} or a combination of both.^{29,41}

A wide range of possible techniques that allow orthodontic traction to be placed on an impacted canine are currently available. Almost all involve direct bonding of a button. Either removable or fixed appliances can be used to apply traction. For canines in less favorable positions, fixed appliances are essential and, as this process can be quite demanding for anchorage, reinforcement should be considered. Using fixed appliances, traction can be applied with flexible piggyback archwires, elastomeric chain, or strong rigid buccal arms or even magnets. The choice of technique will depend largely upon canine position and the preference of the orthodontist. In the included studies, the applied orthodontic techniques varied from conventional mechanics with elastic traction^{30,35,40} to specific devices.

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It is the authors' opinion that, with regard to surgical exposure with or without orthodontic traction, buccal and palatal displacement must be differentiated. Buccal displacement involves different variables and outcomes, as well as different treatment choices and success rates.¹² Cassina et al. stated in their recent systematic review that canine localization (buccal versus palatal) is significantly associated with treatment duration.¹⁴ This could be because palatally impacted canines lie much further from the occlusal plane than labially impacted canines, resulting in a longer eruption path. Though surgical exposure of palatally impacted maxillary canines has little to no periodontal impact, buccal impactions are more challenging to manage without adverse periodontal consequences.¹² Furthermore, Lee et al. concluded that, for the treatment of buccally impacted maxillary canines, a more advanced root development stage, greater mesial sector, and high vertical impaction can aggravate final periodontal conditions.³⁴ Koutzoglou et al. reported that, for both buccal and palatal impaction of canines, the severity of impaction is a significant predictor of ankylosis.²⁹ Though the literature is rather scarce concerning buccal impactions, many articles have been published investigating palatal impaction. In the studies included in this review, the initial vertical position,^{11,27,30,40,41} sector,^{27,29-31,41} and alpha angle^{27,29} were identified as predictors of the final treatment outcome.

Limitations of this review

This review is limited by the inclusion of retrospective studies and non-randomized trials. Moderate to high risk of bias was observed for all of these trials. In addition, considering both palatal and buccal impaction of canines could lead to improper interpretation of results when considering the relationship between initial position and treatment outcome. According to the GRADE approach, the level of certainty was graded as very low for all outcomes.²⁶

CONCLUSIONS

This review summarized the current evidence regarding the influence of the initial position of an impacted maxillary canine on treatment outcomes.

Implications for practice

Evidence from the reviewed studies suggest, albeit with a low level of certainty, that some impaction characteristics (e.g., angulation, the vertical dimension of impaction, sector) can be used as predictors of treatment duration, complexity, and outcome. This is important when clinicians are selecting the ideal treatment approach for the case, balancing the potential out-

come and expected difficulties. A palatally impacted maxillary canine in close proximity with the incisors (mesial sector) and/or a horizontal position (higher alpha angle) has a worse prognosis for successful outcome following interceptive treatment. This should be taken into account when estimating the probability of successful treatment.

When performing surgical exposure and orthodontic traction of palatally impacted maxillary canines, the orthodontist and surgeon should be aware that a close proximity with the incisors (mesial sector) and/or a high position (vertical position) can influence the periodontal outcome (e.g., periodontal pocket depth, gingival recession, and width of keratinized tissue), the treatment time, the number of visits, and the risk of developing ankylosis. In case of buccally impacted maxillary canines, a more horizontal position will worsen the periodontal outcome.

Implications for research

This systematic review has highlighted the scarcity of randomized prospective trials on the subject, underlining the need for further research. Further research on this issue should be based on larger samples and RCT designs to support the conclusions of the current literature.

However, as impacted maxillary canines are a rare anomaly and different aspects, such as the position of the impacted canine, patient age, and patient's demands and expectations, must be considered, it is practically impossible to randomize treatment. Therefore, high-quality observational studies are recommended.⁴⁷ Heterogeneity in outcome assessment in the reviewed studies suggests the need for standardized outcome measures in future clinical trials. The present study suggests using the following set of validated outcome measures at baseline and 1- and 2-year follow-up: Maxillary Canine Aesthetic Index (MCAI) for esthetic evaluation and periodontal evaluation, including periodontal pocket depth, gingival recession, and width of keratinized tissue on the impacted and contralateral canine quadrant, according to the protocol described by Smailiene et al.^{48,49} The proposed composite index needs verification with further implementation in future clinical trials.

FIGURES

Figure 1. Flow chart describing systematic research and study selection process.

SUPPLEMENTAL MATERIAL

Supplemental Table 1. Search strategy

Supplemental Table 2. Additional information of risk of bias for RCTs using the RoB 2.0 tool (n= 3 studies)

Supplemental Table 3. Additional information of risk of bias for non-RCTs using the ROBINS I tool for cohort studies (n= 14 studies)

Supplemental Table 4. Overview of outcomes reported by the included studies

Supplemental Figure 1. Overview of included studies investigating buccal impaction of canines and outcomes

Blue: retrospective study

Green: prospective study

[†] In the study population of Zuccatti et al.,⁴¹ the author did not distinguish between buccal and palatal impaction of the maxillary canines.

Supplemental Figure 2. Overview of included studies investigating palatal impaction of canines and outcomes

Blue: retrospective study

Green: prospective study

Orange: randomized controlled trial

[†] In the study population of Zuccatti et al.,⁴¹ the author did not distinguish between buccal and palatal impaction of the maxillary canines.

CONFLICT OF INTEREST

None to declare.

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Table 1. Criteria for including studies in this systematic review

Types of studies (S)
Randomized or non-randomized studies investigating the treatment of buccally, midcrestal, and/or palatally impacted maxillary canines.
Participant characteristics (P)
Subjects receiving treatment to correct unilateral and bilateral impacted canines. No restriction for age, malocclusion, or treatment strategy (surgical vs. non-surgical). Exclusion of subjects with craniofacial deformity/syndrome.
Intervention (I)
Interceptive treatment, such as removal of deciduous canine, headgear therapy, and/or rapid maxillary expansion treatment. Surgical exposure with or without orthodontic traction.
Comparison (C)
Various treatment strategies were reviewed and compared for treatment outcome of impacted maxillary canines considering the initial canine position.
Outcome (O)

<i>Primary outcome</i>	Success of treatment, defined as complete eruption of the canine crown sufficient to allow for orthodontic alignment, or improvement in position compared to the initial position.
<i>Secondary outcomes</i>	<ul style="list-style-type: none">• Esthetic outcome• Periodontal tissue outcome• Treatment time, number of treatment visits• Resorption of neighboring teeth• Ankylosis

Table 2. Summary of study characteristics and outcomes

Author (year)	Study design	Number of participants	Mean age $\pm$ SD, years [†]	Gender, M/F	Number of impacted canines	BP position			Methods used for diagnosis of canine position	Interventions	Study duration / observational period	Outcomes	Outcome measures		
						P	B	M C					2D Rx	3D Rx	Clinical
Arriola-Guillén et al. (2019) ²⁷	Retrospective cohort	45	16.16 $\pm$ 7.3	19/11	45	x	x	x	Ericson and Kurol classification; clinical examination	Surgical exposure and orthodontic traction	Not specified	Root resorption of incisors		x	x
Baccetti et al. (2011) ²⁸	RCT	117	9.5 - 13	46/71	178	x			Ericson and Kurol classification; clinical examination	RME, TPA, deciduous canine extraction	24-48 months	Canine eruption	x		x
Bazargani et al. (2014) ³²	RCT	24	11.6 $\pm$ 1.2	8/16	48	x			Ericson and Kurol classification; clinical examination	Deciduous canine extraction	18 months	Canine eruption	x		x
Caprioglio et al. (2019) ³¹	Retrospective cohort	271	13.8 $\pm$ 1.2	-	293	x			Ericson and Kurol classification; clinical examination	Surgical exposure and orthodontic traction	Debonding	Periodontal outcome in relationship with impaction sector	x		x
Crescini et al. (2007) ⁴²	Retrospective cohort	125	12.8 $\pm$ 5.2	31/94	125	x	x	x	Ericson and Kurol classification; clinical examination	Surgical exposure and orthodontic traction	Debonding	Periodontal outcome and canine eruption	x		x
Fleming et al. (2009) ³⁰	Retrospective cohort	36	14.81 $\pm$ 2.83	9/36	54	x			Own classification	Surgical exposure and orthodontic traction	Debonding	Predictive factors for treatment duration	x		x

Iancu Potrubacz et al. (2018) ³³	Retrospective cohort	22	15	10/12	30	x			Ericson and Kurol + Stivaros and Mandall classification; clinical examination	Surgical exposure and orthodontic traction	12 months after debonding	Canine eruption and predictive factors for treatment duration	x		x
Koutzoglou et al. (2012) ²⁹	Prospective cohort	118 ⁺	18.11 ± 7.88	46/72	150	x	x	x	Own classification	Space gaining, surgical exposure and orthodontic traction, RME	Debonding	Canine eruption and predictive factors for ankylosis	x		x
Lee et al. (2019) ³⁴	Retrospective cohort	54	12.85 ± 3.50	21/33	54		x		Ericson and Kurol classification; clinical examination	Surgical exposure and orthodontic traction	1 month after debonding	Canine eruption and periodontal outcome	x		x
Motamedi et al. (2009) ³⁵	Retrospective cohort	80	16	19/61	146	x			Ericson and Kurol classification, Lindauer modification; clinical examination	Surgical exposure and orthodontic traction	9-12 months	Canine eruption	x		x
Naoumova et al. (2014) ³⁶	RCT	67	11.4 ± 1	27/40	89	x			CBCT and own 3D classification; clinical examination	Deciduous canine extraction	12 months	Canine eruption		x	x
Power et al. (1993) ³⁷	Prospective cohort	39	11.2 ± 1.4	12/27	47	x			Own classification	Deciduous canine extraction	24 months	Canine eruption	x		x
Schubert et al. (2009) ³⁸	Retrospective cohort	57	12.4 ± 0.8	16/41	57	x			Ericson and Kurol classification; clinical examination	Surgical exposure and orthodontic traction	25.4 months	Canine eruption	x		x
Sigler et al. (2011) ³⁹	Prospective cohort	39	10.5 ± 0.5	15/24	65	x			Ericson and Kurol classification; clinical examination	RME, TPA, deciduous canine extraction	43 months ± 17 months	Canine eruption	x		x

Stewart et al. (2001) ¹¹	Retrospecti ve cohort	47	14.4 ± 2.2	17/30	65	x			Ericson and Kurol classi- fication; clinical exami- nation	Surgical expo- sure and or- thodontic trac- tion	Debonding	Canine eruption	x		x
Zasciurinskiene et al. (2008) ⁴⁰	Retrospecti ve cohort	32	18.2 ± 5.1	10/22	32	x			Ericson and Kurol classi- fication (modified); clin- ical examination	Surgical expo- sure and or- thodontic trac- tion	3 months after debonding	Periodontal outcome	x		x
Zuccati et al. (2006) ⁴¹	Retrospecti ve cohort	87	16.7	Not specifie d	108	x	x	x	Ericson and Kurol classi- fication (modified); clin- ical examination	Surgical expo- sure and or- thodontic trac- tion	Debonding	Canine eruption	x		x

†Data not reported in this format are given as stated in the reference.

BP: Buccopalatinal position

CBCT: Cone beam computed tomography

RCT: Randomized controlled trial

RMA: Rapid maxillary expansion

TPA: Transpalatal arch

Table 3. Summary of risk of bias for RCTs using the RoB 2.0 tool (n= 3 studies)

Reference	Domain 1	Domain 2a	Domain 2b	Domain 3	Domain 4	Domain 5	Conclusion
Baccetti et al. (2011) ²⁸	Some	High	High	Low	Low	Low	High
Bazargani et al. (2014) ³²	Low	Low	Low	Low	Low	Low	Low
Naoumova et al. (2014) ³⁶	Low	Low	Low	Low	Low	Low	Low

Domain 1: risk of bias arising from the randomization process

Domain 2a: risk of bias due to deviation from the intended intervention (effect of assignment to intervention)

Domain 2b: risk of bias due to deviation from the intended intervention (effect of adhering to intervention)

Domain 3: missing outcome data

Domain 4: risk of bias in measurement of outcome

Domain 5: risk of bias in selection of reported result

Table 4. Summary of risk of bias for non-RCTs using the ROBINS I tool for cohort studies (n= 14 studies)

Reference	Bias due to confounding	Bias in selection of participants	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of the reported result	Conclusion
Prospective studies								
Koutzoglou et al. (2012) ²⁹	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Sigler et al. (2011) ³⁹	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Retrospective studies								
Arriola-Guillén et al. (2019) ²⁷	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
Caprioglio et al. (2019) ³¹	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate

Crescini et al. (2007) 42	Moderate	Moderate	Moderate	Low	Moderate	Low	Low	Moderate
Fleming et al. (2009) 30	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Iancu Potrubacz et al. (2018) ³³	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Power et al. (1993) ³⁷	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Lee et al. (2019) ³⁴	Moderate	Moderate	Low	Low	Moderate	Low	Moderate	Moderate
Motamedi et al. (2009) ³⁵	Serious	Moderate	Low	Low	low	Low	Serious	Serious
Schubert et al. (2009) 38	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Stewart et al. (2001) 11	Moderate	Moderate	Moderate	Low	Low	Low	Low	Moderate
Zasciurinskiene et al. (2008) ⁴⁰	Serious	Moderate	Moderate	Low	Low	Low	Low	Serious

Zuccati et al. (2006) 41	Moderate	Moderate	Low	Low	Low	Low	Low	Moderate
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Table 5. GRADE summary of findings table of the relationship between the initial position of impacted maxillary canines and outcomes

Outcomes	No. of participants (studies)	Quality of the evidence (GRADE)	Impact	Assumed risk (i.e. control group or baseline risk)	Corresponding risk (treatment risk)	Risk Ratio	interpretation
Success of treatment	Interceptive treatments: 427 teeth (286 patients) Surgical exposure and orthodontic traction: 451 teeth (345 patients) (3 RCTs, 3	⊕⊕⊕⊕ very low	The initial position of the canine (high alpha angle and mesial sector) is a negative prognostic factor; two studies report no relationship between initial position and success of	35% ^{28,29,32,33,35,36,37,38,39}	73.3%	2.094	Treatment leads to a 209% increase in chance for succesfull eruption of the impacted canine.

	prospective studies, and 3 retrospective studies)		treatment				
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Periodontal tissue outcome	Surgical exposure and orthodontic traction: 504 teeth (482 patients) 4 retrospective studies	⊕⊖⊖⊖ very low	The initial position of the canine (high alpha angle and mesial sector) is a negative prognostic factor for the final periodontal outcome; one study reports no relationship between initial position and periodontal outcome	NA (not applicable) ^{31,34,40,42}	3.3%	NA	NA
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Treatment time, number of treatment visits	Surgical exposure and orthodontic traction: 284 teeth (227 patients) 4 retrospective studies	⊕⊖⊖⊖ very low	The initial position of the canine (mesial sector and a high vertical position) is a negative prognostic factor for the duration of treatment	24 visits ^{11,29,30,41} 22 months	33 visits 31 months	1.375 1.409	Impacted canines increase the number of treatment visits by 137.5% and increased the treatment time by 141%.
Resorption of neighboring teeth	Surgical exposure and orthodontic traction: 45 teeth (45 patients) 1 retrospective study	⊕⊖⊖⊖ very low	One study reports no relationship between initial position and root resorption of the incisors	37.5% ²⁷	100%	2.667	Surgical-orthodontical treatment of impacted canines results in an 267% increase in root

							resorption.
Ankylosis	Surgical exposure and orthodontic traction: 296 teeth (198 patients) 1 retrospective and 1 prospective study	⊕⊕⊕⊕ very low	Two studies report a relationship between initial position and the development of ankylosis	29.6% ^{11,29}	NA (not applicable)	NA	NA

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