The efficacy of rapid palatal expansion on the eruption of impacted maxillary canine: a systematic review

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Objective: The purpose of this study was to assess the current literature on the effectiveness of rapid palatal expansion (RPE) in assisting the spontaneous eruption of impacted maxillary canines.

Materials and methods: Four electronic databases were searched (Pubmed, Scopus, Web of Science, Embase) by applying appropriate Medical Subject Headings (MeSH). Two authors independently and systematically reviewed the literature. Randomised controlled trials (RCTs) and prospective controlled clinical trials (pCCTs) were identified and selected. The Cochrane Collaboration's risk of bias tool and the risk of bias in non-randomised studies of interventions (ROBINS-I) were used to assess the quality of the obtained articles. Spontaneous canine eruption was used as a primary outcome.

Results: Three RCTs and two pCCTs met the inclusion criteria. One study was assessed at a high risk of bias in the RCT group, while the remainder were at an unclear risk of bias. Both pCCTs were classified as a moderate risk of bias based on the ROBINS-I tool. The success rate of canine eruption following RPE, with or without additional treatment, ranged from 65.7 to 85.7%, which was statistically significantly different from the control group.

Conclusion: RPE appears to improve the position of displaced maxillary canines and increase the likelihood of spontaneous eruption. However, there is a shortage of high-quality evidence to conclude that RPE can be an effective treatment option for impacted maxillary canines.

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Introduction

Due to a long developmental and eruption pathway, a maxillary canine is a frequently ectopic and impacted tooth, second only to third molars. The impaction of a maxillary canine (IMC) affects 0.2–2.3% of orthodontic patients and the incidence of impaction is twice as high compared with the mandibular canine. Furthermore, the prevalence is twice as high in females compared with males and the ratio of palatal to buccal impaction is 8 to 1. This condition is also associated with other dental anomalies such as third molar agenesis and peg-shaped maxillary lateral incisors. The aetiology of impacted maxillary canines is controversial and considered multifactorial. Associated environmental factors include over-retained primary canines, anomalous permanent lateral incisors, disturbances in the permanent tooth eruption sequence, trauma, premature root closure, the rotation of the tooth buds, and localised pathological lesions (cysts, odontomas).
Disturbances in the gene transcription factors, MSX1 and PAX9, are considered to be involved in palatal canine displacement. These genes have also been linked to the agenesis of third molars.

The treatment options for impacted maxillary canines range from no treatment, to interceptive therapy, the extraction of deciduous canines to surgical exposure and orthodontic traction in the permanent dentition. The treatments offered in the permanent dentition are usually more complex and come with a higher risk of root resorption, ankylosis, and surgical morbidity. Therefore, an early diagnosis and interceptive management are considered preferred options to avoid complications.

The extraction of the primary canine is a promoted interceptive treatment for IMC. Previous studies demonstrated a significant improvement of a displaced canine after primary canine extraction. Baccetti et al. found that 65% of palatally displaced canines spontaneously erupted after the extraction of primary canines without additional treatment, while only 36% erupted in a matched control group. The difference was noted to be statistically and clinically significant. Naoumova reported that an interceptive extraction of a primary canine at 10–13 years of age resulted in a significantly greater likelihood of spontaneous eruption of an ectopic maxillary canine (69% in the extraction group compared to 39% in a control group). A previous systematic review by Almasoud concluded that the interceptive extraction of a primary canine significantly increased the success rate for the spontaneous eruption of IMC. Additionally, Leonardi et al. stated that using a cervical pull headgear in conjunction with the extraction of a primary canine raised the successful eruption incidence of the permanent canine to 80%.

McConnell et al. and Schindel et al. reported a correlation between palatally displaced canines and narrow maxillary arches. The finding prompted many clinicians to use maxillary expansion as an alternative treatment for IMC. Baccetti et al. conducted a randomised controlled trial (RCT) to investigate the effect of rapid palatal expansion (RPE) on the eruption of IMC. It was reported that 65.7% of the impacted canines erupted spontaneously following RPE therapy. To the best of current knowledge, there has not been a systematic review conducted to investigate the post-treatment effect of RPE on the spontaneous eruption of IMC. Therefore, the purpose of this study was to assess the effectiveness of RPE as an alternative treatment option in the management of impacted maxillary canines.

Materials and methods

Guideline

This systematic review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines for reporting. To date, there has not been a review registration to assess the efficacy of RPE on the eruption of IMC.

Data source and searches

The search keywords with appropriate Medical Subject Headings (MeSH) were based on PICOS criteria (participants, intervention, comparisons, outcomes, and study design) criteria.

- P = Impacted maxillary canines.
- I = Rapid palatal expansion, rapid maxillary expansion.
- C = No treatment.
- O = Canine eruption.

The citations of articles published in journals, dissertations, and conference proceedings were located by searching four major databases (PubMed, Web of Science, Scopus, and EMBASE). The four databases were searched for a year until April 2021. The searches were appropriately customised to each database (Table I). A manual search for potentially relevant articles was also performed to identify additional studies that could have been previously overlooked.

Study selection and data extraction

A calibration of inter-examiner reproducibility was carried out by two reviewers (N.P. and T.P.). Both independently screened titles, abstracts, and full-text reports according to the inclusion and exclusion criteria shown in Table II. Both authors came to a consensus regarding the studies which met the inclusion and exclusion criteria. Inter-reviewer agreement regarding study eligibility was 98.52% (134/136). Any disagreement was resolved
Table 1. The electronic databases searched, the search strategies used, and the corresponding results

| Electronic databases               | Search strategy used                                                                                           | Extend of search | Hits |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------|------------------|------|
| Pubmed searched via PubMed on 8th April 2021 http://www.ncbi.nlm.nih.gov/pubmed/ | (((canine OR canines)) AND (impaction OR embedded OR displaced OR impacted OR displacement)) AND (RPE OR rapid palatal expansion OR RME OR rapid maxillary expansion OR maxillary expansion OR palatal expansion) | All fields       | 90   |
| Web of Science on 8th April 2021 https://webofknowledge.com/ | (canine OR canines) AND ALL FIELDS: (impaction OR embedded OR displaced OR impacted OR displacement) AND ALL FIELDS: (RPE OR rapid palatal expansion OR RME OR rapid maxillary expansion OR maxillary expansion OR palatal expansion) | All fields       | 64   |
| Scopus on 8th April 2021 http://www.scopus.com/ | [TITLE-ABS-KEY (canine OR canines) AND TITLE-ABS-KEY (impaction OR embedded OR displaced OR impacted OR displacement)] AND TITLE-ABS-KEY [rpe OR rapid AND palatal AND expansion OR rme OR rapid AND maxillary AND expansion OR maxillary AND expansion OR palatal AND expansion] | All fields       | 21   |
| EMBASE on 8th April 2021 https://www.embase.com | (canine OR canines OR cuspid) AND (impaction OR impacted OR displaced OR displacement) AND (rpe OR rme OR ‘rapid maxillary expansion’ OR ‘rapid palatal expansion’) | All fields       | 21   |
by consultation with a third reviewer (S.P.) until a final consensus was reached. The titles, abstracts, and when necessary, the study manuscripts were reviewed to establish whether all inclusion criteria were met. A data extraction spreadsheet was developed to record the extracted data from eligible studies which included the authors and the publication year, the study design, the characteristics of the participants, the criteria for identifying the impacted canine, interventions, the criteria for successful treatment, follow-up duration, and the outcome.

### Quality assessment

To assess the quality of the studies, the Oxford Centre for Evidence-Based Medicine (OCEBM) criteria were used.\(^{19}\)

### Risk of bias assessment

The risk of bias for RCTs was assessed using the Cochrane Collaboration’s risk of bias tool.\(^{20}\) The following domains were considered: 1. random sequence generation, 2. allocation sequence concealment, 3. blinding of outcome assessment, 4. incomplete outcome data, 5. selective outcome reporting, and 6. other sources of bias. The risk of bias for each domain was judged as ‘low risk’, ‘high risk’, or ‘unclear risk’ for all included trials. Each RCT was assigned an overall risk of bias as ‘low risk’ (low for all key domains), ‘high risk’ (high for \(\geq1\) key domain), or ‘unclear risk’ (unclear for all key domains). For non-RCTs, the risk of bias was assessed using the risk of bias for non-randomised studies of intervention (ROBINS-I).\(^{21}\) In general, the following domains were assessed: bias due to confounding, selection bias, bias in classification of intervention, bias due to missing data, bias in the measurement of outcomes, and selective reporting. Each domain was scored as a low, moderate, serious, or a critical risk of bias. If there was no clear indication that the study was at serious or critical risk of bias, and there was a lack of information in one or more domains, the study was judged as having ‘no information’. The overall risk of bias of the study was scored as serious if a serious risk of bias was scored in at least one domain. If not, the study received a moderate risk of bias in the overall evaluation. If all study evaluations were classified as a low risk of bias, then a low risk was assigned as the final study evaluation.

### Results

One hundred and ninety-six articles were identified after the initial search of the four electronic databases. No additional studies were found following the manual search. After the exclusion of duplicates, 136 articles remained. One hundred and twenty-six articles were excluded after abstract screening, leaving ten full-text articles for further assessment. Five additional articles were excluded because one article was a review, three were retrospective studies, and the remaining article was published in a non-English language. Finally, five articles were assessed for the systematic review (Figure 1).

The characteristics of the five included studies are summarised in Table III and the quality assessment of the five studies is shown in Table IV. Three studies were RCTs\(^{17,22,23}\) and the remaining were pCCTs.\(^{24,25}\) One RCT was judged as having a high risk of bias while the others had an unclear risk of bias. Both pCCT studies were assessed as having a moderate risk of bias.

The definition of an IMC was different between the included studies. Three investigations\(^{22,23,25}\) used the method described by Ericson and Kurol,\(^{26}\) which measured the angulation and displacement distance of the canine from a panoramic radiograph. One study\(^{24}\) used the Ericson and Kurol method later modified and described by Lindauer et al.\(^{27}\) Lastly, Baccetti et al.\(^{17}\) used a posteroanterior (PA) cephalogram to assess canine position as reported by Sambatoro et al.\(^{28}\) Four studies\(^{17,22,23,25}\) compared RPE with no treatment (control group). Only Barros

### Table II. Inclusion and exclusion criteria.

| Inclusion criteria | Exclusion criteria |
|--------------------|-------------------|
| 1. Randomized controlled trials and prospective clinical controlled trails | 1. Review article, retrospective studies, case report, personal opinion, systematic review |
| 2. Human studies | 2. Animal studies, In vitro studies |
| 3. Published in English only | 3. Non-English articles |
| 4. Clear study design | |

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et al.\textsuperscript{24} used no treatment and normally erupting canine groups as controls. The use of cervical headgear and the extraction of the primary canine and transpalatal arch therapy (TPA) were included as additional interventions in three studies.\textsuperscript{22,23,25} The participants dental development was in the mixed to early permanent dentition with a mean age ranging from 8 to 12 years.

Bacetti et al.,\textsuperscript{17} Armi et al.,\textsuperscript{22} and Sigler et al.\textsuperscript{25} used banded and bonded RPE when reporting RPE protocols. Expansion activation was a quarter turn per day (0.25 mm) until 7 mm of expansion was reached. Bacetti et al.\textsuperscript{23} used a banded RPE and expanded the maxilla until the palatal cusps of the upper posterior teeth were in contact with the buccal cusps of the lower posterior teeth. However, there was no detail regarding the frequency of screw activation. Barros et al.\textsuperscript{24} also utilised a banded RPE which was activated by two quarter turns per day (0.5 mm) until overcorrection was achieved.

All of the studies evaluated the position of the maxillary impacted canines by a clinical examination, panoramic radiograph, and a lateral cephalogram. A postero-anterior (PA) cephalogram\textsuperscript{17} and dental cast measurements\textsuperscript{17,22,25} were also required as additional evaluation tools in three studies. One study was performed during the early mixed dentition (7.6–9.6 years),\textsuperscript{17} whereas the remaining studies were conducted during the late mixed dentition or early permanent dentition.\textsuperscript{22–25} The shortest follow-up period was 12 months,\textsuperscript{24} while the longest follow-up period was up to 4.4 years.\textsuperscript{17}
Table III: Summary of characteristics of the included studies.

| Author         | Study design | Criteria for impacted canine | Intervention | Participant gender and age | Method/measurement | Criteria for successful treatment | Follow-up duration and dropout | Outcome |
|----------------|--------------|-------------------------------|--------------|-----------------------------|--------------------|-----------------------------------|--------------------------------|---------|
| Armi (2011)    | RCT          | PDCs:                         | 3 groups     | Total 60 subjects           | Panoramic radiographs, lateral cephalogram and measurement on dental cast | Full eruption of the tooth which permitting bracket positioning for final arch alignment | All groups: 18 months and 4 dropouts | Successful eruption of the permanent canine were 82.3% in the HG group and 85.7% in the RPE/HG group significantly greater than those of the CG. No statistically significant difference was found for the prevalence of successful subjects between the HG and RME/HG groups (P<0.001) |
|                |              | Intraosseous palatal position | 1. HG group  | 1. HG group: 17 subjects (with 25 PDCs) M/F = 9/8, 11.9 years |                    |                                  |                                |         |
| Bacetti (2009) | RCT          | PDCs: diagnosed from PA       | 2 groups     | Total 54 subjects           | PA cephalograms, panoramic radiographs and measurement on dental cast | Full eruption of maxillary canine | 1. TG: 4.4 years, 3 dropouts | The rates for successful eruption of the maxillary canines were 65.7% in the RPE group and 13.6% in the CG. The difference is statistically significant (P<0.001) |
|                |              | radiographs according to the method by Sambataro et al. | 1. RPE group | 1. RPE group: 32 subjects (with 42 PDCs) M/F = 12/20, 8.8 years ± 9 months |                    |                                  |                                |         |
|                |              |                               | 2. CG        | 2. CG: 22 subjects (with 31 PDCs) M/F = 8/14, 8.4 years ± 1 year |                    |                                  |                                |         |


### Bacetti (2011) RCT

| PDCs: diagnosed from panoramic radiographs & followed by TPA therapy, and extraction of deciduous canines | Clinical examination, panoramic and lateral cephalogram |
|-----------|---------------------------------------------------|
| 4 groups  | Total 117 subjects                               |
| 1. RPE/TPA/EC group: 40 subjects (with 66 PDCs) M/F = 15/25, 10y5m ± 10m | The full eruption of the canine, thus permitting bracket positioning for final arch alignment with an early permanent dentition and a postpubertal stage of cervical vertebral maturation (CS 5 or CS 6) |
| 2. TPA/EC group: 24 subjects (with 36 PDCs) M/F = 10/14, 10y9m ± 11m |
| 3. EC group: 24 subjects (with 34 PDCs) M/F = 10/14, 11y1m ± 11m |
| 4. CG: 42 PDCs) M/F = 11/18, 10y5m ± 10m |

#### Barros (2018) pCCT

| Ectopic eruption of at least 1 maxillary canine overlapping sector II, III, or IV of the lateral incisor roots, diagnosed from panoramic radiographs, according to the method of Lindauer et al. | Panoramic radiographs |
|----------------------------------------------------------|----------------------|
| 3 groups                                                | All groups: 1 year |
| 1. ECC: ectopically erupting canines (with 49 ectopically erupting canines) M/F = 13/19, 9.53 years ± 1.10 year | The ECC and NEC groups had greater angular, vertical, and horizontal canine improvements. RME had a positive impact on the eruption path of both the ectopically and normally erupting canines |
| 2. NEC: normally erupting canines (with 9 expanded subjects from the ECC group with unilateral normally erupting canines) M/F = 8/10, 9.25 years ± 1.00 year |
| 3. CG: 36 subjects (with 54 normally erupting canines) M/F = 17/19, 9.03 years ± 0.72 year |

#### Bacetti (2011) RCT

- **RCT**
- **PDCs:** diagnosed from panoramic radiographs and followed by TPA therapy, and extraction of deciduous canines
- **Groups:**
  - **RPE/TPA/EC group:** 40 subjects (66 PDCs) M/F = 15/25, 10y5m ± 10m
  - **TPA/EC group:** 24 subjects (36 PDCs) M/F = 10/14, 10y9m ± 11m
  - **EC group:** 24 subjects (34 PDCs) M/F = 10/14, 11y1m ± 11m
  - **CG:** 42 subjects (PDCs) M/F = 11/18, 10y5m ± 10m

#### Barros (2018) pCCT

- **pCCT**
- **Ectopic eruption of at least 1 maxillary canine overlapping sector II, III, or IV of the lateral incisor roots, diagnosed from panoramic radiographs, according to the method of Lindauer et al.**
- **Groups:**
  - **ECC group:** 32 subjects (49 ectopically erupting canines) M/F = 13/19, 9.53 years ± 1.10 year
  - **NEC group:** 18 subjects (27 normally erupting canines) M/F = 8/10, 9.25 years ± 1.00 year
  - **CG:** 36 subjects (54 normally erupting canines) M/F = 17/19, 9.03 years ± 0.72 year

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**Note:** The rate of successful eruption of the maxillary canines was 80% for the RME/TPA/EC group, 79.2% for the TPA/EC group, 62.5% for the EC group, and 27.6% in the CG. There are statistically significant differences between all the groups (P<0.05), with the exception of the RME/TPA/EC group vs. TPA/EC group.
The criteria for a successful study outcome varied. Four studies\textsuperscript{17,22,23,25} used the full eruption of the canine on clinical examination, while Barros et al.\textsuperscript{24} measured an improvement in the angulation and the distance of canine displacement on a panoramic radiograph.

A success rate for canine eruption following RPE alone was reported to be 65.7%, compared with 13.6% in the control group.\textsuperscript{17} The second study describing RPE alone as an intervention demonstrated a significant improvement in IMC position but did not report the rate of spontaneous canine eruption.\textsuperscript{24} Higher success rates were also reported when RPE was used in combination with headgear (85.7%)\textsuperscript{22} and the extraction of a primary canine along with TPA placement (80%).\textsuperscript{23,25} However, the success rate for RPE in association with headgear was not significantly different from that of RPE alone.\textsuperscript{22} Similarly, the addition of RPE to a protocol that already included the extraction of the primary canine and a TPA did not significantly increase the success of permanent canine eruption.\textsuperscript{25}

**Discussion**

The impaction of a maxillary canine is a relatively common eruption problem. If left unmanaged, the complexity of subsequent orthodontic treatment increases considerably. A number of treatment strategies have been advocated to encourage the spontaneous eruption of an IMC. Primary canine extraction\textsuperscript{10,29} and RPE are two of the favoured interceptive treatments.\textsuperscript{17,22–25} While there has been a published systematic review on the efficacy of primary canine extraction,\textsuperscript{13} a systematic review of the effects of RPE has not been conducted. Given the usual enthusiasm bias in a newly introduced treatment and methodological differences in study design, a systematic review was needed to determine if RPE would be an effective interceptive strategy.
The purpose of the present systematic review was to qualitatively assess the currently available publications on the efficacy of RPE to assist the spontaneous eruption of an impacted maxillary canine. There were a total of 376 patients who presented with 494 maxillary impacted canines described in the five included studies. The present review found that the success rate of canine eruption following RPE, with or without additional appliances, ranged between 65.7 and 85.7%. The success appeared to be higher when compared to the extraction of primary canines alone (50–69%).

In three studies, RPE was used in conjunction with other orthodontic treatment and the success rate of the additional protocols was significantly higher compared to the clinical control groups. However, a combination of RPE and headgear did not increase the likelihood of successful eruption of IMC when compared to a protocol using RPE alone. Similarly, the addition of RPE to a protocol incorporating the extraction of primary canines and a TPA did not significantly increase the successful eruption of IMC when compared to a protocol involving the extraction of primary canine and a TPA only. The current review therefore suggests that the extraction of a primary canine could be a viable first-line therapy option for IMC due to its less invasive nature and a favourable success rate. Further treatment would depend on other presenting orthodontic problems. A RPE could be considered if there was no improvement of IMC position after primary canine extraction and if a transverse maxillary deficiency or mild-to-moderate arch length discrepancy was present. When space maintenance is required, a TPA could be placed and if molar distalisation or additional anchorage is needed, a headgear could be employed. In addition to the likely success rate of each protocol and in a consideration of other orthodontic problems, cost-effectiveness and compliance should be taken into account when formulating a comprehensive orthodontic treatment plan.

A higher success rate of IMC therapy in younger children may be attributed to an early diagnosis of impaction. Therefore, establishing an early diagnosis of IMC is crucial to increase the chance of spontaneous eruption. Studies have reported that the prognosis of successful eruption of IMC worsens with increasing age. Consequently, diagnosis should be performed in the mixed dentition well before the eruption of maxillary canines (mean eruption age = 12.3 and 13.1 years for females and males, respectively). A panoramic radiograph was the most popular evaluation method identified in this systematic review as four of the included studies used this radiograph as the primary diagnostic tool. Sajnani reported that the detection of an impacted maxillary canine from a panoramic radiograph could be made as early as 8 years of age. The popularity of the panoramic radiograph as a diagnostic aid was likely due to its common use in a routine dental exam. The radiograph also readily displays canine displacement in relation to surrounding structures. Only one study utilised a PA cephalogram to diagnose patients aged between 8 and 9 years, while Sambataro et al. described the use of a PA cephalogram as an early diagnostic tool. An equation was created based on permanent canine position on the PA cephalogram to calculate an individual score that predicted a canine impaction as early as 8 years of age with a probability of error of 5%.

The follow-up period of the included studies ranged from 1 to 5 years. This variation was a result of differences in re-evaluation criteria. Two studies used an arbitrary time point, while the remaining studies employed an objective post-pubertal stage of cervical vertebral maturation of CS4 to CS6 to re-assess. According to Baccetti et al., the prevalence of spontaneous maxillary canine eruption at CS4 is less than 6% and 0% after CS5.

Varying treatment protocols and appliances were employed in the included studies. Only two studies used RPE alone without any additional appliance, and one did not report the success rate of canine eruption. Headgear and a TPA were utilised in addition to RPE in three studies. In addition, the criteria for a successful outcome were different between the studies. As a result, a meta-analysis could not be performed due to the methodological heterogeneity and non-comparability of the original results.

The major limitation of the present systematic review is the small number of included studies. All were of inadequate quality and quantity to robustly conclude that RPE could be an effective interceptive therapy for IMC. The studies also lacked methodological rigor and consistency between the treatment protocols and outcome measurements. This is reflected by the qualitative rather than quantitative assessment of all of the included studies. Additionally, four of the five
studies reported including only subjects of Caucasian ancestry. Barros et al.\textsuperscript{24} did not specify the race nor ethnicity of their sample but conducted the study in Brazil. This may limit the general nature of the findings to individuals from other parts of the world. A study\textsuperscript{35} published in a non-English language was excluded due to a lack of resources to translate the manuscript with accuracy. The English abstract of the article\textsuperscript{35} reported only an improved IMC position after RPE instead of a success rate for spontaneous eruption. Therefore, it is considered that exclusion of the article did not have a significant impact on the overall results of the present review. A shortage of high-quality studies is evident and more rigorously designed clinical investigations to confirm the effectiveness of RPE, as an alternative therapy for IMC involving different population groups, are needed.

Conclusion
The present systematic review suggests that RPE appears to improve the position of impacted maxillary canines and increase the likelihood of spontaneous eruption during the mixed and early permanent dentition. However, there is a lack of high-quality evidence to conclude that RPE alone can be used to increase the spontaneity and successful eruption of impacted maxillary canines. More rigorously designed studies are needed to substantiate the effectiveness of RPE as an alternative treatment for IMC across the different populations.

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Conflict of Interest
The authors declare that there is no conflict of interest.

References
1. Litsas G, Acar A. A review of early displaced maxillary canines: etiology, diagnosis and interceptive treatment. Open Dent J 2011;5:39–47.
2. Peck S, Peck L, Kataja M. The palatally displaced canine as a dental anomaly of genetic origin. Angle Orthod 1994;64:249–56.
3. Manne R, Gandikota C, Juvvadi SR, Ramas HRM, Anche S. Impacted canines: etiology, diagnosis, and orthodontic management. J Pharm Bioallied Sci 2012;4(Suppl 2): S234–S8.
4. Herrera-Atoche JR, Agüayo-de-Pau MDR, Escoffé-Ramírez M, Aguilar-Ayala FJ, Carrillo-Avila BA, Rejón-Peraza ME. Impacted maxillary canine prevalence and its association with other dental anomalies in a Mexican population. Int J Dent 2017;2017:7326061.
5. Peck S, Peck L, Kataja M. Prevalence of tooth agenesis and peg-shaped maxillary lateral incisor associated with palatally displaced canine (PDC) anomaly. Am J Orthod Dentofacial Orthop 1996;110:441–3.
6. Bishara SE, Ortho D. Impacted maxillary canines: a review. Am J Orthod Dentofacial Orthop 1992;101:139–71.
7. Peck S, Peck L, Kataja M. Concomitant occurrence of canine malposition and tooth agenesis: evidence of orofacial genetic fields. Am J Orthod Dentofacial Orthop 2002;122:657–60.
8. Nisha S, Shashikumar P, Chandra S. Maxillary canine impaction to treat or not. Indian J Multidiscip Dent 2017;7:124–8.
9. Sajnani AK, King NM. Complications associated with the occurrence and treatment of impacted maxillary canines. Singapore Dent J 2014;35:53–7.
10. Ericson S, Kuroj E. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. Eur J Orthod 1988;10:283–95.
11. Baccetti T, Leonard M, Armi P. A randomized clinical study of two interceptive approaches to palatally displaced canines. Eur J Orthod 2008;30:381–5.
12. Naoumova J. Interceptive treatment of palatally displaced canines. Swed Dent J Suppl 2014;234:7–118.
13. Almasoud NN. Extraction of primary canines for interceptive orthodontic treatment of palatally displaced permanent canines: a systematic review. Angle Orthod 2017;87:878–85.
14. Leonard M, Armi P, Franchi L, Baccetti T. Two interceptive approaches to palatally displaced canines: a prospective longitudinal study. Angle Orthod 2004;74:581–6.
15. McConnell TL, Hoffman DL, Forbes DP, Janzen EK, Weintraub NH. Maxillary canine impaction in patients with transverse maxillary deficiency. ASDC J Dent Child 1996;63:190–5.
16. Schindel RH, Duffy SL. Maxillary transverse discrepancies and potentially impacted maxillary canines in mixed-dentition patients. Angle Orthod 2007;77:430–5.
17. Baccetti T, Mucedero M, Leonard M, Cozza P. Interceptive treatment of palatal impaction of maxillary canines with rapid maxillary expansion: a randomized clinical trial. Am J Orthod Dentofacial Orthop 2009;136:657–61.
18. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009;339:b2535.
19. CoE-B M. Oxford Centre for Evidence based Medicine-Levels of Evidence. Centre for Evidence-Based Medicine (CEBM), 2009.
20. Higgins JPT, Altman DG, Gotzsche PC, Juni P, Moher D, Oxman AD. The Cochrane Collaboration’s tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.
21. Sterne JAC, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355:i4919.
22. Armi P, Cozza P, Baccetti T. Effect of RME and headgear treatment on the eruption of palatally displaced canines: a randomized clinical study. Angle Orthod 2011;81:370–4.
23. Baccetti T, Sigler LM, McNamara JA Jr. An RCT on treatment of palatally displaced canines with RME and/or a transpalatal arch. Eur J Orthod 2011;33:601–7.
24. Barros SE, Hoffelder L, Araújo F, Janson G, Chiqueto K, Ferreira E. Short-term impact of rapid maxillary expansion on ectopically and normally erupting canines. Am J Orthod Dentofacial Orthop 2018;154:524–34.
25. Sigler LM, Baccetti T, McNamara JA. Effect of rapid maxillary expansion and transpalatal arch treatment associated with deciduous canine extraction on the eruption of palatally displaced canines: a 2-center prospective study. Am J Orthod Dentofacial Orthop 2011;139:e235–44.
26. Ericson S, Kurol J. Radiographic examination of ectopically erupting maxillary canines. Am J Orthod Dentofacial Orthop 1987;91:483–92.
27. Lindauer SJ, Rubenstein LK, Hang WM, Andersen WC, Isaacson RJ. Canine impaction identified early with panoramic radiographs. J Am Dent Assoc 1992;123:91–2.
28. Sambataro S, Baccetti T, Franchi L, Antonini F. Early predictive variables for upper canine impaction as derived from posteroanterior cephalograms. Angle Orthod 2005;75:28–34.
29. Power SM, Short MB. An investigation into the response of palatally displaced canines to the removal of deciduous canines and an assessment of factors contributing to favourable eruption. Br J Orthod 1993;20:215–23.
30. Becker A, Chaushu S. Success rate and duration of orthodontic treatment for adult patients with palatally impacted maxillary canines. Am J Orthod Dentofacial Orthop 2003;124:509–14.
31. Zhang J, Zhang WJ, Wang XX, Xu JG, Huang Y. Orthodontic traction of impacted maxillary canine: a comparison of different ages. Shanghai J Stomatol 2006;15:130–2.
32. Hurme VO. Ranges of normalcy in the eruption of permanent teeth. J Dent Chil 1949;16:11–5.
33. Sajnani AK, King NM. Early prediction of maxillary canine impaction from posteroanterior cephalographs. Am J Orthod Dentofacial Orthop 2012;142:45–51.
34. Baccetti T, Franchi L, De Lisa S, Giuntini V. Eruption of the maxillary canines in relation to skeletal maturity. Am J Orthod Dentofacial Orthop 2008;133:746–51.
35. Wolff J, Rinkenbach R, Grollemund B, Wagner D. Effects of maxillary disjunction on canine impaction in patients presenting a maxillary transverse skeletal deficiency. Orthod Fr 2017;88:243–50.