What’s in a canine?

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WHAT'S IN A CANINE?

DEVELOPMENT OF CLINICAL GUIDANCE NOTES FOR AUTOGENOUS TRANSPLANTATION OF MAXILLARY CANINES

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Humor en geduld zijn de kamelen
waarmee je door alle woestijnen kunt gaan.

Phil Bosmans

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three- dimensional
AMCRI	Autotransplanted Maxillary Canine Radiographic Index
BP	Buccopalatinal Position
CBCT	Cone Beam Computed Tomography
CEJ	Cemento Enamel Junction
CI	Confidence Interval
COS	Core Outcome Set
GRADE	Grading of Recommendations, Assessment, Development, and Evaluation
ICC	Intraclass Correlation Coefficient
IQR	Interquartile Range
LL	Lower Limit
MCAI	Maxillary Canine Aesthetic Index
MD	Mean Difference
MGJ	Muco Gingival Junction
MINORS	Methodological Index for Non-Randomized Studies
NS	Not Significant
PD	Pocket Depth
PDC	Palatally Displaced Canine
PDL	Periodontal Ligament
PICO	Patient/Population, Intervention, Comparison and Outcomes
PR	Panoramic Radiographs
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomized Controlled Trial
RMA	Rapid Maxillary Expansion
SS	Statistically Significant
TPA	Transpalatal Arch
UL	Upper Limit
VAS	Visual Analogue Scale

PREFACE

This doctoral thesis is based on the following research papers:

CHAPTER 1:

Grisar K, Vanpoecke J, Raes M, Albdour EA, Willems G, Politis C, Jacobs R. Development and validation of the autotransplanted maxillary canine radiological index. Clin Exp Dent Res. 2018 Aug 17;4(5):167-173. doi: 10.1002/cre2.125. PMID: 30386638; PMCID: PMC6203832.

CHAPTER 2:

Grisar K, Claeys G, Raes M, Albdour EA, Willems G, Politis C, Jacobs R. Development and validation of the Maxillary Canine Aesthetic Index. Clin Exp Dent Res. 2018 Oct 26;4(5):216-223. doi: 10.1002/cre2.133. PMID: 30386643; PMCID: PMC6203826.

CHAPTER 3:

Grisar K, Denoiseux B, Martin C, Hoppenreijs T, Calburean F, Politis C, Jacobs R. How to treat critically impacted maxillary canines: Clinical versus scientific evidence. J Stomatol Oral Maxillofac Surg. 2021 Apr 17:S2468-7855(21)00080-X. doi: 10.1016/j.jormas.2021.03.013. Epub ahead of print. PMID: 33862266.

CHAPTER 4:

Grisar K, Piccart F, Al-Rimawi AS, Basso I, Politis C, Jacobs R. Three-dimensional position of impacted maxillary canines: Prevalence, associated pathology and introduction to a new classification system. Clin Exp Dent Res. 2019 Feb;5(1):19-25. doi: 10.1002/cre2.151. Epub 2018 Dec 19. PMID: 31943949.

CHAPTER 5:

Grisar K, Luyten J, Preda F, Martin C, Hoppenreijs T, Politis C, Jacobs R. Interventions for impacted maxillary canines: A systematic review of the relationship between initial canine position and treatment outcome. Orthod Craniofac Res. 2020 Aug 15. doi: 10.1111/ocr.12423. Epub ahead of print. PMID: 32799419.

CHAPTER 6:

Grisar K, Fransen J, Smeets M, Hoppenreijs T, Ghaeminia H, Politis C, Jacobs R. Surgically assisted orthodontic alignment of impacted maxillary canines: A retrospective analysis of functional and esthetic outcomes and risk factors for failure. Am J Orthod Dentofacial Orthop. 2021 Mar 27:S0889-5406(21)00172-4. doi: 10.1016/j.ajodo.2020.12.019. Epub ahead of print. PMID: 33785231.

CHAPTER 7:

Grisar K, Chaabouni D, Romero LPG, Vandendriessche T, Politis C, Jacobs R. Autogenous transalveolar transplantation of maxillary canines: a systematic review and meta-analysis. Eur J Orthod. 2018 Nov 30;40(6):608-616. doi: 10.1093/ejo/cjy026. PMID: 29860316; PMCID: PMC6265659.

CHAPTER 8:

Grisar K, Nys M, The V, Vrielinck L, Schepers S, Jacobs R, Politis C. Long-term outcome of autogenously transplanted maxillary canines. Clin Exp Dent Res. 2019 Jan 17;5(1):67-75. doi: 10.1002/cre2.159. PMID: 30847235; PMCID: PMC6392819.

CHAPTER 9:

Grisar K, Smeets M, Ezeldeen M, Shaheen E, De Kock L, Politis C, Jacobs R. Survival and success of autotransplanted impacted maxillary canines during short-term follow-up: A prospective case-control study. Orthod Craniofac Res. 2020 Aug 10. doi: 10.1111/ocr.12422. Epub ahead of print. PMID: 32777135.

INTRODUCTION AND AIMS

1.1 GENERAL INTRODUCTION

In 1951, Lappin stated that “one of the most perplexing problems the dental practitioner has to face is the proper management of the impacted maxillary canine”.[1]

There is a great amount of papers describing diagnostic and treatment approaches, which help to inform clinicians on the many scientific developments in the field (new orthodontic and surgical techniques, materials and appliances, imaging tools such as Cone Beam Computed Tomography (CBCT) scans). The vast majority of patients diagnosed with impacted maxillary canines will experience a smooth trajectory from initial diagnosis to treatment and end up with a successful outcome. For these patients there is a lengthened treatment time, but in the long run no complications are expected.[2-4]

However, when analyzing the multiple scientific publications concerning this topic, it is striking how a subgroup of patients with an impacted maxillary canine is excluded from the study populations. Often these studies employ strict inclusion criteria, eliminating patients of an older age or patients in which the canine is in a complex initial position.[2-4] Also, when discussing the topic of maxillary canine impaction with fellow surgeons and orthodontists, there tends to be agreement that the vast majority of cases can be treated without any problems, but equally that there is an occasional patient who cannot be treated successfully or only after a complex process.

When confronted with these findings, the idea for this dissertation was to define and investigate this subgroup of ‘non-standard’ or ‘critical’ maxillary canine impactions.

1.2 MAXILLARY CANINE IMPACTION

Permanent maxillary canines are the second most frequently impacted teeth with an incidence ranging from 0.9 to 2.2 percent, the most frequent being wisdom teeth.[5]

Impaction is defined as 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.[5,6] Impacted maxillary canines may present in a wide three-dimensional range of variations with a corresponding difference in treatment difficulty.[5-8] The process of eruption of the permanent canines, leading to their final positioning in the oral cavity, is complex; and canines have the longest eruption trajectory of all the permanent teeth.[1]

There are two theories that attempt to explain the phenomenon of the impacted canine: the guidance theory and the genetic theory.[6,9-11]

The **guidance theory** suggests that the canine erupts along the root of the lateral incisor, which serves as a guide. In case of impaction, it is due to local predisposing factors such as congenitally missing or malformed lateral incisors, supernumerary teeth, odontomas, tooth transposition and other mechanical determinants, all of which interfere with the eruption path of the canine.[11]

The second theory, **the genetic theory**, is based on the observation that in case of a palatal impacted canine, there are often associated tooth anomalies such as agenesis or peg-shaped lateral incisors, hypoplastic enamel, infra-occluded primary molars and aplastic second bicuspids. An inadequate arch space and a vertical developmental position are often associated with buccal canine impactions.[10] It has been postulated that some genetically modulated mechanisms underlie the linkage between coincidental dental abnormalities, as evidenced by their frequency of association.[10,12]

Maxillary canines support the overall dentition and contribute to posterior disocclusion during lateral movements.[13] When considering facial and smile aesthetics, multiple authors have reported the importance of the maxillary canines. This is due to their position at the corners of the dental arch, in a transition zone between the anterior and posterior teeth. Here they form the canine eminence, supporting the alar base and the upper lip.

Besides aesthetic and functional problems, untreated partially erupted or impacted canines may result in various complications such as 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 these.[14,15] Therefore, a definitive diagnosis of an impacted canine is often directly followed by further treatment and while the decision to treat impacted canines is clearly backed up by this tooth's important role in a healthy dentition, therapeutic conduct is neither obvious to choose nor predictable enough to guarantee a favorable outcome.

Initially, diagnosis of impacted maxillary canines is clinical, with attention to asymmetry in the exfoliation and eruption between the right side and left side of the maxilla, distal displacement or distal inclination of the lateral incisor (ugly duckling), lateral incisor mobility, retention of the primary canine in the dental arch beyond the age of 14 to 15, local palatal swelling or absence of the typical vestibular prominence.[5,10-15] Patients with missing lateral incisors, prolonged retention of a deciduous canine, or peg-shaped upper lateral incisors need further investigation.[16]

Further radiographic analysis with panoramic radiographs (PR) and Cone Beam Computed Tomography (CBCT) is essential for the assessment of canine position and to detect canine root malformations, local obstructing pathology or incisor root resorption.

Many classification systems are available to assess the level and severity of maxillary canine impaction. Ericson and Kurol introduced the sector classification, which is based on the location of the canine tip in relation to the roots of the lateral and central incisor.[7] Additionally, angular (angle measured between the long axis of the impacted canine and the midline) and linear (distance between the canine cusp tip and the occlusal plane) measurements are used to describe the position of the impacted canine (Figure 1).

Alternatively, Stivaros et al described the vertical position of the impacted maxillary canines in relation to the adjacent incisor (cemento-enamel junction, middle of the root and apex of the adjacent incisor).[17]

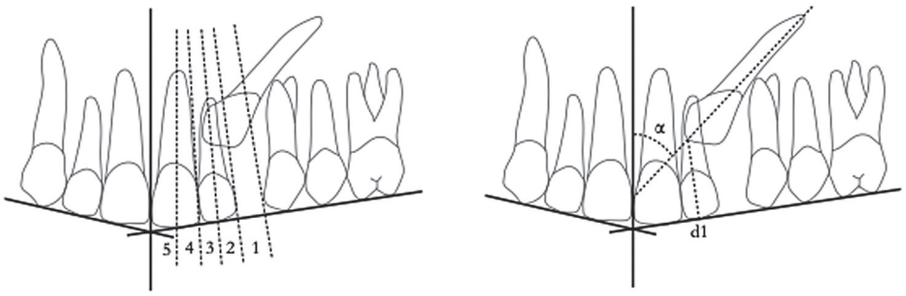

Figure 1. *a) Distribution of the permanent maxillary canines according to the medial position of the canine crown in sectors 1–5. b) Mesial inclination (α) to the midline and distance (d1) to the occlusal plane of the permanent canine in the frontal plane, according to Ericson and Kurol (1988).*[7]

Whereas 2D panoramic radiography has its limitations, 3D Cone Beam Computed Tomography (CBCT) images allow detailed localization of impacted canines and their relation to adjacent teeth in the horizontal, vertical and sagittal axes. 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.[18] De Grauwe et al and Kapetanovic et al agreed that the use of CBCT is justified when 2D radiography fails to provide an accurate diagnosis.[19,20]

Early diagnosis and prompt intervention represent the most desirable approach in managing impacted canines. Treatment options for impacted canines are early interceptive treatment, such as removal of the deciduous canine and removal of the first deciduous molar, headgear treatment, and/or maxillary expansion; surgical exposure with or without orthodontic traction to align the malpositioned tooth; autotransplantation 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.[21-27] The success of treatment is related to the complexity, duration, and complications, as well as functional and aesthetic 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 with a high (above the apex of the adjacent incisor) and/or horizontal position are considered to be difficult to treat, either because of the challenging surgical access or due to a clinically disadvantageous or long eruption path.[28] The presence of root dilaceration, ankylosis or odontoma further complicates the treatment plan and excludes a straightforward orthodontically assisted eruption. Severe root resorption of the maxillary incisors may have a significant effect on the treatment strategies. Further orthodontic traction might worsen resorption if the direction of traction is not controlled, and can lead to irreparable damage and even loss of these teeth. In these cases, a decision must be made whether to extract the resorbed tooth and orthodontically align the impacted canine, whether to move the impacted canine away from the resorbed tooth, or whether to remove or autotransplant the impacted maxillary canines and prevent further root resorption. [6,27,30,31]

Moreover, orthodontic treatment is not always accepted by patients because treatment time may increase. This might tilt the cost/benefit balance towards inefficiency, especially when a first attempt has already failed. In some cases, when the impacted canine does not respond to conventional orthodontic or surgical options, the labeling as "critical" becomes a post-factum judgement instead of being the end-result of a diagnostic process. Recurrently, critically impacted canines are removed when the treatment outcome proved to be or is expected to be disappointing.[29] In such cases, and with sufficient diastema, autotransplantation might be a valuable treatment alternative.

1.3 AIMS AND HYPOTHESES

It is evident that prior knowledge on treatment outcome and predictors of success is crucial in orthodontic decision making. Therefore, further research on this subject is highly advocated to assist physicians in their clinical practice.

The aim of this thesis is to compose recommendations that will help to identify critically impacted maxillary canines and at the same time support the decision-making process for further treatment options. These guidelines will be based upon the findings of multiple systematic reviews of the current literature and clinical research (prospective and retrospective) of different treatment options.

In order to reach the main purpose, the following sub-objectives were identified:

The development of indices for the evaluation of radiological outcome after transplantation of impacted maxillary canines.

Rationale: An important part of the follow-up of an autotransplanted maxillary canine is the radiographic control with intra-oral and 3D CBCT images. We aimed to validate a new index for assessing the radiological outcome of autotransplanted maxillary canines.

Hypothesis: The outcome of a transplanted canine is related to several radiological variables. We can identify these variables based upon the existing literature.

Methods: Eleven radiological variables were selected. The imaging data from randomly selected participants will be used for method validation.

The development of indices for the evaluation of aesthetic outcome of maxillary canines.

Rationale: Aesthetic appraisal is rarely included in the objective assessment in outcome studies of impacted maxillary canine treatment. We aimed to validate a new index for assessing the aesthetic appearance of maxillary canines.

Hypothesis: The outcome of a transplanted canine is related to several aesthetic variables. We can identify these variables based upon the existing literature.

Methods: Twelve relevant aesthetic variables were selected. The clinical data from randomly selected participants will be used for method validation.

To study the different subtypes of maxillary canine impaction and to gain insight in the possible treatment options for the management of complex canine impaction.

Rationale: Complex impacted maxillary canines raise unparalleled treatment challenges for the therapeutic team. Treatment outcomes offer various degrees of satisfaction to both clinician and patient. Diagnostic and treatment planning tools should be carefully exploited for optimal results.

Hypothesis: (1) The literature lacks high quality research concerning complex maxillary canine impaction. (2) There is a wide variation in the positions in which impacted canines can present themselves.

Methods: (1) A systematic review will be performed on complex maxillary canine impaction. (2) A cohort of impacted maxillary canines (130 patients; 162 canines) was classified using a 3D classification for impacted maxillary canines. The proposed classification was based on four criteria: vertical crown position, mesio-distal tooth position, bucco-lingual crown position and associated pathology.

To identify position related outcomes after surgically assisted orthodontic alignment of maxillary canines and possible predictors of treatment success.

Rationale: The overarching aim of this project is to gain insight in the relationship between the initial position of impacted canines and treatment outcomes.

Hypothesis: (1) The complexity of the impaction of a maxillary canine can be defined by analyzing its initial position (bucco-palatal, vertical, angulation) and characteristics such as root development. (2) A more complex initial position is associated with less successful interceptive and active treatment solutions, prolonged treatment time, and inferior outcomes.

Methods: (1) A systematic review will be performed on the relationship between the initial position of impacted canines and treatment outcomes. (2) A retrospective cohort study was designed, containing data of 132 patients with a total of 153 impacted maxillary canines. Aesthetic outcome, treatment duration, success and failure rates were investigated in relation to the initial position of the maxillary canine as assessed on pre-treatment panoramic radiographs.

To study the outcome after autotransplantation of maxillary canines and possible predictors of treatment success.

Rationale: Surgically assisted orthodontic extrusion of impacted maxillary canines might not always be possible due to the canine position, aesthetic and/or economic considerations. In such cases, and with sufficient diastema, autotransplantation of the maxillary canine may be a good treatment.

Hypothesis: Autotransplantation of impacted maxillary canines is a legitimate treatment technique for impacted maxillary canines deemed difficult to treat with surgical exposure and subsequent orthodontic alignment.

Methods: (1) A systematic review will be performed on transalveolar transplantation of maxillary canines and the long-term outcome. (2) In two separate studies we will retrospectively and prospectively investigate the outcome of autotransplanted maxillary canines and the influencing parameters.

To conclude, impaction of maxillary canines is a complex problem which presents a challenge for the treating clinician, especially when there are additional complicating factors (such as age, difficult position, local pathology, root anomalies). Imaging has the capability to predict the complexity of the treatment process, in order to help the practitioner in choosing a treatment option appropriate for each individual case. However, success of treatment should first of all be defined using objective indices. Secondly, these indices should be used as an indicator for treatment planning.

This thesis aims to identify critical impaction of maxillary canines (prone to failure with conventional treatment), and by doing this, to define the indications for maxillary canine transplantation. This should help the clinician to avoid failure of surgical exposure with orthodontic alignment while also preventing unnecessary maxillary canine transplantations, leading to a patient-specific treatment.

CHAPTER 1

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Vanpoecke J, Raes M, Albdour EA, Willems G, Politis C, Jacobs R. Development and validation of the autotransplanted maxillary canine radiological index. Clin Exp Dent Res. 2018 Aug 17;4(5): 167-173. doi: 10.1002/cre2.125. PMID: 30386638; PMCID: PMC6203832.

DEVELOPMENT AND VALIDATION OF THE AUTOTRANSPLANTED MAXILLARY CANINE RADIOLOGICAL INDEX (AMCRI)

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ABSTRACT

OBJECTIVES: The purpose of this study was to propose and validate an index evaluating 2D and 3D radiographic variables of autotransplanted maxillary canines.

MATERIAL AND METHODS: A new Autotransplanted Maxillary Canine Radiological Index (AMCRI) was proposed. It consisted of eleven variables. These variables were based on 2D (intra-oral) and 3D (CBCT) radiographs. Intraclass Correlation Coefficient (ICC) and Fleiss' kappa statistics were performed to analyze intra-rater and inter-rater agreement.

RESULTS: Considering cumulative assessment of the Autotransplanted Maxillary Canine Radiological Index (AMCRI), the mean Intraclass Correlation Coefficient (ICC) value for the inter-rater agreement of the eight examiners was 0.94, representing an excellent agreement. Intra-rater agreement was 0.91.

CONCLUSION: The Autotransplanted Maxillary Canine Radiological Index (AMCRI) is an objective tool in rating radiological outcomes of autotransplanted canines and adjacent bone, when compared to the contralateral canine.

INTRODUCTION

Maxillary canine impaction has been reported to occur in 2-3% of the population.[1] Autotransplantation is a potential treatment option in cases in which surgical exposure and orthodontic traction is not successful or impossible.[2] This treatment could be preferred considering an unfavorable displacement, as well as failure of orthodontic alignment due to immobility or because the patient refused a conventional orthodontic therapy.[3]

Ideally, an autotransplanted tooth can be present in the jaw bone for the patient's entire life. However, there are other reasons supporting this treatment, even if life-long survival cannot be achieved. Transplanted teeth have the capacity to preserve the alveolar ridge, especially during growth, during which dental implants are contraindicated.[4-6] By analogy, avulsed teeth, even those with poor prognosis, are recommended for replantation in cases of dental trauma.[5]

An important part of the follow-up of an autotransplanted maxillary canine is the radiographic control with intra-oral and 3D CBCT images. A standardized radiological evaluation protocol does not yet exist. It was our aim to develop a brief, simple, and easy to use questionnaire to objectively score the radiological appearance of autotransplanted maxillary canines in the long-term follow-up. This index can be helpful for the general dentist, orthodontist, as well as for the maxillofacial surgeon. It can be used in the screening for important variables determining outcome and the assessment of the final result.

The aim of the present report is to introduce the Autotransplanted Maxillary Canine Radiological Index (AMCRI), based on a combined 2D and 3D radiological evaluation, and validated in a random sample of autotransplanted maxillary canines. [7-9]

MATERIAL AND METHODS

This study was conducted at the Department of Oral and Maxillofacial Surgery, University Hospitals Leuven, Belgium. The study protocol was approved by the Ethics Committee of the University Hospitals Leuven, Belgium (s number: s53225).

Eleven radiological variables were selected based on the available evidence in literature regarding their relation to treatment outcome.[10-13] The radiological variables were based on the follow-up protocols of multiple studies concerning autotransplantation of maxillary canines.[2,14-25] Six radiological variables were evaluated both in 2D and 3D imaging, thus having a final 17 variables. All variables and their assessment were described in Tables 1 and 2.

The index comprised the cumulative scoring of the variables. Teeth were evaluated on each of the variables indicated. If indicated, the examined tooth was compared with the contralateral canine tooth. Points were given to each of these items: zero points for the desired result, one point for a moderate result and two, five or ten points for a gross deviation. For the gross deviations, five or ten points were assigned for the variables that were considered to be the most important for the final outcome, two points were assigned when the variable was considered to be less important.

It can be noticed that an apical radiolucency suggesting infection, root resorption or internal root resorption, automatically leads to a poor radiological result and can never be accepted as moderate or satisfactory. It should be recognized that patients who had treatment for bilateral impacted maxillary canines are more difficult to assess with the AMCRI. Before objectively scoring the teeth, the observers were asked to subjectively score each case with

'excellent', 'good', 'acceptable' and 'poor' final outcome. These scorings were correlated with the total objective scores. An expert consensus allowed for benchmarking of the rating scale and calibrated scoring with the new index.

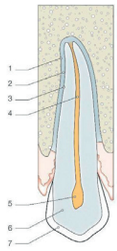
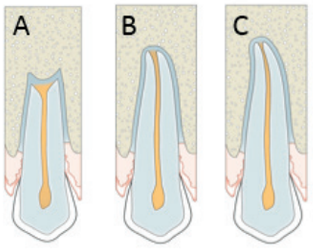
Table 1. *AMCRI scoring sheet.*

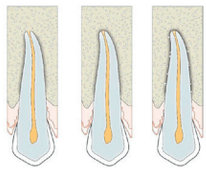
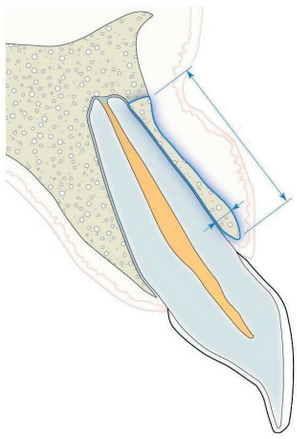
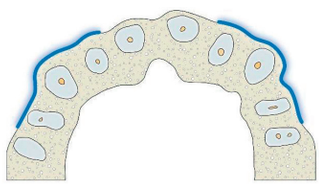
2D radiographic scoring			
Parameter	**Absent**	**Present but incomplete**	**Present**
Periodontal ligament	2	1	0
Lamina dura	2	1	0
Apical root closure	2	1	0
	Present		**Absent**
Apical radiolucency	10		0
Ankylosis	2		0
Root resorption	5		0

3D radiographic scoring			
Parameter	**Absent**	**Present but incomplete**	**Present**
Periodontal ligament	2	1	0
Lamina dura	2	1	0
Apical root closure	2	1	0
Peritransplant bone volume	2	1	0
	Present		**Absent**
Apical radiolucency	10		0
Ankylosis	2		0
Root resorption	5		0
Internal root resorption	5		0
	Major discrepancy	**Minor discrepancy**	**No discrepancy**
Vestibular bone height	2	1	0
Vestibular bone thickness	2	1	0
Vestibular prominence canine	2	1	0
Total score	0-5 points = excellent 6-13 points = good 14-20 points = moderate 21 or more points = poor outcome		

To test the reliability of the newly developed index, intra- and inter-observer agreement must be calculated.[26] Nine patients with twelve autotransplanted maxillary canines (5 male, 4 female; mean age 24.3 years) were randomly selected out of the patient database of the Department of Oral and Maxillofacial Surgery, University Hospitals Leuven. Mean follow-up time was 2.3 years. Minimal follow-up after autotransplantation was two years. Radiological imaging (intra-oral and CBCT) was collected, standardized (single view intra-oral radiographs and examiners were provided with sections from the CBCT). Observations were performed on standard screens. Initial training and calibrations of all observers were performed. Observations were performed at T0 (baseline), T1 (2 weeks after T0) and T2 (4 weeks after T0) after randomization. Eight examiners (all oral-maxillofacial surgeons) underwent familiarization with the index, followed by calibration. Each of the transplanted maxillary canines was rated on a form with the 17 items of the rating index. The rating was carried out three times by each of the examiners. There was a two week time interval between the ratings to prevent recollection of the first rating. ICC and Fleiss' kappa tests have been calculated to express the intra- and inter-observer agreement.

Table 2. *AMCRI variables.*

Variables	Description	Judgement instructions	Outcome	Figures
Periodontal ligament (PDL)	PDL should be visible on 2D & 3D (no radiological sign of ankyloses).	Judgement made on a three-point rating scale	Absent Present but incomplete Present	 1: lamina dura; 2: periodontal ligament; 3: cementum; 4: pulp canal; 5: pulp chamber; 6: dentin; 7: enamel
Lamina dura	Lamina Dura should be visible on 2D & 3D (no radiological sign of ankyloses).			
Apical root closure	Root closure should be visible on 2D & 3D as a result of further development of the autotransplanted tooth.			 A: open root; B: partially closed root; C: closed root
Peritransplant bone volume	Peritransplant bone volume should be visible (only in 3D), demonstrating further development of surrounding bone.			

Variables	Description	Judgement instructions	Outcome	Figures
Apical radiolucency	Associated with apical infection and poor prognosis.	Judgement made on a two-point rating scale	Absent Present	
Ankylosis	Disappearance of the PDL space and lamina dura, bone replacement of the root dentin, but no adjacent radiolucency.			
Root resorption	Associated with poor prognosis & radiologically visible as radiolucency on the external root surface of dentin and adjacent bone.			
Internal root resorption	Associated with poor prognosis. Only visible on 3D images, presenting as a uniform, circular radiolucent area within pulpal canal.			
Vestibular bone height	Vestibular bone height (long arrow) can be visible only in 3D imaging as a result of further development of surrounding bone.	Judgement on a three-point rating scale	a. No discrepancy b. Minor discrepancy c. Major discrepancy	
Vestibular bone thickness	Vestibular bone thickness (short arrow) can be visible only in 3D imaging as a result of further development of surrounding bone.			
Vestibular prominence canine	Visible only in 3D imaging as a combined result of initial positioning of autotransplanted canine and final orthodontic movements.			

RESULTS

The intra- and inter-observer agreement for the 17 variables and final score are listed in Figure 1. It can be noticed that the highest inter-observer agreement was obtained when assessing 2D and 3D apical infection, 2D and 3D root resorption and 3D vestibular bone height. Lowest inter-observer agreement was obtained when assessing 3D lamina dura, 3D apical root closure and 3D pulpolith.

The subjective scoring of each observer was correlated with the total scores (Figure 2). A Spearman correlation test showed a value of 0.89, demonstrating good correlation.

Based upon these results, the following classification was proposed (Table 3). A total objective score of 0-5 points correlates with an excellent final outcome, a total objective score of 6-13 points with a good final outcome, a total objective score of 14-20 points with an acceptable final outcome and a total objective score of 21 points or more with a poor final outcome.

Table 3. *Correlation final score AMCRI with outcome.*

Total score AMCRI	Final outcome
0-5	Excellent
6-13	Good
14-20	Acceptable
≥ 21	Poor

DISCUSSION

In the present study, we introduced a new index (AMCRI) and validated it. It was developed considering the lack of a standardized method of evaluating and measuring radiographic outcome after autotransplantation of impacted maxillary canines. The goal was to develop an index that could be used in both research and clinical settings as a guideline for diagnosing and documenting outcome.

High inter- and intra-observer agreement results on final end score were obtained (Figure 1). Both 2D and 3D imaging appear to be reliable as tools for assessment of final outcome.

Low scores on inter- and intra-observer agreement were found when assessing 3D pulpolith. This can be explained by the fact that one observer gave a different score (2) while all other observers indicated the same score (0). This creates a major imbalance in Fleiss' kappa statistics, resulting in an inter-observer agreement of almost zero.

These initial results with the radiographic index are very promising, but its practical use as a standard procedure has to be confirmed in a large-scale clinical study.

The index could be a very useful tool in scientific research. Results of the AMCRI might be checked for correlation with the final outcome, whereby a possible correlation and a predictive value can be linked to it. The index could also give a better, more objective insight into one's own results in daily practice.

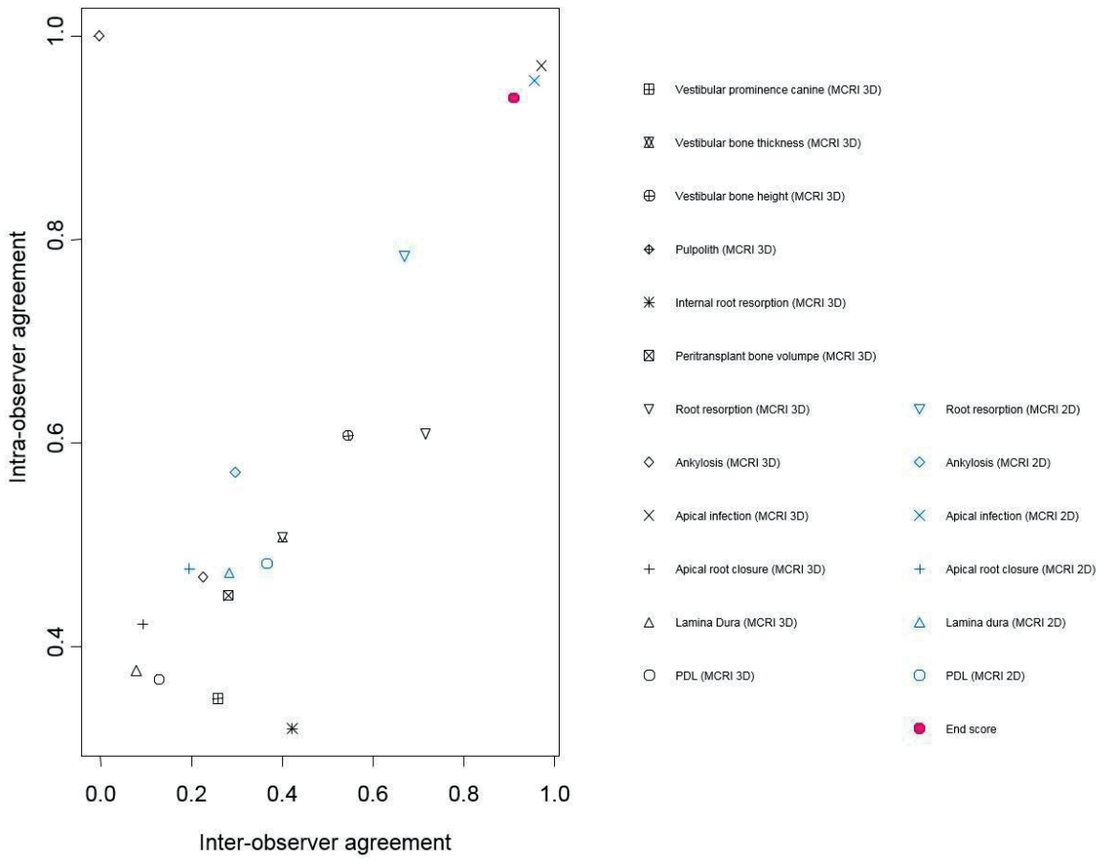


Figure 1. *Inter- and intra-observer agreement (Intraclass Correlation Coefficient (ICC) and Fleiss' kappa tests).*

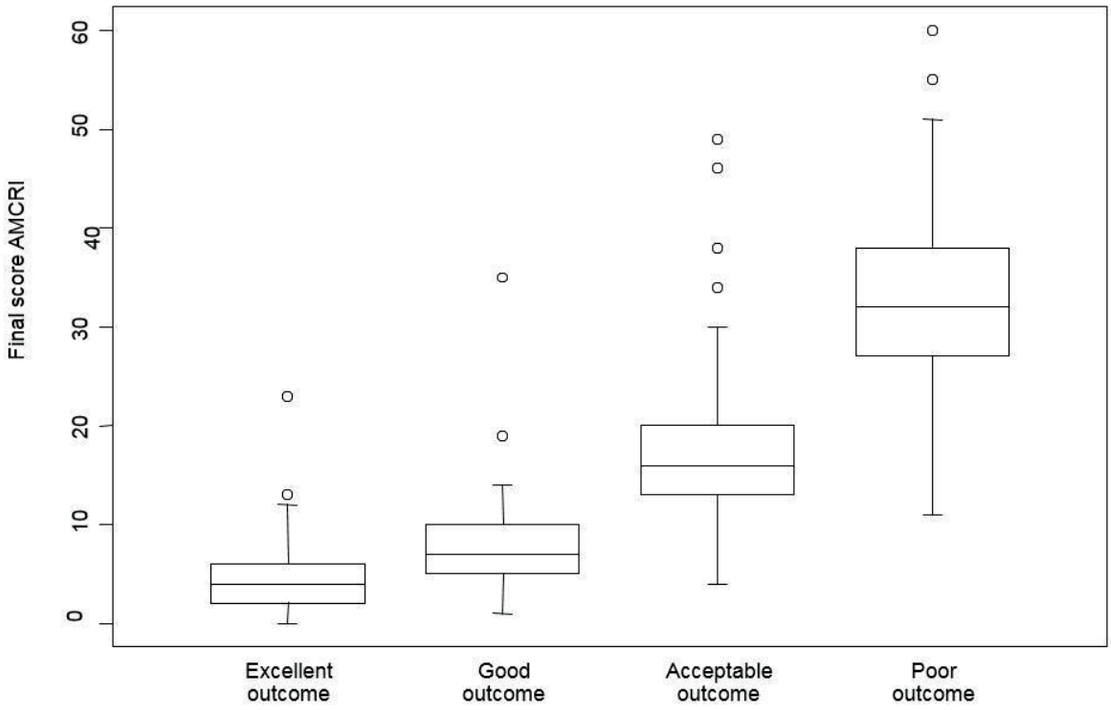


Figure 2. ***Box plots displaying correlations between objective and subjective scoring.*** *X-axis represents the subjective scoring as given by the different observers, Y-axis represents the corresponding mean final objective score on the AMCRI. Cut-off values for correlation of objective and subjective scoring were obtained based upon the full range of variation (from min. to max.), the likely range of variation (the IQR) and the median value.*

CONCLUSIONS

From this study it can be concluded that the Autotransplanted Maxillary Canine Radiological Index (AMCRI) is an objective tool in rating radiographic outcomes of autotransplanted maxillary canines. Clinicians might find it useful in daily clinical practice and scientific research. However, one must be aware that this index only judges the radiographic and not the functional outcome of the canine. A poor radiographic result does not imply malfunction, though it can be related to premature loss of the transplanted tooth due to apical infection or root resorption. To verify its clinical applicability, the AMCRI should be used on a larger data sample.

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CHAPTER 2

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

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DEVELOPMENT AND VALIDATION OF THE MAXILLARY CANINE AESTHETIC INDEX (MCAI)

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ABSTRACT

OBJECTIVES: Aesthetic appraisal is rarely included in the objective assessment of outcome studies of impacted maxillary canine treatment. The present study aimed to validate a new index for assessing the aesthetic appearance of maxillary canines and adjacent soft tissues.

MATERIAL AND METHODS: Twelve relevant aesthetic variables were selected based on the anatomic form, color and surface characteristics of the canine crown and on the anatomic form, color and surface characteristics of the adjacent soft tissues. Intraclass Correlation Coefficient (ICC) and Fleiss' kappa statistics were performed to analyze the intra-rater and inter-rater agreement.

RESULTS: The index proofed to be a reliable assessment tool. Considering the cumulative assessment of the Maxillary Canine Aesthetic Index (MCAI), the mean Intraclass Correlation (ICC) value for the inter-rater agreement of the ten examiners was 0.71, representing a good agreement. Intra-rater agreement ranged from 0.67 to 0.89. Inter-rater agreement (Fleiss' kappa statistics) calculated for each variable ranged from 0.52 to 0.91.

CONCLUSION: The MCAI is a reliable tool for rating aesthetic outcomes of impacted canine treatment and adjacent soft tissues. The MCAI can be used to evaluate the aesthetic outcome after surgical exposure or transalveolar transplantation of maxillary canines.

INTRODUCTION

Aesthetic appraisal is crucial yet rarely included in the objective assessment of outcome studies of impacted maxillary canine treatment. In 2005, Fürhauser et al. proposed an excellent index termed the Pink Esthetic Score (PES), focusing essentially on the soft tissue aspects of an anterior implant restoration. This PES is based on seven variables: mesial papilla, distal papilla, soft-tissue level, soft-tissue contour, alveolar process deficiency, soft-tissue color, and texture. Belser et al. developed an implant restoration index White Esthetic Score, WES) for analyzing a single-tooth implant. The suitability of the PES/WES index for the objective outcome assessment of the aesthetic dimension of anterior single-tooth implants was confirmed.[1-3]

Few studies have investigated the aesthetic outcome of previously impacted canines after treatment.[4,5] In the few studies that have been conducted, no clinically detectable differences in tooth color between the exposed teeth and the control groups have been reported.[6,7] Furthermore, shape and position did also not show any differences, yet inclination was reported to be significantly different in the impacted canine group: 80% of the normally erupted canines had a normal inclination, whereas only 57% of the previously impacted canines had a normal inclination after treatment.[7] Other authors reported that the previously impacted canines were more intruded after treatment.[8,9] The three most common reasons given for identifying the previously impacted canines are torque, gingiva and alignment.[10]

As there are hardly any clinical yet objective assessment methods available, the overall aim of the present study was to introduce the Maxillary Canine Aesthetic Index (MCAI) as a brief, simple, and easy to use questionnaire to objectively score the aesthetic appearance of maxillary canines. This MCAI index is adapted from a combined set of parameters as measured with the highly standardized international Pink and White Esthetic Scoring system. This study describes the use of the MCAI index, meanwhile validating it for assessing the aesthetic appearance of maxillary canines and adjacent soft tissues. As a sub-objective, the differential use of the index by different specialists and dental professionals was studied.

MATERIAL AND METHODS

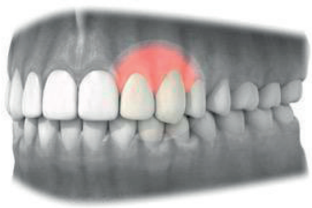
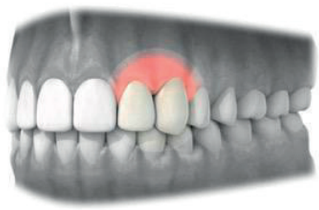
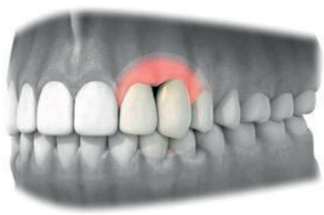
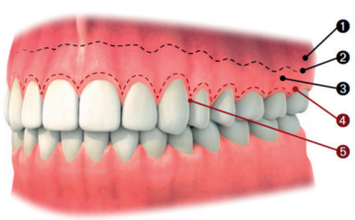
This retrospective cross-sectional study was conducted at the Department of Oral & Maxillofacial Surgery, University Hospitals Leuven, Belgium. The study protocol was approved by the Ethics Committee of the University Hospitals Leuven, Belgium (s number: s53225).

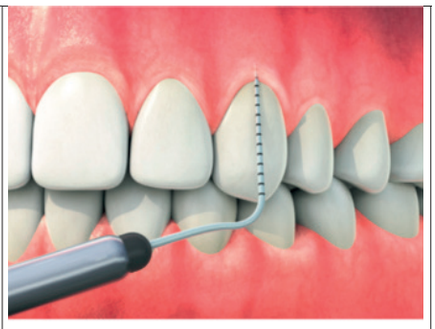
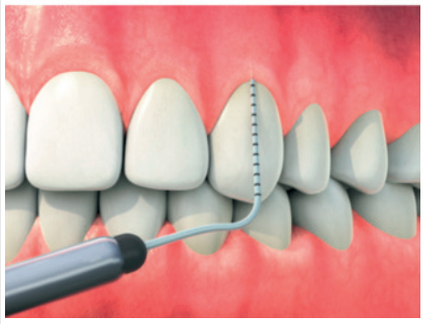
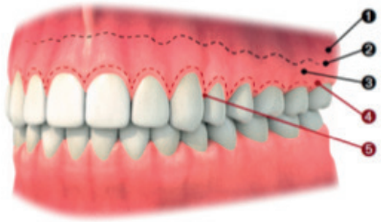
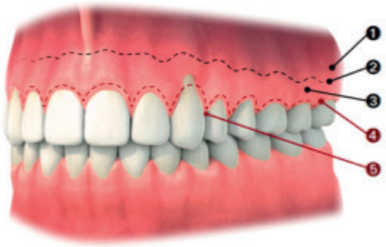
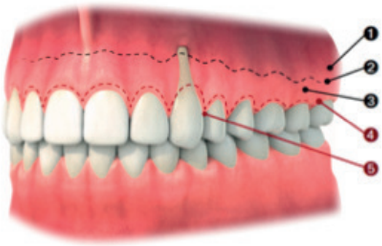
From of the literature, twelve variables were selected, which have an influence on the aesthetic result (Table 1). The variables were based on the anatomic form, color and surface characteristics of the crown and on the anatomic form, color and surface characteristics of the adjacent soft tissues. All variables and their assessment are described in Tables 1 and 2.

Rather than using rules for shape and position of the teeth, adjacent and contralateral teeth were used as a reference for normality instead. This allowed for maintaining the patient's proportions between the general shape of the face, size, sex and other teeth. It should be recognized that patients who had treatment for bilateral impacted maxillary canines are more difficult to assess with the MCAI.

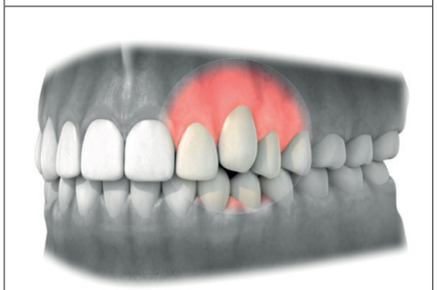
In general, MCAI works with a subjective rating scale, according to the following classification: zero points for the desired result, one point for a moderate result and two or five points for a gross deviation. For the gross deviations, five points are assigned to the variables considered to be the most important for the aesthetic outcome, while two points are assigned when the variable is considered to be less important. The higher the score, the worse the aesthetic appearance. It can be noticed that one gross deviation (five points) can never be accepted to be an excellent outcome.

Table 1. *Maxillary Canine Aesthetic Index variables.*

Variables	Explanation	Judgement instructions	Outcome	Figures
Parameters investigating the previously impacted canine				
Mesial papilla	Interdental papilla must be in natural position.	Judgement should be made on a three-point rating scale	Complete	
Distal papilla	Interdental papilla must be in natural position.		Incomplete	
			Absent	
Marginal gingiva	Length of the marginal gingiva must be in harmony with the contralateral tooth.	Judgement should be made on a three-point rating scale	Absent, incomplete (<3mm) or complete (>3mm)	

Marginal gingival thickness	Thickness of the marginal gingiva must be in harmony with the contralateral tooth.	Judgement should be made on a two-point rating scale	Thin	
			Thick	
Recession	Level of displacement of the marginal tissue apical compared to the cemento-enamel junction (CEJ).	Judgement should be made on a three-point rating scale	No recession	
			Recession that does not extend to the mucogingival junction (MGJ)	
			Recession that extends to or beyond the mucogingival junction (MGJ)	

Mesiodistal crown angulation	Position must be in harmony with the adjacent and contralateral tooth.	Judgement should be made on a three-point rating scale	Mesial Straight Distal	

Parameters comparing both canines				
Curvature of marginal gingiva	Curvature of the marginal gingiva must be in harmony with the contralateral tooth.	Judgement should be made on a three-point rating scale	Major discrepancy, minor discrepancy or no discrepancy	
Soft tissue color and texture	Color (redness) and texture must be in harmony with the contralateral canine and must have a natural appearance.			
Root convexity	Root convexity and its projection through the overlying mucosa must be in harmony with the contralateral canine.			
Tooth morphology	Tooth morphology must be in harmony with the contralateral canine.			
Vertical tooth position	Vertical position must be in harmony with the adjacent teeth and contralateral canine.			

Parameters investigating relation previously impacted canine and neighboring teeth				
Buccolingual angulation crown	Buccolingual angulation of the crown must be in harmony with the contralateral canine	Judgement should be made on a three-point rating scale	Major discrepancy Minor discrepancy No discrepancy	

1: Alveolar mucosa;
2: Mucogingival junction;
3: Attached gingiva;
4: Free gingival groove;
5: Free gingiva

Table 2. *MCAI variables.*

Parameters investigating the previously impacted canine			
	Absent	**Incomplete**	**Complete**
Mesial papilla	5	1	0
Distal papilla	5	1	0
Marginal gingiva	5	1 (<3mm)	0 (>3mm)
Recession	**(apical to MGJ)**	**(coronal to MGJ)**	**(no recession)**
	5	1	0
Marginal gingival thickness	**Thin**	**___**	**Thick**
	1	_____	0
Mesiodistal crown angulation	**Distal**	**Straight**	**Mesial**
	2	1	0
Parameters comparing both canines			
	Major discrepancy	**Minor discrepancy**	**No discrepancy**
Curvature of marginal gingiva	2	1	0
Soft tissue color and texture	2	1	0
Root convexity	2	1	0
Tooth morphology	2	1	0
Vertical tooth position	2	1	0
Parameters investigating relation previously impacted canine and neighboring teeth			
Buccolingual angulation crown acc. neighboring teeth	2	1	0
Total score	0–3 points = excellent 4-8 points = good 9-13 points = moderate 14 or more points = poor aesthetics		

For the observational tasks, the ten observers (four oral-maxillofacial surgeons, two orthodontists, two prosthodontists and two lay persons) were asked to subjectively score each case with 'excellent', 'good', 'acceptable' and 'poor' final outcome. These scorings were correlated with the total objective scores. Initial training and calibration of all observers were performed.

Observations were performed at T0 (baseline), T1 (2 weeks after T0) and T2 (4 weeks after T0) after randomization. Each of the maxillary canines and the adjacent soft tissues were rated on a form with twelve variables of the rating index. While blinded for patient history and treatment, observers had to score the canines on their gingival aspects and aesthetics. ICC and Fleiss' kappa tests were calculated to express the intra- and inter-observer agreement.

Observations were carried out in standardized circumstances with dimmed light, on a projection screen with all observers at an equal distance from the screen.

To test reliability of the newly developed index, intra- and inter-observer agreement must be calculated.[11] Eleven patients (6 male, 5 female; mean age 21.8 years) were randomly selected out of the patient database of the Department of Oral & Maxillofacial Surgery and the Department of Orthodontics at the University Hospitals Leuven. Mean follow-up time was 3.4 years. Six patients had a history of autotransplantation of a maxillary canine and five patients had a history of surgical exposure of a maxillary canine. All surgical interventions were performed at the Department of Oral & Maxillofacial Surgery, University Hospitals Leuven. All patients had finished their treatment at the final examination. Intra-oral images were collected and standardized.

RESULTS

The inter-rater and intra-rater agreements and comparison between the different groups are listed in Table 3. It can be noticed that orthodontists in particular have an excellent inter-rater reliability. Best intra-rater agreement was noticed within the group of prosthodontists.

Inter-rater agreement (Fleiss' kappa statistics) ranged from 0.52 (laymen) to 0.91 (orthodontists). Lowest scores were noted within the layman group assessing marginal thickness of the gingiva and mesial papilla. Highest scores were noted within the group of orthodontists and maxillofacial surgeons assessing gingival recession.

The subjective scoring of each observer was correlated with the total scores (Figure 1).

Based upon these results, the following classification was proposed (Table 5). A total objective score of 0-3 points correlated with an excellent final outcome, a total objective score of 4-8 points with a good final outcome, a total objective score of 9-13 points with an acceptable final outcome and a total objective score of 14 or more points with a poor final outcome.

Table 3. *Inter-rater agreement on final end score.*

Observer type	Intra-Class Correlation (ICC)
Oral-maxillofacial surgeons	0.65
Prosthodontists	0.76
Orthodontists	0.91
Laymen	0.52
Comparison	**P-value**
Oral-maxillofacial surgeons - Prosthodontists	0.50
Oral-maxillofacial surgeons - Orthodontists	0.05
Oral-maxillofacial surgeons - Laymen	0.47
Prosthodontists - Orthodontists	0.33
Prosthodontists - Laymen	0.23
Orthodontists - Laymen	0.02

Table 4. *Intra-rater agreement on final end score.*

Observer type	Intra-Class Correlation (ICC)
Oral-maxillofacial surgeons	0.81
Prosthodontists	0.89
Orthodontists	0.80
Laymen	0.67
Comparison	**P-value**
Oral-maxillofacial surgeons - Prosthodontists	0.50
Oral-maxillofacial surgeons - Orthodontists	0.97
Oral-maxillofacial surgeons - Laymen	0.42
Prosthodontists - Orthodontists	0.66
Prosthodontists - Laymen	0.21
Orthodontists - Laymen	0.60

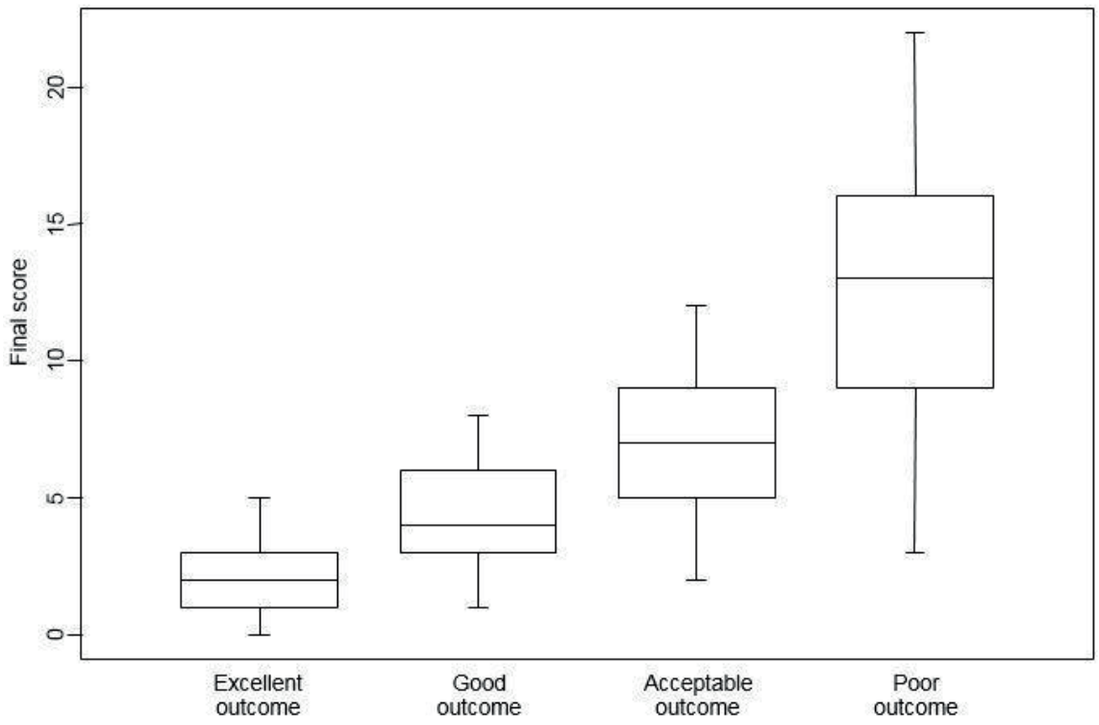


Figure 1. Box plots displaying correlations between objective and subjective scoring. *X-axis represents the subjective scoring as given by the different observers, Y-axis represents the corresponding mean final objective score on the MCAI. Cut-off values for correlation of objective and subjective scoring were obtained.*

Table 5. *Correlation final score MCAI with outcome.*

Total score MCAI	Final outcome
0-3	Excellent
4-8	Good
9-13	Acceptable
>13	Poor

DISCUSSION

In the present study, we introduced a new index (MCAI) and validated it. It was developed considering the lack of a standardized method of evaluating and measuring aesthetics after treatment of impacted maxillary canines. The goal was to develop an index that could be used in both research and clinical settings as a guideline for diagnosing and documenting aesthetics.

The best inter-observer agreement (Table 3) was found between the orthodontists. Intra-observer results concerning the final score (Table 4) indicated an excellent agreement in the three groups of medically trained observers. For the layman group there is a good agreement.

It has been chosen to use the adjacent and contralateral tooth as a reference and not the generally accepted rules for shape and position of teeth. One should always consider the harmony with other teeth, even if gross deviations exist with aesthetic principles.

As consistency is a key feature of the aesthetic evaluation, the high intra-rater and inter-rater reliability were considered high-quality features of the MCAI. The examiner was trained and calibrated in the use of the index before the evaluation sessions, which confirms the need for those steps. This step contributed to the good results. Ratings have been carried out under standardized viewing conditions for all observers. Thus, observation settings are standardized, without interference of the possible opinion of the patient. On the other hand, real color and surface characteristics were more difficult to examine. Also, a clinical chairside evaluation would contribute to a better comparison with the contralateral tooth.

These initial results with the aesthetic index are very promising, but its practical use as a standard procedure has to be confirmed in a large-scale clinical study. The index could be a very useful tool in scientific research and in a clinical setting. It makes a comparison between various surgical procedures possible. The index could also give a better, more objective insight into one's own aesthetic results in daily practice.

CONCLUSIONS

The current investigation presents the Maxillary Canine Aesthetic Index (MCAI), an objective tool for rating aesthetics of maxillary canines and adjacent soft tissues after surgical treatment. Clinicians might find it useful in daily clinical practice and scientific research. However, one must be aware that this index only judges the aesthetic and not the functional outcome of the canine. A poor aesthetic result does not imply malfunction.

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CHAPTER 3

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Denoiseux B, Martin C, Hoppenreijs T, Calburean F, Politis C, Jacobs R. How to treat critically impacted maxillary canines: Clinical versus scientific evidence. J Stomatol Oral Maxillofac Surg. 2021 Apr 17:S2468-7855(21)00080-X. doi: 10.1016/j.jormas.2021.03.013. Epub ahead of print. PMID: 33862266.

TREATMENT FOR CRITICALLY IMPACTED MAXILLARY CANINES: CLINICAL VERSUS SCIENTIFIC EVIDENCE – A SYSTEMATIC REVIEW

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ABSTRACT

OBJECTIVES: Critically impacted maxillary canines are prone to failing to respond to conventional surgical exposure and orthodontic traction. Correct identification of a critical impaction requires enhanced diagnosis modalities and might lead to incorporating alternative surgical strategies in the treatment plan. Predictability of techniques such as apicotomy or tooth autotransplantation is, however, yet to be determined. The objective of this study was to systematically review treatment perspectives for critically impacted maxillary canines.

MATERIAL AND METHODS: A systematic review of the available literature until April 2020 was conducted using an electronic search in Embase, Cochrane Central, Web of Science and PubMed databases. Randomized and non-randomized studies investigating treatment options and treatment outcome for buccal and/or palatal critically impacted maxillary canines were considered for the review. Information recorded concerned study design and setting, participants' characteristics and details regarding the type of intervention, types of outcomes measured and follow-up time. The included studies received a methodological quality scoring and risk-of-bias analysis according to a tool suggested by Murad et al (2018).

RESULTS: Five studies were included in the quality analysis, all case series. The included studies enrolled a total of 302 patients and counted 346 critical maxillary canine impactions. Apicotomy and autotransplantation were listed as potential surgical approaches with surgical outcome presented for both surgical strategies. Adequate aesthetic and/or functional outcomes were reported in most of the included studies. According to the quality assessment tool used, the reviewed studies scored medium on the proposed scale.

CONCLUSION: Literature featuring protocols for identifying and treating critical maxillary canine impaction only consists of case series and case reports, which

provide low level evidence. The rather good results reported by the reviewed studies must be put into perspective as the methodology of these studies was insufficient and potential bias was identified. Comprehensive clinical research is needed to further investigate treatment options and form a basis for clinical guidelines.

INTRODUCTION

Maxillary canines can become impacted due to unfavorable positioning inside the alveolar bone or proximity to neighboring structures that impede spontaneous eruption within the normal eruption sequence.[1,2] Impacted canines with a high and/or horizontal position are considered to be difficult to treat either because of the challenging surgical access or due to a clinically disadvantageous or long eruption path. The relationship between initial canine position and treatment outcome has been described in the literature: mesial position, high α-angle (the angle formed between the long axis of the impacted canine and the inter-incisor median line; normal value = 53–20°) and high vertical localization have been associated with prolonged treatment time.[3-5] The presence of root dilaceration, ankylosis or odontoma further complicates the treatment plan and excludes a straightforward orthodontically assisted eruption (Figure 1).

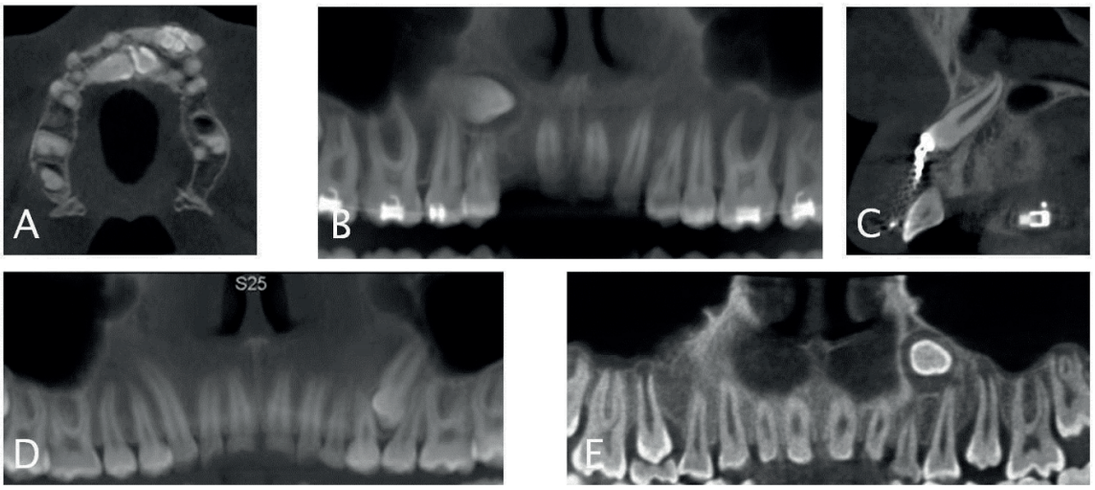

Figure 1. *Critical maxillary canine impaction. A: Associated local pathology (presence of odontoma), B: Horizontal position, C: Severe root dilaceration, D: Transposition, E: High vertical position*

Some impacted canines fail to respond to surgical exposure and orthodontic traction. A potential complicating factor for canine impaction is the increased need for patient compliance in case of prolonged treatment. For some cases, this might tilt the cost/benefit balance towards inefficiency, especially when a first attempt has already failed. Failure to respond to conventional orthodontic or surgical options, defines maxillary canine impaction as critical. Recurrently,

critically impacted canines are removed when the treatment outcome proved to be or is expected to be disappointing.[6]

Aside from aesthetic and functional problems, untreated partially erupted or impacted canines may result in various complications such as displacement, loss of vitality or resorption of the adjacent teeth, arch length discrepancy, dental midline shift, formation of follicular cysts, ankylosis, recurrent infections, pain, root resorption of the canine and adjacent teeth or combinations of these aggravations.[7] While the decision to treat impacted canines is clearly backed up by this tooth's important role in a healthy dentition, therapeutic conduct is neither obvious to choose nor predictable enough to guarantee a favorable outcome.

A detailed assessment of the impacted maxillary canine's location and orientation is essential for treatment planning. For this purpose, a variety of radiographic devices and tools are used for evaluation and classification, such as 2D panoramic radiography (with its limitations) and 3D Cone Beam Computed Tomography (CBCT). CBCT images allow detailed localization of impacted canines and their relation to adjacent teeth and other anatomical structures in the horizontal, vertical and sagittal axes.[3,6,8-17] Ideally, this diagnostic imaging tool should allow for a clear indication either in favor of the standard surgical exposure or in favor of a more comprehensive approach.

Treatment options for impacted canines usually include early interceptive treatment and surgical exposure with or without orthodontic traction and alignment of the malpositioned tooth. Facing a more challenging impaction, clinicians might opt for autotransplantation of the permanent canine or add apicotomy to the surgical exposure.[19,20]

Autotransplantation of the impacted tooth would bring a critically impacted canine in the dental arch with only one surgical procedure and with a shortened orthodontic treatment. The risk of necrosis or resorption of the transplanted tooth is not negligible, nor is the complexity of the procedure.[19,21] Apicotomy is performed when there is evidence of apical ankylosis or dilacerations or when the proximity of the impacted canine to adjacent anatomical structures would resist the movement of the canine.[22]

So far, no systematic reviews assessing treatment perspectives for critical maxillary canine impaction and their outcomes have been reported in literature. The ultimate clinical application would be early diagnosis of critical maxillary canine impaction. Therefore, the aim of the present study was to identify available evidence for different treatment modalities addressing critically impacted maxillary canines in order to better define treatment pathway and predictability, thereby preventing prolonged and dissatisfying treatment or unnecessary removal of maxillary canines.

MATERIALS AND METHODS

Protocol and registration

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines were followed to ensure transparency and comprehensiveness in this systematic review.[23] A search protocol was specified and registered at PROSPERO (International Prospective Register of Systematic Reviews) No. CRD42019137030. The initial PROSPERO record was updated after revisions following a first peer review.

Selection criteria applied to the review

Eligibility criteria were determined a priori according to the PICOS (Participant Intervention Comparison Outcome Study design) scheme (Table 1). Inclusion criteria comprised studies concerning maxillary canines that meet the definition of critical maxillary canine impaction (associated local pathology: presence of odontoma or other local pathology - Figure 1A, horizontal position - Figure 1B, transposition - Figure 1D, high vertical or inverted position - Figure 1E, root dilaceration - Figure 1C, ankylosis, increased patient age), investigating the treatment procedure and reporting the final outcome. All study designs were considered and no restrictions regarding time or language of publication were established.

Search strategy for the identification of studies

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 January 2020. The search strategy used a combination of controlled vocabulary and free text terms and was run with the recommended EMBASE and MEDLINE filters.[24] The full search protocol for the different databases is displayed in Table 2. No language or date restrictions were applied when searching the electronic databases. Additionally, references of selected full-text articles were manually screened for potentially useful articles.

Study selection was performed according to the PRISMA 2009 flow diagram (Figure 2).

Table 1. *Criteria for including studies in this review.*

Types of studies (S)	
Prospective and retrospective studies, randomized and non-randomized trials that assessed treatment strategies for critical maxillary canine impaction	
Participant characteristics (P)	
Studies on human participants of any gender or malocclusion in the permanent dentition with full or incomplete development of the roots and critical maxillary canine impaction	
Intervention (I)	
Different treatment strategies for critical maxillary canine impaction	
Comparison (C)	
Given the lack of standardized approaches to diagnostic imaging or therapy, the outcome measures were not compared to a specific diagnostic/treatment approach. Rather, the outcomes from the various groups were compared with each other.	
Outcome (O)	
Bone related outcomes	• Presence of lamina dura surrounding the canine • Alveolar bone resorption • Vestibular thickness, height and prominence of the bone • Vertical bone loss
Tooth related outcomes	• Root resorption • Changes in pulp chamber • Tooth vitality • Change of canine color • Tooth mobility and/or presence of ankylosis • Endodontic treatment need
Periodontal outcomes	• Periodontal attachment: pocket depth • Periodontal space dimensions and continuity • Gingival recession
Aesthetic outcome	• Patient satisfaction • Objective criteria

Table 2. *Search strategy.*

PubMed	((“Maxilla”[Mesh] OR maxilla*[tiab] OR “upper jaw”[tiab] OR “upper jaws”[tiab]) AND (“Cuspid”[Mesh] OR cuspid*[tiab] OR canine*[tiab]))
Embase	((‘maxilla’/exp OR maxilla*:ti,ab OR ‘upper jaw’:ti,ab OR ‘upper jaws’:ti,ab) AND (‘canine tooth’/exp OR ‘canine tooth’:ti,ab OR ‘canine teeth’:ti,ab OR cuspid*:ti,ab OR canine*:ti,ab))
Web of Science	((maxilla* OR “upper jaw” OR “upper jaws”) AND (cuspid* OR canine*))
Cochrane	(maxilla* OR “upper jaw” OR “upper jaws”) AND ([cuspid] OR cuspid* OR canine*))

Titles and abstracts of relevant studies identified through the electronic searches were screened by three authors (KG, BD and CM). Full-text articles were obtained from the studies that fulfilled the inclusion criteria. These full-text articles,

together with articles found through the manual search, were independently assessed by these authors. Case reports with less than 10 participants, studies reporting impacted maxillary canines in patients with systemic diseases, syndromes, or cleft lip and palate and studies without specified treatment protocol or follow-up period were further excluded from the quality analysis. Disagreements between researchers were resolved through discussion.

Data extraction and management

Data extraction was independently performed by three researchers (KG, BD and CM) according to a modified version of the Cochrane data extraction form.[24] Information recorded concerned study design, setting of the trial, period of recruitment, data concerning participants (inclusion and exclusion criteria, demographics, number of participants and number of impacted maxillary canines), and details regarding the type of intervention, types of outcomes measured and follow-up time. Data extraction forms were subsequently compared between the researchers (KG, BD and CM) and upon discussion and agreement a final form was constructed.

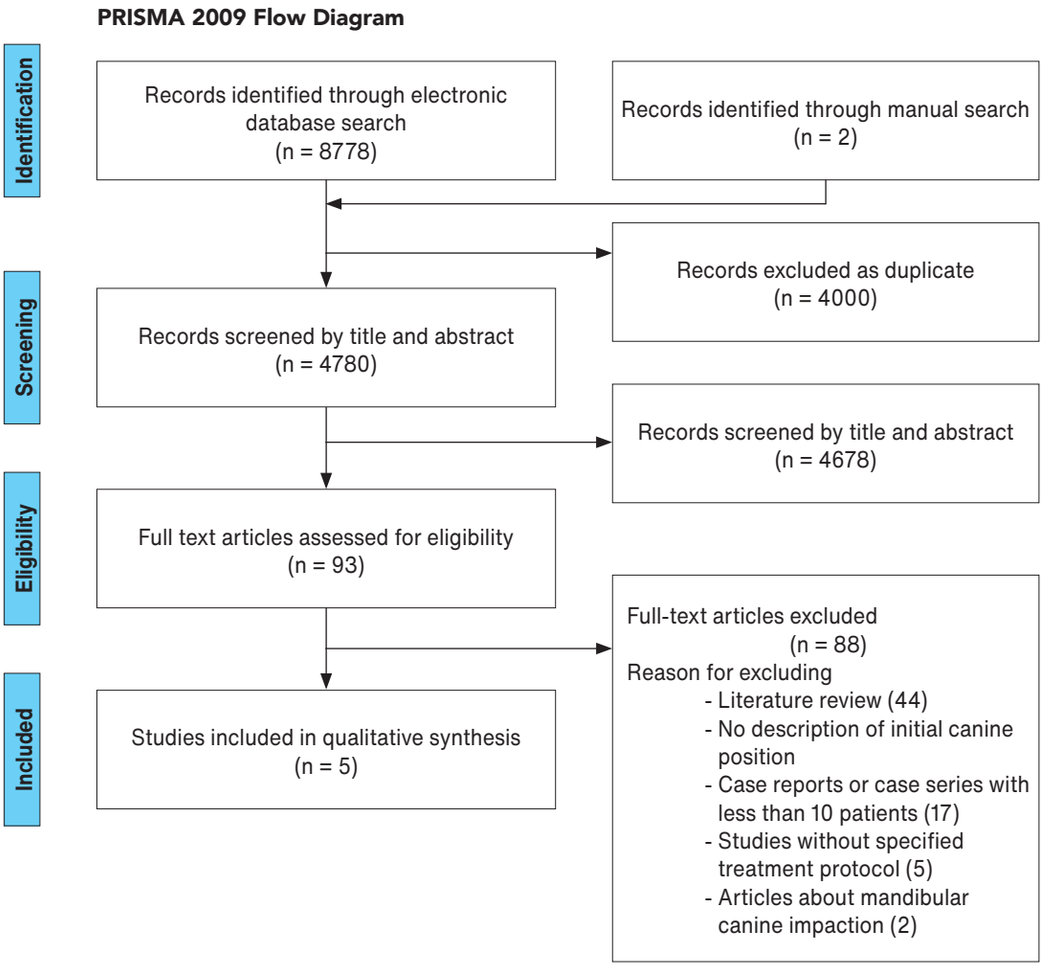

Figure 2. *Prisma flow chart.*

Quality assessment

All of the included studies were case series. Quality and risk-of-bias analyses were performed with the tool suggested by Murad et al.[25] This tool consists of eight items that can be categorized into four domains: selection, ascertainment, causality and reporting. Questions 4, 5 and 6 were removed since these are mostly relevant to cases concerning adverse drug events. As suggested by the authors, an overall judgment about methodological quality based on the questions was made. The overall quality of the case report was considered as: 'low quality', 'medium quality' or 'high quality'.

RESULTS

After screening titles and abstracts of 4780 unique papers, 93 potentially eligible articles were selected (Figure 2). Each title and abstract were independently reviewed by three researchers (KG, BD and CM) and the obtained information was compared. Inter-examiner disagreements were resolved in a consensus meeting. Full text versions of the 93 potentially eligible articles were obtained and 88 of them were consequently excluded (Figure 2). Five articles were included in this review.[19-21,26,27]

Characteristics of the reviewed studies

All articles selected for the quality analysis were case series with a minimal of 10 patients included. Our search of the literature retrieved no randomized controlled clinical trials. Apicotomy and autotransplantation were the surgical techniques described in these studies and the outcomes of these procedures were presented. More details about the reviewed studies can be found in the table of study characteristics (Table 3).

Table 3. *Summary of study characteristics and outcomes.*

Study	Ahlberg et al (1983) [26]	Grisar et al (2018) [19]	Hall et al (1983) [21]	Puricelli et al (2007) [20]	Sagne et al (1997) [27]
Study type	CS	CS	CS	CS	CS
Number of canine cases	33 (21 F; 12 M)	41 (20 F; 21 M)	141 (n: 113: 80 F; 33 M)	30 (15 F; 15 M)	101 (n: 85: 54F; 31 M)
Age	MA: 34y (25- 55)	MA: 21y (± 10)	MA: 20y (13-43)	MA: 21y	MA: 31y (11-76)
Critical maxillary canine impaction definition					
Complex position	x				
Failure of a previous treatment				x	
Dilaceration		x		x	
Ankylosis		x		x	
Orthodontist opinion			x		x
Pre-treatment radiologic assessment	nm	Panoramic + CBCT	nm	2D radiographs	2D radiographs
Management approach					
Autotransplantation	x	x	x		x
Apicotomy				x	
Post-treatment assessment					
Clinical	x	x	x	x	x
Radiologic assessment	x	x		x	x
Follow-up	6y	>20y	4y	1.5y	9y

Legend:
CS: case series; nm: not mentioned;
M: Male; F: Female;
MA: mean age; y: years; x: present

Characteristics of the participants

The included studies enrolled a total of 302 patients and counted 346 critical maxillary canine impactions and candidates for comprehensive surgical approach. The impacted canines were defined by complex position, failure of a previous attempt at treatment, dilaceration, ankylosis, suggestion from the orthodontist. The age of the participants ranged from eleven to 76 years old (mean age 22.5 years). The distribution of men and women was described in all of the studies (112 males and 190 females).

Decision criteria for labeling maxillary canine impaction as critical (Fig. 3)

One study only included patients with a diagnosis of a complex impaction described as follows: the canines were all impacted and in a difficult position, so

that orthodontic treatment was either impossible or would have been complicated and time-consuming.[26] Two studies included canines with dilacerations or apical root ankylosis.[19,20] One of those studies only included canines with a history of failure of previous treatment with surgical exposure and/or orthodontic traction.[20]

Two studies considered canine impaction to be critical based upon the opinion of the orthodontist concerning the severity of impaction.[21,27]

Pre-operative assessment

In four studies pre-treatment assessment was performed with clinical and radiographic examination (2D).[20,21,26,27] One study mentioned the use of a CBCT scan.[19]

Characteristics of the interventions (Figure 3)

Autotransplantation was performed for 313 of the impacted canines (Figure 3), whereas 33 canines received an apicotomy. These surgical techniques were sufficiently described in the reviewed articles.

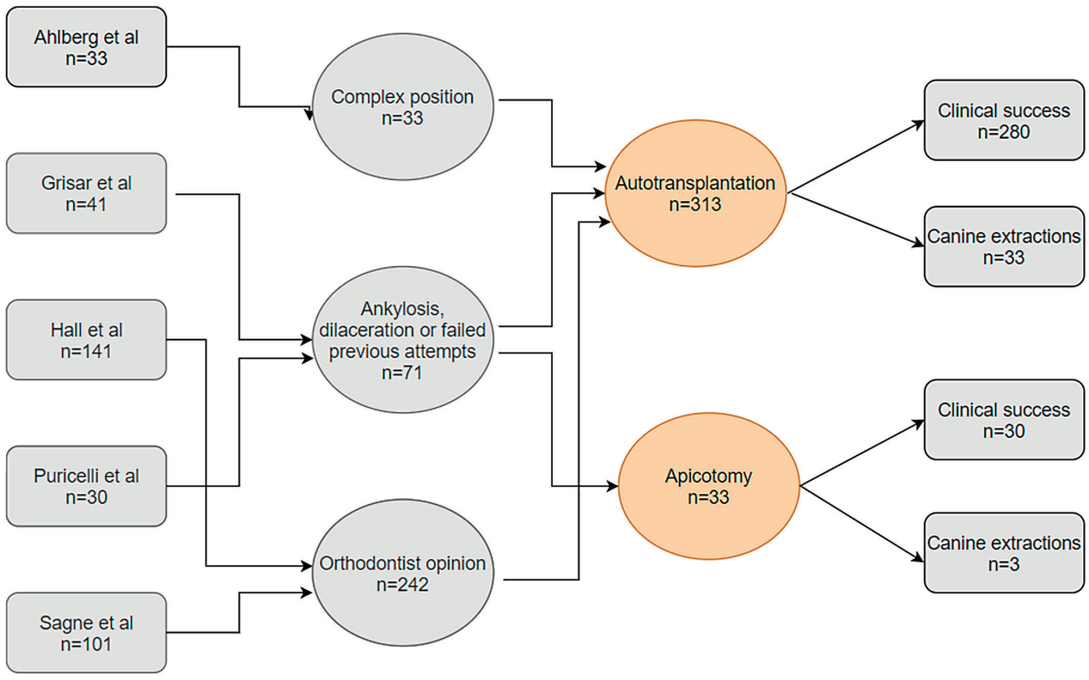

Figure 3. *Criteria for critical canine impaction, surgical interventions and their outcome.*

Four articles reported autotransplantation of the critically impacted maxillary canine: autotransplantation is the atraumatic surgical removal and movement of the maxillary canine from the impaction site to the correct position within the alveolar crest.[19,21,26,27] One study evaluated an apicotomy procedure as described by Puricelli et al: a sufficient flap is elevated in order to expose the apical region of the canine. Manual removal or removal by means of an osteotomy of the cortical bone covering the apex of the impacted canine, is performed. The apical third is separated from the rest of the root with a double-bevel chisel applied in a bone grove previously prepared with a bur. Separation of the two segments has to be established and then the crown section is prepared for further orthodontic traction.[20]

Post-operative assessment

Post-operative follow-up was performed by clinical examination or combined clinical and radiographic examination, including panoramic radiography and/or CBCT. Only one study reported the use of standardized indices for follow-up after treatment.[19]

Characteristics of the outcome measures (Figure 3)

Aesthetics or function outcomes were reported in most of the included studies. One study reported the use of standardized indices for radiographic and aesthetic evaluation.[19] The presence of the canine in the tooth arch was considered a successful outcome. Out of the 313 autotransplantations performed, 280 interventions were considered adequate, while 33 canines were lost. Apicotomy was successful in 30 of the 33 cases enrolled in the reviewed studies and 3 other cases resulted in extraction of the impacted canine.

Duration of treatment time and mean follow-up

Mean follow-up varied between the different studies, ranging from 1.5 years to more than 20 years. The duration of maintenance treatment and follow-up varied considerably between studies, ranging from 1.5 years to more than 20 years.

Quality assessment

The reviewed studies were considered to be of medium quality after assessment with the tool suggested by Murad et al.[25] The risk-of-bias assessment was independently performed by two review authors (Table 4).

Table 4. *Risk-of-bias analysis according to Murad et al (2018).*

	Ahlberg et al (1983)[26]	Grisar et al (2018)[19]	Hall et al (1983)[21]	Puricelli et al (2007)[20]	Sagne et al (1997)[27]
Selection					
Do(es) the patient(s) represent(s) the whole experience of the investigator (center) or is the selection method unclear to the extent that other patients with similar presentation may not have been reported?	yes	yes	yes	yes	yes
Ascertainment					
Was the exposure adequately ascertained?	NA	NA	NA	NA	NA
Was the outcome adequately ascertained?	yes	yes	yes	yes	yes
Causality					
Was follow-up long enough for outcomes to occur?	yes	yes	yes	yes	yes
Reporting					
Is/are the case(s) described with sufficient details to allow other investigators to replicate the research or to allow practitioners to make inferences related to their own practice?	yes	yes	yes	yes	yes
Overall judgement					
	medium quality	medium quality	medium quality	medium quality	medium quality

DISCUSSION

DEFINITION OF CRITICAL MAXILLARY CANINE IMPACTION

The tendency of impacted upper canines to fail to respond to conventional orthodontic and/or surgical treatment options, categorizes the condition as critical maxillary canine impaction. Maxillary canine impaction shows great variability, with a corresponding range of treatment strains. The majority of impacted maxillary canines display mesially tipped crowns pressing on the roots and distally tipping the lateral incisors. Any additional deviation from this position will further raise the difficulty of treatment planning and lower the predictability of the procedures. A number of studies have reported that the majority of the impacted maxillary canines are situated in a palatal position and intra-alveolar. Only a minority are impacted in a labial position.[18] A complete horizontal orientation of the canine is considered difficult to treat. However, this is rarely found.[28] Vertical position in the alveolar ridge or palate may range from low to very high. Highly positioned canines with severely transposed roots are considered to have the most unfavorable treatment prognosis.[29] Canines positioned 14 millimeter or more above the occlusal plane require a longer

treatment time.[3] Furthermore, a patient's age may also affect treatment difficulty and duration, with a strong positive correlation between increasing age, vertical height and mesial displacement of the cusp tip with treatment difficulty.[5,30]

Apart from the impacted canine position, ankylosis, local obstructive pathology or root abnormalities will further increase treatment complexity.[3]

Imaging modalities for critical maxillary canine impaction

In severe maxillary canine impactions, the use of CBCT will enhance the diagnostic capabilities and improve the chances of treatment success to a level similar to that of simpler cases treated on the basis of 2D information.[15] Wriedt et al stated that small volume CBCT may be justified as a supplement to a routine panoramic radiograph in cases where canine inclination in the panoramic radiograph exceeds 30°, when root resorption of adjacent teeth is suspected and/or when the canine apex is not clearly discernible, raising suspicion of dilaceration.[32] CBCT images will provide different information regarding tooth position (especially concerning the mesio-distal apex position and the labio-palatal cusp position) but also in the assessment of root resorption and ankylosis.[33]

A recent systematic review of the literature comparing CBCT and conventional radiography in localization of maxillary impacted canines suggested that CBCT is more effective than conventional radiography in evaluating cases that are difficult to diagnose in the initial evaluation with 2D radiography.[34] The reviewed studies are not confirmatory for these findings, nor do they contradict them, as labeling the impaction as critical was only in one study supported by 3D imagery.[19]

Management of critical maxillary canine impaction

Different treatment strategies have been reported in the literature concerning critical maxillary canine impaction. The literature provides mainly case reports addressing this condition and usually revolves around successful treatments whereas failure is seldom mentioned. Treatment or re-treatment with conventional surgical exposure and orthodontic traction is frequently reported in the literature in the form of case reports.[35-41] Similarly, autotransplantation and apicotomy are techniques often illustrated in one-patient reports.[42-44]

Other studies reported segmental osteotomy, removal of the impacted canine with partial maxillary osteotomy, removal of the deciduous canine and monitoring, removal of the central incisor with surgical exposure and orthodontic traction of the impacted canine and finally also removal of both canines followed by orthodontic mesialization of maxillary posterior teeth.[44-48]

Primary or secondary treatment with surgical exposure and orthodontic traction of the impacted canine and autotransplantation are to the most frequently reported in the literature. And although there are sufficient studies reporting good to excellent outcomes for these approaches concerning impacted

maxillary canines, there are no high-quality studies reporting the outcome of these approaches in critical maxillary canine impaction.[49]

When local factors inhibit tooth movement, a second surgical intervention is often needed. In case of ankylosis, mobilization of the ankylosed tooth with forceps and immediate orthodontic traction is a technique used to enhance orthodontic movement. However, there are no studies reporting the outcome of this treatment strategy. When this fails, removal of the impacted canine is often the treatment of choice.[6,31]

Aside from the patient-related factors mentioned above, orthodontist or surgeon related factors can equally influence treatment prognosis. Failure of orthodontic traction therefore does not automatically mean critical maxillary canine impaction. Comprehensive treatment planning, with accurate determination of the canine position and anatomy, along with good communication between orthodontist and surgeon (using a standardized classification describing the canine position) are essential for treatment outcome.

As the literature mainly consists of case reports and series, it can be assumed that there is an underreporting of the amount of critical maxillary canine impactions and attempts to treat them. Oftentimes, these teeth will be surgically removed or not treated at all.

Summary of the evidence

Both apicotomy and autotransplantation score a rather encouraging success rate converging to 90% in the reviewed studies (30 successful apicotomies out of 33 performed, 280 favorable results for autotransplantations from a total of 313 performed). This observation, however, should be carefully appraised and objectively put into the context of the qualitative analysis of these studies.

The studies included in this systematic review provide low evidence to support the clinical techniques investigated. Besides study design (case series), other sources of bias are present: high heterogeneity of the study populations (different types of impactions, age, treatment modalities) and non-standardized outcome measurements. Additionally, some of the included studies are somewhat outdated considering their date of publication. There is bias in the pre-treatment radiological assessment. Some studies only performed 2D imaging while others also included 3D imaging. One could argue that this might affect the outcome of the research, as the choice of treatment could have been different depending on whether initial diagnostics comprised CBCT or conventional radiography. However, all studies did succeed in long patient follow-ups. One study even reported a mean follow-up period of 20 years.[19]

Overall completeness and applicability of the evidence

This review included five case series on the treatment of critical maxillary canine impaction (Table 4). Considering the small number and the type of study design in these papers, there is insufficient evidence for powerful conclusions on the efficiency of the surgical techniques presented.

None of the included studies reported adequate guidelines for pre-operative clinical and radiographic assessment, a comprehensive definition of critical maxillary canine impaction or a protocol for treatment planning according to clinical presentation of the anomaly.

CONCLUSIONS

Implications for practice

Through the findings of the current study, it has become clear that the literature is lacking high-quality clinical trials that could form the basis of clinical guidelines or at least define predictability of different treatment modalities for critically impacted canines. Although there is currently insufficient evidence, interventions like apicotomy and autotransplantation may be considered as alternative treatment modalities, alongside the classic strategies, mainly for critical maxillary impactions.

Implications for research

The lack of randomized controlled trials limits the power of the present review as a source for practical recommendations. The results do, however, emphasize the need for further research in this area. It should focus on clearer definitions of critical maxillary canine impaction, diagnostic protocols, a more patient-specific clinical strategy, standardized long-term clinical success and patient satisfaction parameters. Within the framework of randomized controlled trials and with sufficient sample sizes of critical canine impactions, future research might validate apicotomy and autotransplantation as predictable treatment options.

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CHAPTER 4

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Piccart F, Al-Rimawi AS, Basso I, Politis C, Jacobs R. Three-dimensional position of impacted maxillary canines: Prevalence, associated pathology and introduction to a new classification system. Clin Exp Dent Res. 2019 Feb;5(1):19-25. doi: 10.1002/cre2.151. Epub 2018 Dec 19. PMID: 31943949.

THREE-DIMENSIONAL POSITION OF IMPACTED MAXILLARY CANINES: PREVALENCE, ASSOCIATED PATHOLOGY AND INTRODUCTION TO A NEW CLASSIFICATION SYSTEM

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ABSTRACT

OBJECTIVES: Classification of impacted maxillary canines facilitates interdisciplinary communication. Cone Beam Computed Tomography (CBCT) has proven to be superior for the localization of impacted maxillary canines compared to 2D imaging. The purpose of this study was to retrospectively classify a cohort of impacted maxillary canines, using a newly developed 3D classification for impacted maxillary canines that is easy to use and does not require complex analysis of the 3D images.

MATERIAL AND METHODS: A retrospective cohort study was designed, containing CBCT data of 130 patients (male/female: 48/82; median age: 16) with a total of 162 impacted maxillary canines. The proposed classification was based on four criteria: vertical crown position, mesiodistal tooth position, buccolingual crown position and associated pathology. For all included patients, classification criteria were identified and correlated to treatment selection using a newly developed 3D classification.

RESULTS: The most common positions were vertical crown position at apical one third of neighboring teeth, mesiodistal tooth angulation and palatal crown position. The most frequently associated pathologies were dilaceration of the root and resorption of a neighboring tooth. Significant associations among classification variables and treatment options were observed.

CONCLUSION: CBCT enabled 3D assessment of impacted maxillary canines allowing a classification system that may have an impact on further treatment strategies.

INTRODUCTION

Impacted maxillary canines are relatively common. When not considering the third molar, the maxillary canine is the most frequently impacted tooth.[1-3] The prevalence of impacted maxillary canines is reported to be in between 0.9 and 3.3%.[1-3] The maxillary impacted canine is more often located palatally (85%) than labially (15%).[1-6] Root dilaceration is reported to be present in up to 59.5% of the cases.[7]

Maxillary canines play a key role in facial aesthetics, development of the dental arch, and occlusion. However, impacted maxillary canines are difficult and time consuming to treat. Moreover, they vary greatly in the inclination and location. Untreated partially erupted or impacted canines may result in several complications such as shortening of the dental arch, formation of follicular cysts, canine tooth ankylosis, recurrent infections, pain, internal resorption, external resorption of the canine and adjacent teeth, or combinations of these factors.[8]

Management of impacted maxillary canines requires an accurate localization. Conducting an assessment by a 3D radiographic examination allows for the evaluation of several positional factors that are related to the degree of difficulty of further treatment, such as the exact position relative to neighboring structures and the orientation over the longitudinal, vertical and horizontal axis of the impacted tooth.[9] Diagnosis of associated pathology such as root resorption of the lateral incisors, root dilaceration or ankylosis will influence further treatment decisions.[10]

Impacted teeth are reportedly more difficult to treat in adults. Becker stated that the success rate among patients over 30 years of age was 41%, whereas the success rate for those 20 to 30 years of age was 100%.[11]

So far, few studies have suggested 3D classification systems for impacted maxillary canines based upon their radiological position. The intention is, based on these classifications, to allow for a quick determination of the degree of difficulty of an impacted maxillary canine, thus impacting any related treatment strategy.[12-14]

However, these classifications do not consider possible root anomalies, interactions with surrounding anatomical structures or associated pathology. Moreover, they require multiple measurements and are time consuming.

Given the lack of studies with an easy to use and straightforward CBCT-based classification for impacted maxillary canines, the aim of the present study is to propose a 3D classification of the position of impacted maxillary canines. A secondary objective is to determine a potential association between the proposed classification and further treatment options.

MATERIAL AND METHODS

Subjects

The study protocol was approved by the Ethics Committee of the university Hospitals Leuven (s number: s53225).

CBCT imaging of the upper jaw, taken at the department of oral and maxillofacial surgery between 2012 and 2016 was screened for the presence of impacted maxillary canines. An impacted tooth is one that fails to erupt into the dental arch within a specific time period. In this study, a tooth was considered impacted when completely or partially intraosseous with more then two thirds of its root developed. Patients were 13-40 years of age at the time of the radiographic acquisition. Patients with syndromic diseases were excluded. There was no active orthodontic treatment at the time of acquiring CBCT.

Out of the initial group of 4399 CBCT scans, data from 130 patients (48 male, 82 female; age range 13-41 years) with 162 impacted maxillary canines was obtained. Thirty-two CBCT scans showed bilateral impaction of the maxillary canines. Information on gender, unilateral/bilateral occurrence, side, location, root dilaceration, root resorption of the adjacent teeth and other associated local conditions was gathered. The selected impacted maxillary canines were matched to our classification system.

Radiographic evaluation of canine location

CBCT images were obtained with ProMax 3D (Planmeca, Helsinki, Finland), 3D Accuitomo 170 (J. Morita, Kyoto, Japan) or Newtom VGi evo (Newtom, Verona, Italy) according to the normal clinical protocol for the specific indication and related to the specific machine parameters. Images were evaluated in axial, sagittal and coronal planes using IMPAX software (Agfa, Mortsel, Belgium). In this software it is possible to scroll through the x, y and z planes to best locate and report on the issue of interest.

Next to assessing the location of the canine in three dimensions of the CBCT dataset, the index also scores possible root anomalies, ankylosis and ectopic position. This combination will lead to a proposal for classification and associated treatment plan as well as a proposal on the prognosis in case an easily located canine has one of the before mentioned anomalies. The proposed classification system is easy to use and does not require complex analysis of the 3D imaging. In this way a clinician should be able to perform the classification procedure directly following the clinical assessment of the patient.

1. The 3D variations of impaction

a. Vertical position of the canine cusp tip on the y-axis compared to the adjacent teeth. This will be analyzed on the 3D PANORAMIC view (Figure 1).
   i. Cusp tip lies in a horizontal plane occlusal to the cemento-enamel junction of the incisor.
   ii. Cusp tip lies in a horizontal plane with the cervical third of the incisor root.
   iii. Cusp tip lies in a horizontal plane with the middle third of the incisor root.
   iv. Cusp tip lies in a horizontal plane with the apical third of the incisor root.
   v. Cusp tip is supra-apical to the incisor root.

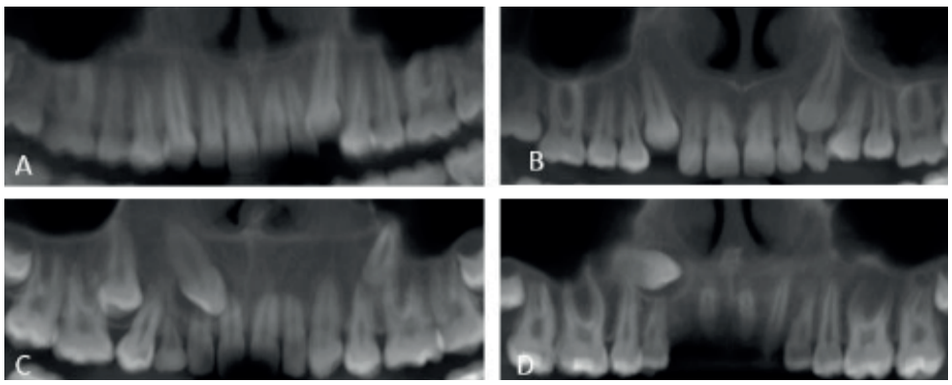

Figure 1. *Vertical position of the impacted maxillary canine cusp (A. Cervical 1/3; B. Middle 1/3; C. Apical 1/3; D. Supra-apical).*

b. Mesiodistal position of the canine on the x-axis compared to the adjacent teeth. This will be analyzed on the 3D PANORAMIC view (Figure 2).
   i. MD angulation (mesial position crown, distal position apex)
   ii. DM angulation (distal position crown, mesial position apex)
   iii. Vertical position
   iv. Horizontal position
   v. Ectopic or inverted position

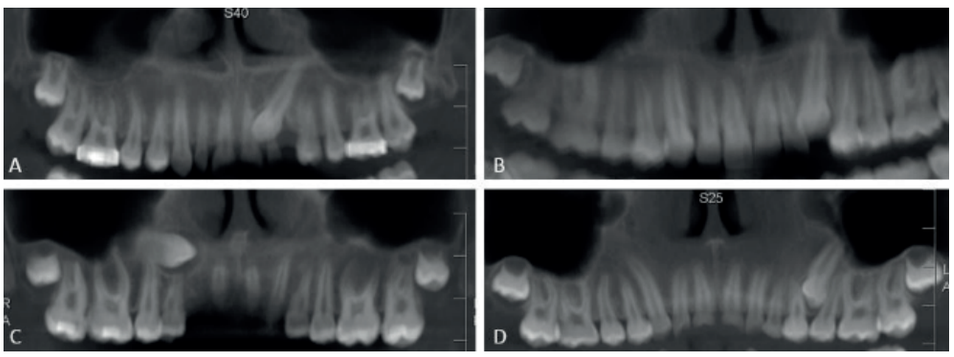

Figure 2. *Mesiodistal position of the impacted maxillary canine cusp (A. Mesiodistal angulation; B. Vertical; C. Horizontal; D. Transposition).*

c. Buccopalatal cusp tip position on the z-axis compared to the adjacent teeth. This will be analyzed on the axial views (Figure 3).
   i. Vestibular position, outside of the outline as suggested by the neighboring teeth
   ii. Intra-alveolar position, within the area as suggested by the vestibular and palatal outlines of the neighboring teeth
   iii. Palatal position, outside of the outline as suggested by the neighboring teeth

Figure 3. *Buccolingual position of the impacted maxillary canine cusp (A. Vestibular; B. Intra-alveolar; C. Palatal).*

2. Associated pathology. This will be analyzed on the axial, sagittal and coronal views (Figure 4).

a. Root dilacerations, interaction with surrounding anatomical structures was evaluated.
   b. Ankylosis
   c. Relation to neighboring anatomical structures
   d. Resorption of neighboring teeth
   e. Presence of odontoma or other local pathology

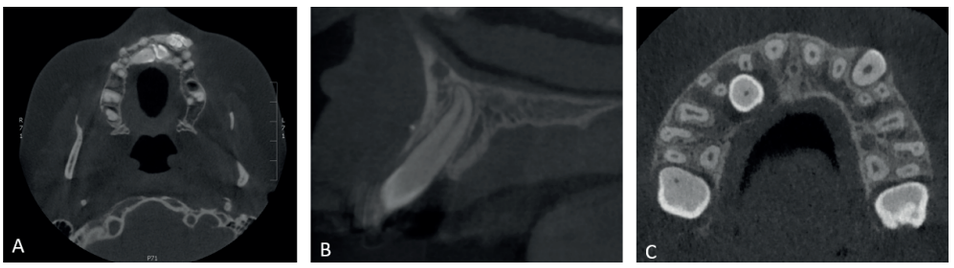

Figure 4. *Associated anomalies of the impacted maxillary canine cusp (A. Odontoma; B. Dilaceration; C. Resorption of lateral incisor).*

Applied treatment

The applied treatment for the impacted maxillary canine was recorded by screening clinical records and graded as follows:

- Monitoring, with or without removing the primary canine
- Surgical exposure
- Surgical removal
- Autotransplantation

Statistical analysis

Data were summarized by means of frequency tables. Relations between the position or treatment on the one hand and (for position) treatment or associated pathology on the other hand were assessed by means of cross-tabulations and a Fisher exact test.

RESULTS

Patient and maxillary canine characteristics

Among the 4399 CBCTs screened, impacted maxillary canines were identified in 130 patients with a total of 162 impacted canines. Patient characteristics are described in Table 1. Patient age ranged from 13-41 years (mean age: 18; SD +/-6.47). Regarding gender, 48 patients were male (36.9%) and 82 female (63.1%). In 32 patients, there was bilateral impaction of the maxillary canines. Unilateral impacted maxillary canines were situated almost equally on both right side (n=79; 49%) and left side (n=83; 51%). Distribution of the 162 impacted maxillary canines according to the proposed classification is presented in Table 2. Impacted maxillary canines were most frequently found to be vertically positioned at the middle third of the incisor root (n=79; 48.8%), to have a mesiodistal angulation (n=111; 68.5%) and an intra-alveolar buccolingual position (n=88; 54.3%). Most frequently associated anomalies were dilaceration of the root (n=29; 17.9%) and resorption of neighboring teeth (n=24; 14.8%). In case of resorption, this was mainly concerning the lateral incisor. 6.8% of the impacted maxillary canines was found to be ankylosed (n=11).

Table 1. *Characteristics of the patients.*

Variables	Frequency (n)	(%)
Patient age (years)		
13-19	107	82.3%
20-29	12	9.2%
30+	12	9.2%
Sex		
Male	51	39.2%
Female	79	60.8%
Location		
Unilateral	98	75.4%
Bilateral	32	24.6%
Right	79	48.8%
Left	83	51.2%

Table 2. *Distribution of impacted maxillary canines along 3D classification.*

Variables	Frequency (n)	(%)
Vertical position		
Above the cemento-enamel junction of the incisor	4	0.6%
At the cervical third of the incisor root	17	10.5%
At the middle third of the incisor root	79	48.8%
At the apical third of the incisor root	55	34%
Supra-apical	7	4.3%
Mesiodistal position		
Mesiodistal angulation	111	68.5%
Distomesial angulation	0	0%
Vertical	28	17.3%
Horizontal	22	13.6%
Ectopic or inverted	1	0.6%
Buccolingual position		
Vestibular	24	14.8%
Intra-alveolar	88	54.3%
Palatal	50	30.9%
Associated anomalies		
Ankylosis	11	6.8%
Dilaceration	29	17.9%
Association with the nasal cavity	10	34.5%
Association with the floor of the sinus	8	27.6%
Association with the roots of the first premolar	2	6.9%
No association	9	31%
Resorption	24	14.8%
Central Incisor	2	8.3%
Lateral Incisor	19	79.2%
Premolar 1	4	17%
Premolar 2	1	4.2%
Odontoma	3	1.9%

Association between tooth position and anomalies

We observed significant relations between tooth position and anomalies considering vertical position and ankylosis, between mesiodistal and buccolingual position and dilaceration. Ankylosis was more frequently observed in cases of high vertical position above cemento-enamel junction CEJ (2 cases, $p<0.05$). Dilaceration was more often observed in case of horizontal position or mesial angulation (respectively 4 and 27 cases, $p=0.05$). Dilaceration was mostly observed in case of palatal position (22 cases, $p<0.05$).

Table 3. *Treatment choices.*

Variables	Frequency (n)	(%)
Monitoring with or without removing the primary canine	11	10.6%
Surgical exposure	59	56.7%
Surgical removal	15	14.2%
Autotransplantation	19	18.3%

Treatment

In 46 patients (58 impacted maxillary canines), the further treatment plan was not reported in the medical records, considering referral by external orthodontist for imaging only. In the group with complete patient records (84 patients, 104 impacted maxillary canines), the following treatment modalities were reported: surgical exposure of the impacted maxillary canine (n=59; 56.7%), autotransplantation (n=19; 18.3%), removal (n=15; 14.2%) and watchful waiting with or without removal of the primary canine (n=11; 14.2%). Treatment options are summarized in Table 3.

Association between tooth position and treatments

The associations between choice of treatment and each of the classification variables were also evaluated (Table 4). We only observed a significant relation between mesiodistal position and treatment option: in case of horizontal position of the impacted maxillary canine, autotransplantation was most often preferred as the treatment choice (10 cases, $p<0.05$). For impacted canines with mesial angulation or vertical position, surgical exposure and traction was the treatment of choice (respectively 43 and 10 cases, $p<0.05$). There was only one case of transposition of the impacted maxillary canine and there the clinician opted for surgical removal of the canine involved.

No significant association could be observed between choice of treatment and vertical or buccolingual position or associated anomalies.

Table 4. *Association between treatment choices and classification variables.*

	Spontaneous eruption	Transplantation	Removal	Surgical exposure	Spontaneous eruption (%)	Transplantation (%)	Removal (%)	Surgical exposure (%)
Mesiodistal position								
Horizontal (n)	0*	10*	3*	6*	0*	52.6*	15.8*	31.6*
Mesio-angulation (n)	10*	7*	11*	43*	14.1*	9.9*	15.5*	60.6*
Transposition (n)	0	0	1	0	0	0	100	0
Vertical (n)	1*	2*	0*	10*	7.7*	15.4*	0*	76.9*
Horizontal (%)	0	52.6	20	10.2				
Mesio-angulation (%)	90.9	36.8	73.3	72.9				
Transposition (%)	0	0	6.7	0				
Vertical (%)	9.1	10.5	0	16.9				
Ankylosis								
Yes (n)	0	3	1	1	0	60	20	20
No (n)	11	16	14	58	11.1	16.2	14.1	58.6
Yes (%)	0	15.8	6.7	1.7				
No (%)	100	84.2	93.3	98.3				

*Significant results are marked with a * ($p<0.001$)*

DISCUSSION

Most of the literature on classification of impacted maxillary canines contains results based on 2D images. Recently suggested 3D classifications do not consider possible root anomalies, interactions with surrounding anatomical structures or associated pathology. Moreover, they require multiple measurements and are time consuming. *

The aim of this study was to propose an alternative 3D classification system for the position and possible associated anomalies of impacted maxillary canines.

A preoperative CBCT examination is considered an important assessment tool for planning the treatment of impacted maxillary canines and for the choice of treatment. Some important findings that may affect this choice can only be obtained from CBCT images and not from 2D images. Among them is the buccolingual position, the real proximity of the roots to the floor of the sinus or nasal cavity, anatomy of the apical part of the root, signs of ankylosis or root resorption of neighboring teeth.[8,15,16]

In our population characteristics we found that most of our patients were 19 years of age or younger (82.3%). This is to be expected when investigating impacted maxillary canines since most of the patients will receive orthodontic or surgical treatment in this age group.

When we consider gender, we observe more female patients within our population. This is in line with the findings in the current literature.[7]

Most of the cases were unilateral and there was an equal left/right distribution. Regarding the distribution of the impacted maxillary canines along our newly suggested classification, we observed that most of the teeth were found in an intra-alveolar position in a mesio-distal angulation with the cusp in the same horizontal plane as the middle third of the incisor root.

Prevalence rates of ankylosis (14.8%), dilacerations (17.9%), resorption of neighboring teeth (14.8%) or odontoma (1.9%) were comparable to other reports in the current literature.[7,17-23]

When considering the relation between the position of the impacted maxillary canine and the choice of treatment, we observed a significant difference evaluating the mesiodistal position. Horizontal position was more frequently associated with autotransplantation of the maxillary canine. In case of mesial angulation or vertical position, surgical exposure and traction was the treatment of choice. This is to be expected, considering that autotransplantation is mostly associated with a more complex localization of the impacted maxillary canine.

Future studies should investigate the relationship between this classification system and treatment outcomes so that a scoring system can be developed for the prediction of treatment duration, risks and success rate. This would be helpful in the management of patients with impacted maxillary canines. It would also help in correctly estimating the costs of the treatment involved.

CONCLUSIONS

Planning of impacted maxillary canine treatment should be based on 3D images. With CBCT it is possible to correctly define the position of the impacted maxillary canine and to recognize accompanying abnormalities such as ankylosis, dilaceration of the root with or without anchorage to the floor of the sinus or nasal cavity, resorption of neighboring teeth or odontoma.

The present study proposes the use of a standardized classification system, aiding identification of more challenging cases. The proposed classification system is easy to use clinically, allowing assessment and decision for further treatment following patient examination. In the long run, this classification may be able to predict outcome expectations.

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CHAPTER 5

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

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INTERVENTIONS FOR IMPACTED MAXILLARY CANINES: A SYSTEMATIC REVIEW ON THE RELATIONSHIP BETWEEN INITIAL CANINE POSITION AND TREATMENT OUTCOME

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ABSTRACT

OBJECTIVES: 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.

MATERIAL AND 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, aesthetics 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 (buccopalatal position, vertical position, canine angulation, root development).

CONCLUSION: 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.

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 aesthetic 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 thereof.[3] Therefore, a definitive diagnosis of an 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 aesthetic 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 the International Prospective Register of Systematic Reviews (PROSPERO no. 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).

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)	
Primary outcome	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.
Secondary outcomes	Aesthetic outcome Periodontal tissue outcome Treatment time, number of treatment visits Resorption of neighboring teeth Ankylosis

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, aesthetics, 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 (aesthetic 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).

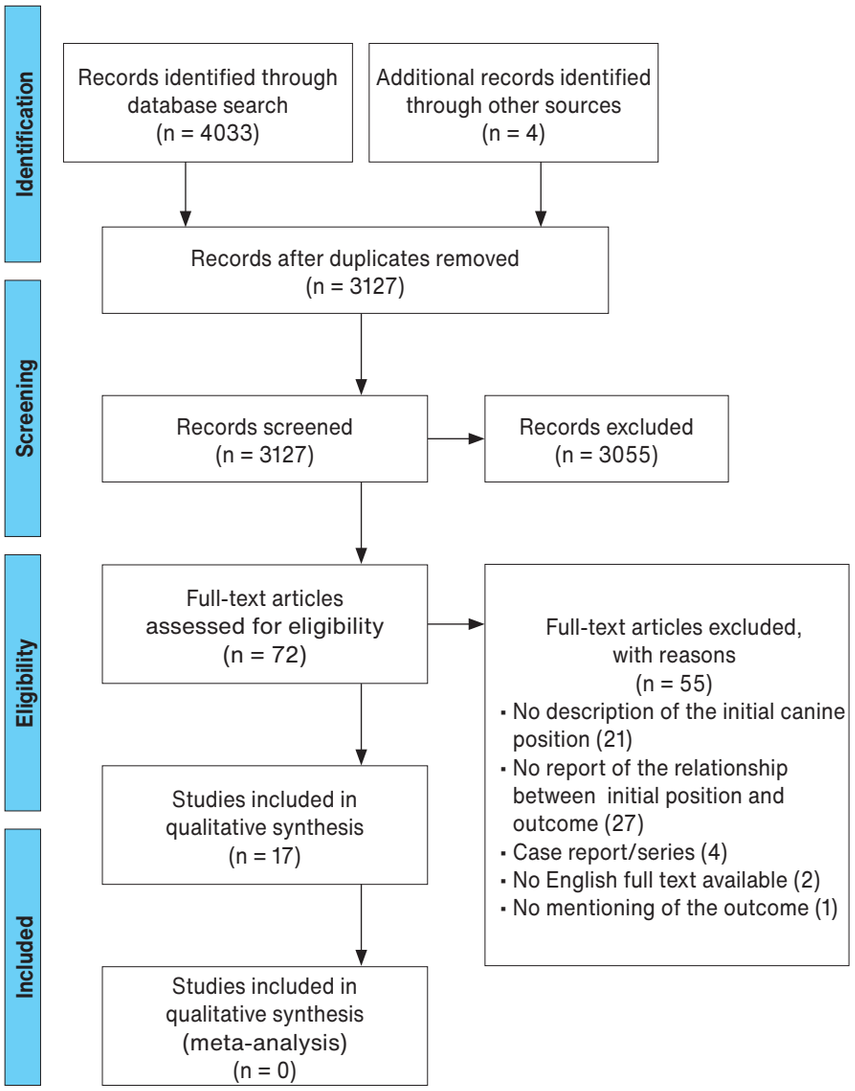

Figure 1. *Flow chart describing systematic research and study selection process.*

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 mid crestal impacted canines.[27,29,41,42]

Three studies failed to include or mention 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]

Table 2. *Summary of study characteristics and outcomes.*

Author (year)	Study design	Number of participants	Mean age ± 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	MC					2D Rx	3D Rx	Clinical
Arriola-Guillén et al (2019) [27]	Retrospective cohort	45	16.16 ±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 ± 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 ± 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 ± 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 ± 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]	Retro-spective 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]	Retro-spective 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]	Pro-spective 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]	Retro-spective 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]	Pro-spective 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]	Retro-spective cohort	47	14.4 ± 2.2	17/30	65	x			Ericson and Kurol classification; clinical examination	Surgical exposure and orthodontic traction	Debonding	Canine eruption	x		x
Zasciurinskiene et al (2008) [40]	Retro-spective cohort	32	18.2 ± 5.1	10/22	32	x			Ericson and Kurol classification (modified); clinical examination	Surgical exposure and orthodontic traction	3 months after debonding	Periodontal outcome	x		x
Zuccati et al (2006) [41]	Retro-spective cohort	87	16.7	Not speci-fied	108	x	x	x	Ericson and Kurol classification (modified); clinical examination	Surgical exposure and orthodontic traction	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

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 mid crestal). 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 retrospective 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 Kurol 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 impacted 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 transpalatal 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 teeth [27]; an "easy cuspid" device, a combination of modified Jonas Jig and modified ballista spring[31]; double arch technique[32]; and traction with cantilever soldered on a 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 one 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 months.[33,34] Total treatment time ranged between 19.6 ± 7.8 months and 30.3 ± 10.8 months.[34,41]

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

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, ten obtained a moderate score overall and two 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.

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)	Corres-ponding 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 prospective studies, and 3 retrospective studies)	⊕⊖⊖⊖ 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 treatment	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.

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
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% increasein 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

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 twelve 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 the 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 (± 21 months) for closed surgical-orthodontic treatment of buccally and palatally displaced maxillary canines.[42] However, they applied strict exclusion criteria (only Ericson and Kurol 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 for 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 mostly 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, 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 an orthodontic button or bracket. 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 arch wires, elastomeric chains, 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.

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 buccally 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 outcome and expected difficulties. A palatally impacted maxillary canine in close proximity to 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 close proximity to 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 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 one- and two-year follow-up: Maxillary Canine Aesthetic Index (MCAI) for aesthetic 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.

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SUPPLEMENTAL MATERIAL

Supplemental Table 1. Search strategy.

PubMed	Concept 1: maxillary and canines ((“Maxilla”[Mesh] OR maxilla*[tiab] OR “upper jaw”[tiab] OR “upper jaws”[tiab]) AND (“Cuspid”[Mesh] OR cuspid*[tiab] OR canine*[tiab]))
	Concept 2: problem tooth ((“Tooth, Impacted”[Mesh] OR “impacted tooth” [tiab] OR “impacted teeth” [tiab] OR “Impacted canine” [tiab] OR “Impacted canines” [tiab] OR “Tooth Eruption, Ectopic”[Mesh] OR “ectopic tooth eruption” [tiab] OR “ectopic tooth” [tiab] OR “ectopic teeth” [tiab] OR “ectopic canine” [tiab] OR “ectopic canines” [tiab] OR “Tooth, Unerupted”[Mesh] OR “unerupted tooth” [tiab] OR “unerupted teeth” [tiab] OR “unerupted canine” [tiab] OR “unerupted canines” [tiab] OR “retained tooth” [tiab] OR “retained teeth” [tiab] OR “retained canine” [tiab] OR “retained canines” [tiab]))
Embase	Concept 1: maxillary and canines ((‘maxilla’/exp OR maxilla*:ti,ab OR ‘upper jaw’:ti,ab OR ‘upper jaws’:ti,ab) AND (‘canine tooth’/exp OR ‘canine tooth’:ti,ab OR ‘canine teeth’:ti,ab OR cuspid*:ti,ab OR canine*:ti,ab))
	Concept 2: problem tooth ((‘tooth disease’/exp OR ‘impacted tooth’:ti,ab OR ‘impacted teeth’:ti,ab OR ‘Impacted canine’:ti,ab OR ‘Impacted canines’:ti,ab OR ‘ectopic tooth eruption’:ti,ab OR ‘ectopic teeth eruption*’:ti,ab OR ‘ectopic tooth’:ti,ab OR ‘ectopic teeth’:ti,ab OR ‘ectopic canine*’:ti,ab OR ‘unerupted tooth’:ti,ab OR ‘unerupted teeth’:ti,ab OR ‘unerupted canine*’:ti,ab OR ‘retained tooth’:ti,ab OR ‘retained teeth’:ti,ab OR ‘retained canine*’:ti,ab))
Web of Science	Concept 1: maxillary and canines ((maxilla* OR “upper jaw” OR “upper jaws”) AND (cuspid* OR canine*))
	Concept 2: problem tooth ((“impacted tooth” OR “impacted teeth” OR “Impacted canine*” OR “ectopic tooth eruption” OR “ectopic teeth eruption” OR “ectopic tooth” OR “ectopic teeth” OR “ectopic canine*” OR “unerupted tooth” OR “unerupted teeth” OR “unerupted canine*” OR retained tooth OR “retained teeth” OR “retained canine*”))
Cochrane	Concept 1: maxillary and canines (maxilla* OR “upper jaw” OR “upper jaws”) AND ([cuspid] OR cuspid* OR canine*))
	Concept 2: problem tooth (“Tooth, Impacted”OR “impacted tooth” OR “impacted teeth” OR “Impacted canine” OR “Impacted canines” OR “Tooth Eruption, Ectopic” OR “Tooth eruption ectopic” OR “teeth eruption ectopic” OR “ectopic tooth” OR “ectopic teeth” OR “ectopic canine” OR “ectopic canines” OR “Tooth, Unerupted” OR “unerupted tooth” OR “unerupted teeth” OR “unerupted canine” OR “unerupted canines” OR “retained tooth” OR “retained teeth” OR “retained canine” OR “retained canines”)

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

Author	Bacetti et al (2011)	Bazargani et al (2014)	Naoumova et al (2014)
Domain 1: risk of bias arising from the randomization process			
1,1	NI	YES	YES
1,2	PN	YES	YES
1,3	NO	NO	PN
	High Risk	Low Risk	Low Risk
Domain 2a: ROB due to deviations from the intended interventions (effect of assignment)			
2,1	YES	NO	YES
2,2	YES	YES	YES
2,3	PN	NO	NP
2,4	NA	NA	NA
2,5	NA	NA	NA
2,6	PY	YES	YES
2,7	NA	NA	NO
	Low Risk	Low Risk	Low Risk
Domain 2b: ROB due to deviations from the intended intervention (effect of adhering to the intervention)			
2,1	YES	NO	YES
2,2	YES	YES	YES
2,3	PY	NO	NA
2,4	PN	PN	NA
2,5	NO	NO	NA
2,6	PN	NO	YES
	High Risk	Low Risk	Low Risk
Domain 3: risk of bias due to missing outcome data.			
3,1	YES	YES	YES
3,2	NA	NA	NO
3,3	NA	NA	YES
3,4	NA	NA	NA
	Low Risk	Low Risk	Low Risk
Domain 4: risk of bias in measurement of the outcome data			
4,1	NO	NO	NO
4,2	NO	NO	NO
4,3	YES	YES	YES
4,4	NO	NO	NO
4,5	NA	NA	NA
	Some Concerns	Low Risk	Low Risk
Domain 5: risk of bias in selection of the reported result			
5,1	YES	YES	YES
5,2	NO	NO	NO
5,3	NO	NO	NO
	Low Risk	Low Risk	Low Risk
OVERALL	High Risk	Low Risk	Low Risk

Abbreviations:
▪ PY: probably yes; ▪ PN: probably no; ▪ NA: not applicable

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

Author	Prospective studies	Koutzoglou et al (2012)	Sigler et al (2011)	Retrospective studies	Arriola-Guillen et al (2019)	Caprioglio et al (2019)	Crescini et al (2017)	
Bias domain								
Bias due to confounding								
1,1		YES	YES		YES	YES	YES	
1,2		NO	NO		NO	NO	NO	
1,3		NO	NO		NO	NO	NO	
1,4		YES	PY		PY	YES	YES	
1,5		YES	NI		YES	YES	YES	
1,6		NO	NO		NO	NO	NO	
1,7		NA	NA		NA	NA	NA	
1,8		NA	NA		NA	NA	NA	
		Moderate	Moderate		Moderate	Moderate	Moderate	
Bias in selection of participants into the study								
2,1		NO	NO		NO	NO	NO	
2,2		NA	NA		NA	NA	NA	
2,3		NA	NA		NA	NA	NA	
2,4		YES	PY		NI	NO	NO	
2,5		NA	NA		NO	PN	NO	
		Moderate	Moderate		Moderate	Moderate	Moderate	
Bias in classification of interventions								
3,1		YES	YES		Yes	Yes	Yes	
3,2		YES	YES		Yes	Yes	Yes	
3,3		YES	YES		No	No	Yes	
		Moderate	Moderate		Low	Low	Moderate	
Bias due to deviations from intended interventions								
4,1		NO	NO		NO	NO	NO	
4,2		NA	NA		NA	NA	NA	
4,3		YES	PY		YES	YES	YES	
4,4		YES	YES		YES	YES	YES	
4,5		YES	YES		YES	YES	PY	
4,6		NA	NA		NA	NA	NA	
		Low	Low		Low	Low	Low	

	Fleming et al (2009)	Potrubacz et al (2018)	Power et al (1993)	Lee et al (2019)	Motamedi et al (2009)	Schubert et al (2009)	Stewart et al (2001)	Zasciurinskiene et al (2008)	Zuccati et al (2006)
	YES	YES	YES	YES	YES	YES	YES	YES	YES
	YES	NO	NO	NO	NO	NO	PN	NO	NO
	NO	NO	NO	NO	NO	NO	NO	NO	NO
	YES	PY	YES	YES	NO	YES	PY	NO	YES
	YES	YES	YES	YES	PY	YES	YES	PY	PY
	NO	NO	NO	NO	NO	NO	PN	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Moderate	Moderate	Moderate	Moderate	Serious	Moderate	Moderate	Serious	Moderate
	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
	NA	NA	NA	NA	NA	NA	NA	NA	NA
	NO	YES	PY	PN	YES	YES	PY	NI	NO
	NO	NA	NA	NO	NA	NA	NA	PN	NO
	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	PY	Yes	Yes	Yes	No	Yes	Yes	No	Yes
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Yes	Yes	Yes	No	No	Yes	PN	Yes	No
	Moderate	Moderate	Moderate	Low	Low	Moderate	Low	Moderate	Low
	NO	NO	PN	NO	NO	NO	NO	PN	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
	PN	YES	YES	PY	YES	PY	YES	YES	YES
	YES	YES	YES	YES	YES	YES	YES	YES	YES
	YES	YES	YES	YES	YES	YES	YES	YES	YES
	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Low	Low	Low	Low	Low	Low	Low	Low	Low

Author	Prospective studies	Koutzoglou et al (2012)	Sigler et al (2011)	Retrospective studies	Arriola-Guillen et al (2019)	Caprioglio et al (2019)	Crescini et al (2017)	
Bias due to missing data								
5,1		YES	YES		YES	YES	PY	
5,2		PN	NO		NO	NO	YES	
5,3		NO	NO		NO	PN	NO	
5,4		NA	NA		NA	NA	YES	
5,5		NA	NA		NA	NA	NO	
		Low	Low		Low	Low	Moderate	
Bias in measurement of outcomes								
6,1		PN	PN		NO	PY	PY	
6,2		YES	PN		YES	YES	YES	
6,3		YES	YES		YES	YES	YES	
6,4		NO	NO		PN	NO	NO	
		Low	Low		Low	Moderate	Moderate	
Bias in selection of the reported result								
7,1		NO	NO		PN	NO	YES	
7,2		NO	NO		NO	NO	PN	
7,3		NO	PN		NO	NO	NO	
		Low	Low		Low	Low	Low	
TOTAL		Moderate	Moderate		Moderate	Moderate	Moderate	

Abbreviations:
- PY: probably yes
- PN: probably no
- NA: not applicable
- NI: no information

	Fleming et al (2009)	Potrubacz et al (2018)	Power et al (1993)	Lee et al (2019)	Motamedi et al (2009)	Schubert et al (2009)	Stewart et al (2001)	Zasciurinskiene et al (2008)	Zuccati et al (2006)
	YES	PY	YES	YES	YES	YES	PY	YES	YES
	NO	NO	NO	YES	NO	NO	PN	NO	NO
	NO	NO	PN	NO	NO	NO	NO	PN	NO
	NA	NA	NA	YES	NA	NA	NA	NA	NA
	NA	NA	NA	NO	NA	NA	NA	NA	NA
	Low	Low	Low	Moderate	Low	Low	Low	Low	Low
	PN	NO	PY	PY	NO	PY	PY	YES	NO
	YES	YES	YES	YES	YES	YES	YES	YES	YES
	YES	YES	YES	YES	YES	YES	YES	YES	YES
	NO	NO	PN	NO	PN	NO	PN	NO	NO
	Low	Low	Low	Moderate	Low	Moderate	Moderate	Low	Low
	NO	NO	PN	NO	YES	NO	NO	NO	PN
	NO	NO	NO	YES	YES	NO	PN	NO	NO
	PN	NO	NO	YES	YES	NO	NO	NO	YES
	Low	Low	Low	Moderate	Serious	Low	Low	Low	Low
	Moderate	Moderate	Moderate	Moderate	Serious	Moderate	moderate	Serious	Moderate

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

Author (year)	Outcome	Specific outcome related to impacted canine position	Diagnosis method for impacted canine position	
		Correlation variables		
Arriola-Guillén et al (2019)	Root resorption of incisors	Root resorption (mm) of maxillary incisors, sagittal section	Location: palatine and buccal vs bicortical	
			Location: palatine vs buccal and bicortical	
			Sector	
			α angle	
			β angle	
			d-distance	
		Root resorption area in (mm2) of maxillary incisors, sagittal section	Location: palatine and buccal vs bicortical	
			Location: palatine vs buccal and bicortical	
			Sector	
			α angle	
			β angle	
			d distance	
		Root resorption (mm) of maxillary incisors, coronal section	Location: palatine and buccal vs bicortical	
			Location: palatine vs buccal and bicortical	
			Sector	
			α angle	
			β angle	
			d-distance	
		Root resorption area (mm2) of maxillary incisors, coronal section	Location: palatine and buccal vs bicortical	
			Location: palatine vs buccal and bicortical	
			Sector	
			α angle	
			β angle	
			d-distance	
	Orthodontic traction complexity	Orthodontic traction complexity	α angle	
			β angle	
			d distance	

	Subgroup of the specific outcome	Effect					Statistical analysis
		95% CI MD (LL, UL)	P	Mean (SD)	SS at P < 0.05	Clinical relevance	
	Maxillary lateral incisor	-	0.200	-	No	No	Multiple linear regression
	Maxillary central incisor	-	0.796	-	No	No	
	Maxillary lateral incisor	-	0.357	-	No	No	
	Maxillary central incisor	-	0.170	-	No	No	
	Maxillary lateral incisor	-	0.218	-	No	No	
	Maxillary central incisor	-	0.364	-	No	No	
	Maxillary lateral incisor	-	0.303	-	No	No	
	Maxillary central incisor	-	0.165	-	No	No	
	Maxillary lateral incisor	-	0.062	-	No	No	
	Maxillary central incisor	-	0.165	-	No	No	
	Maxillary lateral incisor	-	0.486	-	No	No	
	Maxillary central incisor	-	0.107	-	No	No	
	Maxillary lateral incisor	-	0.219	-	No	No	Multiple linear regression
	Maxillary central incisor	-	0.385	-	No	No	
	Maxillary lateral incisor	-	0.982	-	No	No	
	Maxillary central incisor	-	0.012	-	Yes	No	
	Maxillary lateral incisor	-	0.219	-	No	No	
	Maxillary central incisor	-	0.340	-	No	No	
	Maxillary lateral incisor	-	0.094	-	No	No	
	Maxillary central incisor	-	0.053	-	No	No	
	Maxillary lateral incisor	-	0.084	-	No	No	
	Maxillary central incisor	-	0.864	-	No	No	
	Maxillary lateral incisor	-	0.882	-	No	No	
	Maxillary central incisor	-	0.024	-	Yes	No	
	Maxillary lateral incisor	-	0.424	-	No	No	Multiple linear regression
	Maxillary central incisor	-	0.053	-	No	No	
	Maxillary lateral incisor	-	0.888	-	No	No	
	Maxillary central incisor	-	0.207	-	No	No	
	Maxillary lateral incisor	-	0.719	-	No	No	
	Maxillary central incisor	-	0.305	-	No	No	
	Maxillary lateral incisor	-	0.321	-	No	No	
	Maxillary central incisor	-	0.427	-	No	No	
	Maxillary lateral incisor	-	0.827	-	No	No	
	Maxillary central incisor	-	0.417	-	No	No	
	Maxillary lateral incisor	-	0.862	-	No	No	
	Maxillary central incisor	-	0.078	-	No	No	
	Maxillary lateral incisor	-	0.513	-	No	No	Multiple linear regression
	Maxillary central incisor	-	0.228	-	No	No	
	Maxillary lateral incisor	-	0.815	-	No	No	
	Maxillary central incisor	-	0.329	-	No	No	
	Maxillary lateral incisor	-	0.980	-	No	No	
	Maxillary central incisor	-	0.470	-	No	No	
	Maxillary lateral incisor	-	0.811	-	No	No	
	Maxillary central incisor	-	0.959	-	No	No	
	Maxillary lateral incisor	-	0.139	-	No	No	
	Maxillary central incisor	-	0.086	-	No	No	
	Maxillary lateral incisor	-	0.731	-	No	No	
	Maxillary central incisor	-	0.164	-	No	No	
	Low complexity	-21.49 (-30.29, -12.69)	< 0.001	33.3 (17.93)	Yes	Yes	-
	High complexity			54.79 (11.15)			
	Low complexity	-8.77 (-21.27, 3.74)	0.165	38.88 (19.46)	No	No	
	High complexity			47.64 (21.58)			
	Low complexity	-0.64 (-3.13, 1.85)	0.606	11.02 (5.00)	No	No	
	High complexity			11.66 (3.24)			

Author (year)	Outcome	Specific outcome related to impacted canine position	Diagnosis method for impacted canine position	
		Correlation variables		
Baccetti et al (2011)	Canine eruption	Canine eruption after interceptive treatment (in treated groups including RME/TPA/canine extraction, TPA/canine extraction and canine extraction)	α angle	
			d-distance	
			Sectors 1 and 2 (mild/moderate)	
			Sectors 3 and 4 (severe)	
Bazargani et al (2014)	Canine eruption	Canine eruption after interceptive treatment (between time points: just before and 18 months after extraction of the deciduous canine)	α angle	
			-distance	
			Sector	
Caprioglio et al (2019)	Periodontal outcome	Probing depth after treatment	α angle	
			d-distance	
			Sector	
			α angle	
			d-distance	
			Sector	
			α angle	
			d-distance	
			Sector	
			α angle	
			d-distance	
			Sector	
Crescini et al (2007)	Periodontal outcome and canine eruption	Probing depth (mm)	Impacted side (vs normally erupted side)	
		Keratinized tissue (mm)	Impacted side (vs normally erupted side)	
Fleming et al (2009)	Prediction factors for treatment duration	Treatment duration (months)	Angulation	
			Height	
			Mesiodistal position of canine tip	
			Apex position	
Koutzoglou et al (2013)	Canine eruption and prediction factors for ankylosis	Grade of impaction	Mesiodistal position of canine tip in relation to incisors	

	Subgroup of the specific outcome	Effect					Statistical analysis
		95% CI MD (LL, UL)	P	Mean (SD)	SS at P < 0.05	Clinical relevance	
	Unsuccessful eruption	-9.3	< 0.001	33.9 (7.0)	Yes	Yes	Mann–Whitney test
	Successful eruption			24.6 (6.9)			
	Unsuccessful eruption	-0.5	NS	17 (3.8)	No	Yes	
	Successful eruption			16.5 (3.1)			
	Unsuccessful eruption	-	< 0.001	28.5%	Yes	Yes	Chi-squared test
	Successful eruption	-		68.7%			
	Unsuccessful eruption	-		71.5%			
	Successful eruption			31.3%			
	Extraction side	-	0.004	11.7 (18.5)	Yes	Yes	Mixed-Model Analysis, corrected for multiple comparison by Bonferroni method
	Control side	-	0.659	19.6 (17.8)	No	No	
	Difference	-7.9 (-16.2, 0.5)	0.069	-	No	No	
	Extraction side	-	< 0.001	6.0 (5.5)	Yes	Yes	
	Control side	-	0.002	8.0 (4.8)	Yes	Yes	
	Difference	-2.2 (-4.4, 0.6)	0.059	-	No	No	
	Extraction side	-	0.017	-	Yes	Yes	Wilcoxon paired rank sum test corrected for multiple comparison with Bonferroni Holm method
	Control side	-	NS	-	No	No	
	Sides: extraction vs control	-	0.037	-	Yes	Yes	
	(Impaction side)	-	0.920	-	No	No	Multiple backward linear regression
		-	0.067	-	No	No	
		-	0.779	-	No	No	
	PD < 2mm	-	-	19 (10.87)	No	No	t-test*
		-	-	3.09 (10.81)	No	No	
		-	-	2.36 (0.75)	No	No	
	PD > 2mm	-	-	16.5 (11.31)	No	No	
		-	-	2.71 (0.84)	No	No	
		-	-	1.79 (0.84)	No	No	
	CEJ visible	-	-	22.67 (11.31)	No	No	
		-	-	2.83 (0.75)	No	No	
		-	< 0.05	1.67 (0.75)	Yes	No	
	All patients at the end of orthodontic treatment	-	< 0.0001	1.9 (0.6)	Yes	No	Multilevel theoretic models (Goldsetin, 1995)
	Subgroup of patients at follow-up visit	-	0.3014	1.6 (0.6)	No	No	
	All patients at the end of orthodontic treatment	-	0.0028	4.5 (1.2)	Yes	No	
	Subgroup of patients at follow-up visit	-	0.8518	3.5 (0.9)	No	No	
	-	-	0.915	-	No	Yes	Stepwise regression analysis
	-	-	0.065	-	No	Yes	
	-	-	0.042	-	Yes	Yes	
	-	-	0.937	-	No	No	
	Severe grade of impaction (sector VI)	OR: 9.13 (2.28, 36.53)	0.002	-	Yes	Yes	Univariate generalized estimating equation logistic regression
	Severe grade of impaction (sector VI)	OR: 13.53 (1.85, 98.75)	0.01	-	Yes	Yes	Multivariate generalized estimating equation logistic regression

Author (year)	Outcome	Specific outcome related to impacted canine position	Diagnosis method for impacted canine position	
		Correlation variables		
Lee et al (2019)	Canine eruption and periodontal outcome	CEJ cementoenamel junction - alveolar crest (mm)	α angle	
		Root length (mm)		
		Bone support (%)		
		Sulcus probing depth (mm)		
		Bone probing depth (mm)		
		Clinical crown length (mm)		
		Keratinized gingiva width (mm)		
		Attached gingiva width (mm)		
		CEJ cementoenamel junction - alveolar crest (mm)	d-distance	
		Root length (mm)		
		Bone support (%)		
		Sulcus probing depth (mm)		
		Bone probing depth (mm)		
		Clinical crown length (mm)		
		Keratinized gingiva width (mm)		
		Attached gingiva width (mm)		
		CEJ cementoenamel junction - alveolar crest (mm)	Sector	
		Root length (mm)		
		Bone support (%)		
		Sulcus probing depth (mm)		
		Bone probing depth (mm)		
		Clinical crown length (mm)		
		Keratinized gingiva width (mm)		
		Attached gingiva width (mm)		

	Subgroup of the specific outcome	Effect					Statistical analysis
		95% CI MD (LL, UL)	P	Mean (SD)	SS at P < 0.05	Clinical relevance	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.01	-	Yes	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.05	-	Yes	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.01	-	Yes	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.01	-	Yes	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	< 0.05	-	Yes	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	-	-	No	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	

Author (year)	Outcome	Specific outcome related to impacted canine position	Diagnosis method for impacted canine position	
		Correlation variables		
Lee et al (2019)	Canine eruption and periodontal outcome	CEJ cementoenamel junction - alveolar crest (mm)	α angle	
		Root length (mm)		
		Bone support (%)		
		Sulcus probing depth (mm)		
		Bone probing depth (mm)		
		Clinical crown length (mm)		
		Keratinized gingiva width (mm)		
		Attached gingiva width (mm)		
		CEJ cementoenamel junction - alveolar crest (mm)	d-distance	
		Root length (mm)		
		Bone support (%)		
		Sulcus probing depth (mm)		
		Bone probing depth (mm)		
		Clinical crown length (mm)		
		Keratinized gingiva width (mm)		
		Attached gingiva width (mm)		
		CEJ cementoenamel junction - alveolar crest (mm)	Sector	
		Root length (mm)		
		Bone support (%)		
		Sulcus probing depth (mm)		
		Bone probing depth (mm)		
		Clinical crown length (mm)		
		Keratinized gingiva width (mm)		
		Attached gingiva width (mm)		

	Subgroup of the specific outcome	Effect					Statistical analysis
		95% CI MD (LL, UL)	P	Mean (SD)	SS at P < 0.05	Clinical relevance	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.01	-	Yes	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.01	-	Yes	Yes	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.001	-	Yes	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	< 0.01	-	Yes	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	Mesio-buccal	-	< 0.05	-	Yes	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	< 0.05	-	Yes	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	< 0.05	-	Yes	No	
	Disto-lingual	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	-	-	No	No	
	-	-	-	-	No	No	
	Mesial	-	-	-	No	No	
	Distal	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	Mesio-buccal	-	-	-	No	No	
	Mid-buccal	-	-	-	No	No	
	Disto-buccal	-	-	-	No	No	
	Mesio-lingual	-	-	-	No	No	
	Mid-lingual	-	-	-	No	No	
	Disto-lingual	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	
	-	-	-	-	No	No	

Multiple linear regression

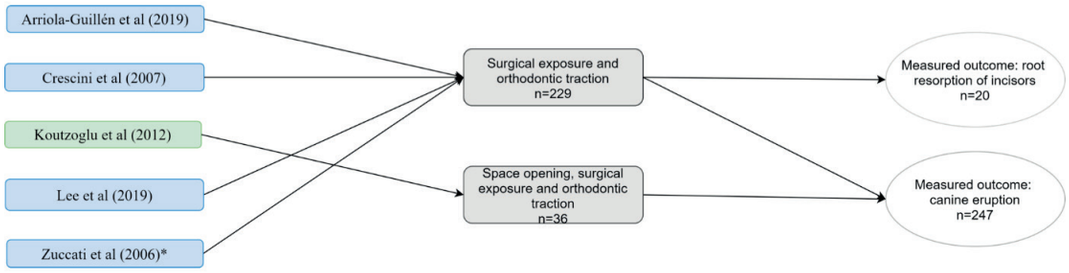
Author (year)	Outcome	Specific outcome related to impacted canine position	Diagnosis method for impacted canine position	
		Correlation variables		
Motamedi et al (2009)	Canine eruption	Canine eruption (alignment of canine)	Canine angulation to the midline	
			Canine crown overlap over the adjacent lateral incisor root	
			Anteroposterior position	
Naoumova et al (2014)	Canine eruption	Eruption of canines after interceptive treatment (extraction of deciduous canine)	Mesioangular angle	
			Sagittal angle	
			Vertical position	
			Canine cusp tip-dental arch plane	
			Canine apex-dental arch plane	
			Canine cusp tip-midline	
			Mesioangular angle	
			Sagittal angle	
			Vertical position	
			Canine cusp tip-dental arch plane	
			Canine apex-dental arch plane	
			Canine cusp tip-midline	
			Mesioangular angle	
			Sagittal angle	
			Vertical position	
			Canine cusp tip-dental arch plane	
			Canine apex-dental arch plane	
			Canine cusp tip-midline	
		Prediction factors for favorable canine eruption after decidous canine extraction	Mesioangular angle	
			Canine cusp tip-dental arch plane	
			Canine cusp tip-midline	
Potrubacz et al (2018)	Canine eruption and prediction factors for treatment duration	Treatment duration (orthodontic active traction time)	α angle	
			Vertical height	
			Overlap on incisor	
			Sector	
Power et al (1993)	Canine eruption	Canine eruption after deciduous canine extraction (prediction factors for favorable eruption)	Overlap on incisor	
			Angulation to midline	
			Eruptive level to incisor	
			Vertical height	

	Subgroup of the specific outcome	Effect					Statistical analysis
		95% CI MD (LL, UL)	P	Mean (SD)	SS at P < 0.05	Clinical relevance	
	> 45°	-	< 0.001	-	Yes	Yes	Chi-square and correlation tests
	> half of the root	-	< 0.001	-	Yes	Yes	
	-	-	-	-	No	No	
	Extraction group: differences of canines erupted between 6 and 12 months and those erupted after 12 months (respectively for mean and SD values)	−2.2 (1.4, 4.8)	0.210	101.5 ± 6.5 103.7 ± 5.2	No	Yes	Independent t-test
		2.9 (7.9, 6.7)	0.248	100.9 ± 8.1 98.0 ± 8.2	No	No	
		1.6 (3.1, 1.9)	0.030	16.1 ± 2.4 14.5 ± 2.3	Yes	Yes	
		−0.5 (0.2, 0.9)	0.129	2.1 ± 1.2 2.7 ± 1.2	No	Yes	
		0.8 (1.8, 1.4)	0.743	2.9 ± 1.8 2.1 ± 1.5	No	No	
		0.2 (1.6, 1.8)	0.120	10.6 ± 2.7 10.4 ± 1.8	No	Yes	
	Control group: differences of canines erupted between 6 and 12 months and those erupted after 12 months (respectively for mean and SD values)	0.8 (6.9, 4.5)	0.785	105.0 ± 6.8 104.2 ± 5.9	No	Yes	
		−3.1 (5.2, 6.1)	0.447	98.4 ± 7.8 101.4 ± 8.1	No	No	
		1.7 (3.9, 1.6)	0.114	15.5 ± 0.8 13.8 ± 2.5	No	Yes	
		−0.5 (0.9, 1.1)	0.463	1.1 ± 1.1 1.7 ± 1.6	No	Yes	
		0.3 (1.5, 0.9)	0.602	3.4 ± 1.6 3.1 ± 1.0	No	No	
		−0.5(1.2, 1.3)	0.519	10.6 ± 1.8 11.1 ± 1.7	No	Yes	
	Canines erupted between 6 and 12 months and those erupted after 12 months	-	0.282	-	No	Yes	
		-	0.618	-	No	No	
		-	0.004	-	Yes	Yes	
		-	0.236	-	No	Yes	
		-	0.905	-	No	No	
		-	0.181	-	No	Yes	
		OR: 1.187 (1.017, 1.386)	0.0295	-	Yes	Yes	Multiple stepwise regression (logistic regression, multivariate)
		OR: 2.237 (0.923, 5.181)	0.0610	-	Yes	Yes	
		OR: 2.995 (1.108, 8.096)	0.0306	-	Yes	Yes	
	-	-	0.103	-	No	Yes	Fisher exact test, chi-square
		-	0.217	-	No	Yes	
		-	0.262	-	No	Yes	
		-	0.323	-	No	Yes	
	Successful Improved Unsuccessful	-	-	-	-	No	Discriminant analysis
		-	-	-	-	No	
		-	-	-	-	No	
		-	-	-	-	No	

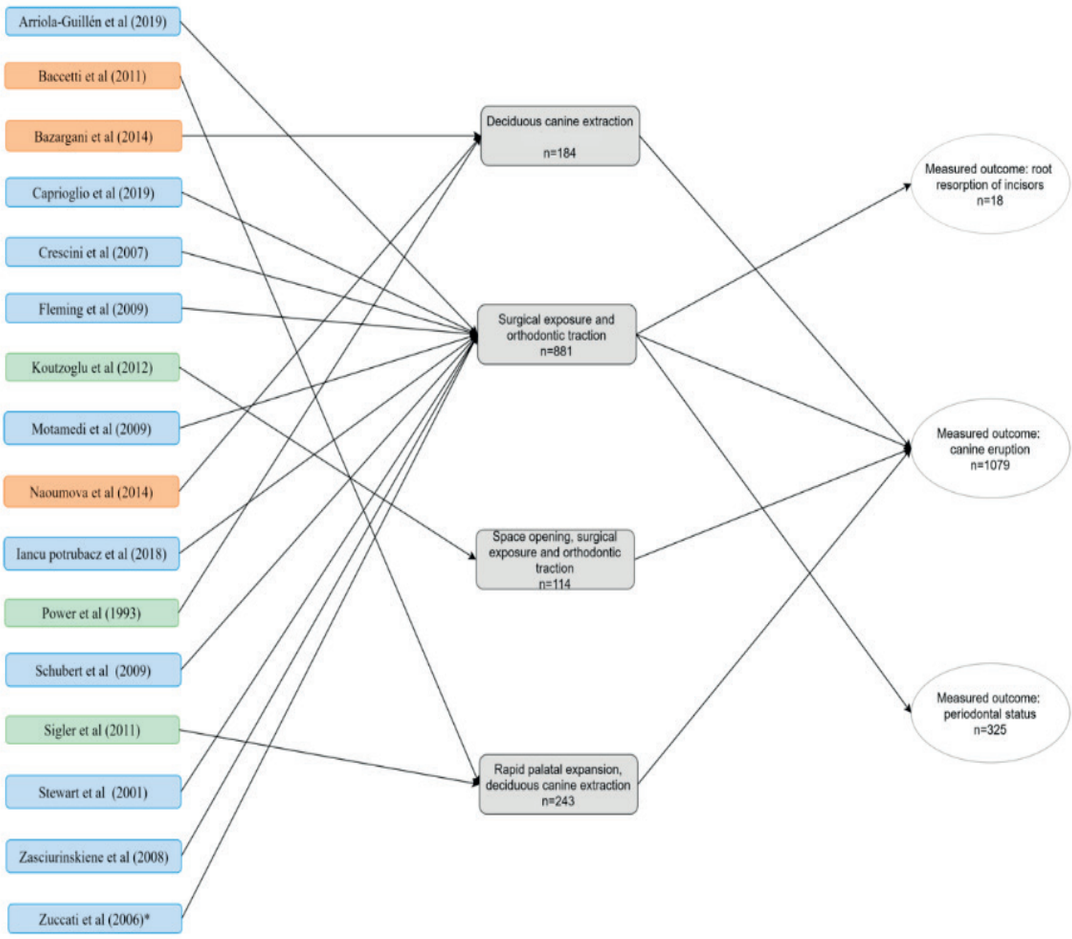
Author (year)	Outcome	Specific outcome related to impacted canine position	Diagnosis method for impacted canine position	
		Correlation variables		
Schubert et al (2009)	Prediction factors for treatment duration	Treatment duration	α angle	
			β angle	
			d-distance	
			Canine tip-target point P on occlusal plane	
			α angle	
			β angle	
			d-distance	
			Canine tip-target point P on occlusal plane	
			α angle	
			β angle	
			d-distance	
			Canine tip-target point P on occlusal plane	
			α angle	
			β angle	
			d-distance	
			Canine tip-target point P on occlusal plane	
Sigler et al (2011)	Canine eruption	Canine eruption after interceptive treatment (including RME, TPA and deciduous canine extraction)	α angle	
			d distance	
			Sectors 1 and 2 (mild/moderate)	
			Sectors 3 and 4 (severe)	
Stewart et al (2001)	Prediction factors for treatment duration	Treatment duration (months)	α angle	
			d-distance	
			Sector	
Zasciurinskiene et al (2008)	Periodontal outcome	Probing depth (mm)	Vertical sectors (canine cusp in the coronal or apical half of the lateral incisor root)	
			Horizontal sectors (canine cusp between premolar, lateral incisor or central incisor)	
Zuccati et al (2006)	Prediction factors for treatment duration	Treatment duration (forced eruption phase, number of visits)	β angle	
			d-distance	
			Mesiodistal position of the cusp tip in relation to incisors	

CI: Confidence interval; MD: Mean difference; LL: Lower limit, UL: Upper limit, P: P-value, SS: Statistically significant, NS: Not significant

	Subgroup of the specific outcome	Effect					Statistical analysis
		95% CI MD (LL, UL)	P	Mean (SD)	SS at P < 0.05	Clinical relevance	
	Duration of canine alignment (unilaterally impacted group)	-	≤ 0.01	-	Yes	Yes	Pearson correlation
		-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
	Total treatment time (from surgery to debonding) (unilaterally impacted group)	-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
	Number of visits (unilaterally impacted group)	-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.05	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
		-	≤ 0.01	-	Yes	Yes	
	Duration of canine alignment	-	< 0.001	-	Yes	Yes	Linear regression
		-	< 0.001	-	Yes	Yes	
		-	< 0.001	-	Yes	Yes	
		-	< 0.001	-	Yes	Yes	
	Unsuccessful	MD: -4.7	NS	33.2 (9.6)	No	Yes	Mann-Whitney test
	Successful			28.5 (5.1)			
	Unsuccessful	MD: 1.7	NS	15.8 (3.8)	No	Yes	
	Successful			17.5 (2)			
	Unsuccessful	-	< 0.001	25%	Yes	Yes	Chi-square test
	Successful			77,40%			
	Unsuccessful	-	< 0.001	75%	Yes	Yes	
	Successful			22,60%	Yes	Yes	
	Impacted canine group	-	0.965	28.3 (8.2)	No	Yes	Pearson correlation
		-	0.003		Yes	Yes	
		-	0.795		No	Yes	
	MPP	-	NS	-	No	No	Mann-Whitney U-test
	PP	-	NS	-	No	No	
	DPP	-	NS	-	No	No	
	MLP	-	NS	-	No	No	
	LP	-	NS	-	No	No	
	DLP	-	NS	-	No	No	
	MPP	-	< 0.01	-	Yes	No	
	LP		< 0.01	-	Yes	No	
	PP	-	NS	-	No	No	
	DPP	-	NS	-	No	No	
	MLP	-	NS	-	No	No	
	DLP	-	NS	-	No	No	
	-	-	0.0289	-	Yes	Yes	Stepwise regression
		-	< 0.0001	-	Yes	Yes	
		-	0.0058	-	Yes	Yes	



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.

CHAPTER 6

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Fransen J, Smeets M, Hoppenreijs T, Ghaeminia H, Politis C, Jacobs R. Surgically assisted orthodontic alignment of impacted maxillary canines: A retrospective analysis of functional and esthetic outcomes and risk factors for failure. Am J Orthod Dentofacial Orthop. 2021 Mar 27:S0889-5406(21)00172-4. doi: 10.1016/j.ajodo.2020.12.019.
Epub ahead of print. PMID: 33785231.

SURGICALLY ASSISTED ORTHODONTIC ALIGNMENT OF IMPACTED MAXILLARY CANINES: A RETROSPECTIVE ANALYSIS OF FUNCTIONAL AND AESTHETIC OUTCOMES AND RISK FACTORS FOR FAILURE

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ABSTRACT

OBJECTIVES: The initial position of the impacted maxillary canine might influence the outcome of surgically assisted exposure and orthodontic alignment. The purpose of the present study was therefore to evaluate existing correlations between the initial position of the maxillary canine and the outcomes of treatment.
MATERIAL AND METHODS: A retrospective cohort study was designed, containing data of 132 patients (male/female: 47/106; median age at the date of surgical exposure 14 ± 4.6 years; range 10-39) with a total of 153 impacted maxillary canines. The sample was based on orthodontic referrals over a four-year period at the department of Oral and Maxillofacial Surgery, Rijnstate Hospital Arnhem. Aesthetic outcome, treatment duration, success and failure rate were investigated in relation to the initial position of the maxillary canine as assessed on pre-treatment panoramic radiographs (vertical and antero-posterior sector position and angulation of the canine (α-angle)). Aesthetic evaluation was performed using the Maxillary Canine Aesthetic Index (MCAI). Success of treatment was defined as achieving a fully functional eruption of the canine, with an aesthetically excellent result, without the need for re-interventions. Failure of treatment was defined as the need for reintervention or removal of the canine.
RESULTS: In 96% of the impacted canines, a successful orthodontically assisted eruption was achieved. Age, vertical distance and angulation are predictors of the aesthetic outcome of impacted canines after treatment. Age, bilateral impaction, sector, vertical distance and angulation are predictors of treatment duration. Age, vertical distance and buccolingual position are predictors of the need for reintervention.

CONCLUSION: Pre-treatment radiographic variables can help in predicting outcome and treatment duration of surgically exposed maxillary impacted canines.

INTRODUCTION

The overall prevalence of maxillary canine impaction varies between 0.9% and 2.2%.1,2 Impaction is defined as 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. Various etiological factors of maxillary canine impaction are mentioned in the literature, such as dental discrepancy, ectopic position of the tooth germ, lack of space, lack of guidance, presence of hard and soft tissue pathologies or genetic factors.[3,4]

The location of the impacted canine is a predictor of treatment success. There are multiple studies investigating this topic and reporting significant relationships between the initial position and the outcome. In the literature, a successful treatment is defined as a complete eruption of the canine's crown, sufficient to allow orthodontic alignment, or improve its position compared to the initial situation. Root resorption of the maxillary incisors, ankylosis, treatment duration, and periodontal outcome related to the initial position of the impacted canine are evaluated.[5–17] Previous studies selected the patient population on age, antero-posterior sector position and/or buccopalatal location of impacted maxillary canines.[7,8,15] While some authors discussed aesthetic outcome, few studies analyzed the relationship between initial canine position and the final aesthetic outcome.[8,18–22] Parkin et al evaluated the aesthetics of post-treatment canines through a panel of orthodontists and laypeople.[18] Smailiene et al used tooth color, position in the dental arch, inclination and shape as aesthetic criteria.[19] They did not include gingival parameters in their aesthetic appraisal.

As reported by Luyten et al, one of the most important shortcomings in currently available research is that it is difficult to pool data and compare the outcome of studies due to a lack in standardization of the parameters used in evaluating aesthetic outcome.[23] Luyten et al suggested addressing this problem by determining a Core Outcome Set (COS) such as the Maxillary Canine Aesthetic Index (MCAI).[23]

The aim of this retrospective study is to evaluate the position of a maxillary canine in relation to treatment duration, success, failure rate and aesthetic outcome.

MATERIAL AND METHODS

Subjects

This study consisted of all patients treated at the local department of oral and maxillofacial surgery between January 2015 and December 2018 for impaction of maxillary canines. All patients were referred by orthodontists.

All patients with unilateral or bilateral impacted maxillary canines referred for surgical treatment, were eligible for inclusion in this study. The exclusion

criteria were as follows: a) absence of preoperative radiographs, b) absence or poor-quality post-treatment photographs and c) patients with a craniofacial syndrome or cleft lip and palate.

The variables of interest were defined as:

- Predictor
  - Radiographic position of canine (sector, vertical height, angulation)
  - Age
  - Crestal position (buccal, mid-crestal, palatal)
- Outcome
  - Treatment duration
  - Success of treatment
  - Need for re-intervention
  - Failure of treatment and removal of canine
  - Aesthetic outcome as defined by MCAI [23]

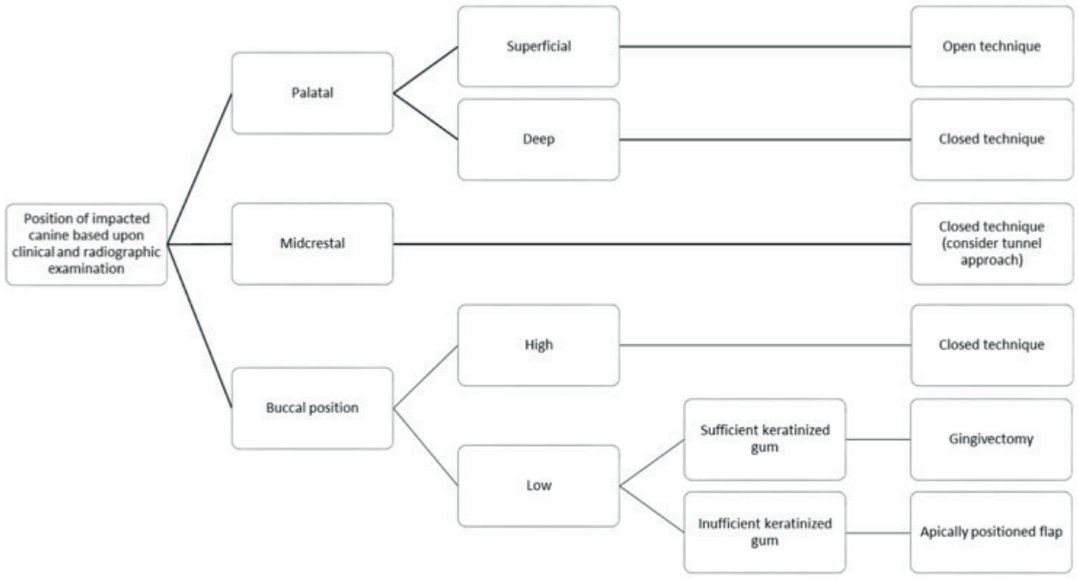
An initial evaluation was performed before the surgical treatment of the impacted maxillary canines, based on panoramic radiographs and the report of the clinical investigation.

Table 1. *The Maxillary Canine Aesthetic Index (MCAI) and parameters.*

Parameters investigating the previously impacted canine			
	Absent	Incomplete	Complete
Mesial papilla	5	1	0
Distal papilla	5	1	0
Marginal gingiva	5	1 (<3mm)	0 (>3mm)
Recession	(Apical to MGJ)	(Coronal to MGJ)	(No recession)
	5	1	0
Marginal gingival thickness	Thin		Thick
	1		0
Mesiodistal crown angulation	Distal	Straight	Mesial
	2	1	0
Parameters investigating comparison between both canines			
	Major discrepancy	Minor discrepancy	No discrepancy
Curvature of marginal gingiva	2	1	0
Soft tissue color and texture	2	1	0
Root convexity	2	1	0
Tooth morphology	2	1	0
Vertical tooth position	2	1	0
Parameters investigating relation previously impacted canine and neighboring teeth			
Buccolingual angulation crown acc. neighboring teeth	2	1	0
Total score	0–3 points = excellent 4-8 points = good 9-13 points = moderate 14 or more points = poor aesthetics from Grisar et al		

Applied treatment protocol

After the initial evaluation and diagnosis of buccolingual position, all patients underwent the same standardized treatment strategy as outlined in Figure 1. We differentiated between a closed and an open procedure.



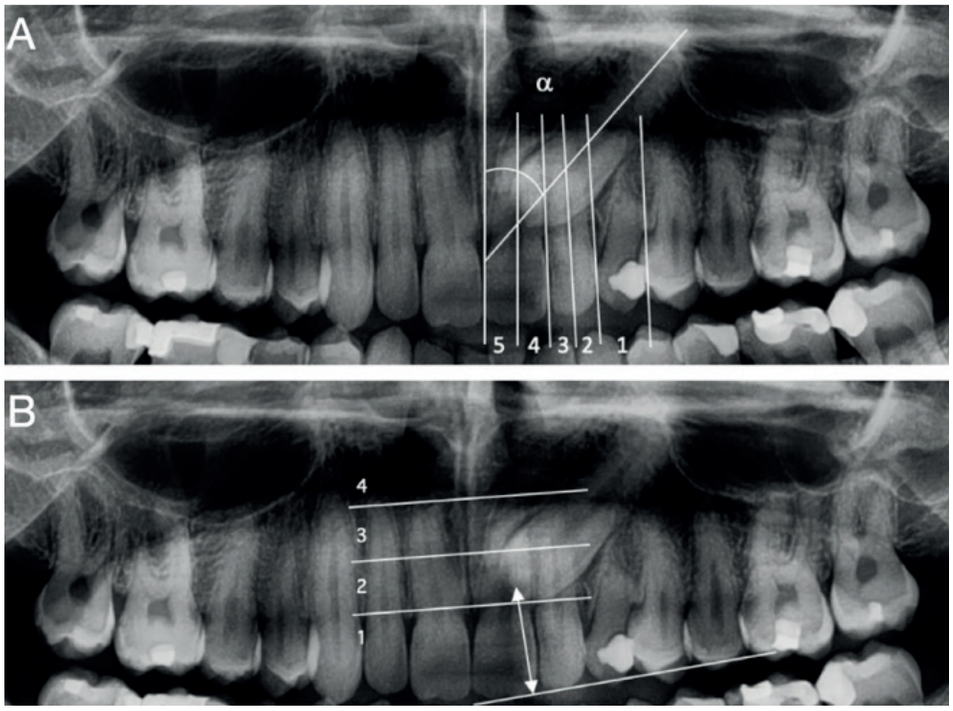


Figure 1. *Protocol for treatment of impacted maxillary canines.*

Figure 2. Radiographic measurements of initial canine position. Figure 2A: Panoramic radiograph illustrating the antero-posterior sector of the canine, according to the Ericson and Kurol method, and the angular measurement of the canine position in degrees, with α-angle of maxillary canine to midline.[26] Figure 2B: Panoramic radiograph illustrating the vertical position of the canine, according to the method as described by Stivaros.[25]

The closed treatment group consisted of 113 canines (29 buccal; 18 mid-crestal; 66 palatal). A palatal or buccal full thickness flap of the mucosa covering the site of impaction was prepared. The bone covering the impacted crown was removed and during the procedure a bracket or cleat was bonded to the tooth surface close to the cusp. With a gold chain or twined wire, the cleat or bracket was connected to the orthodontic appliance. After the bonding, the mucoperiosteal flap was closed and sutured in place with the gold chain or wire exiting from the surgery site.

The open treatment group consisted of 40 canines (6 buccal; 13 mid-crestal; 21 palatal). The canine is exposed to ome extent. In case of buccal impaction, a mucoperiosteal flap was made and the overlying bone layer was removed, then the flap was repositioned apically towards the cemento-enamel junction and sutured in place. In case of palatal impaction, the gingiva covering the canine was excised and the overlying bone layer was removed. A special wound packing material was applied to prevent wound closure, or a cleat was bonded by the orthodontist once the tooth was exposed to further assist eruption and alignment. All canines underwent traction after the procedure, in most cases with a gold chain or wire ligature connected to a fixed appliance, and in some cases with an extrusion plate.

Treatment duration

The duration of treatment was taken as the period from the date of surgical exposure to the debonding date. In bilateral cases, separate treatment durations were considered for the individual canines.

Aesthetic evaluation (MCAI)

The intraoral photographs from 1-2 weeks after debonding were collected and assessed by two researchers (KG and MS). Both were trained and calibrated to use the MCAI system for using a reference training data set. Twelve variables of the MCAI were scored according to the scoring system found in Table 1. For unilateral impaction cases, the contralateral biologically erupted canine was used as a reference. For bilateral cases, the contralateral canine was used as a reference; however, in the event of severe aesthetic failure, a hypothetical ideal canine was used as a reference. Only MCAI values ≤ 3 were considered to be associated with an excellent aesthetic outcome.24 After evaluation, all canines included in the study were divided into two groups according to aesthetic outcome (MCAI): MCAI ≤ 3 (group 1) and MCAI > 3 (group 2). This procedure allowed for

comparison of all other parameters between the two groups. Disagreements between the researchers were resolved through discussion. Grisar et al showed a good intraclass correlation for the MCAI (0.71).24

Radiographic evaluation of canine location

The location of the impacted canine was identified through clinical and radiological assessment. On a panoramic radiograph, the angulation of the canine, the vertical position and the antero-posterior position of the crown were determined (Figure 2). Angulation was determined by measuring the angle between the canine and the vertical line parallel to the central incisor. For the purpose of statistical analysis, the results of the angulation measurements were divided into three groups: group 1 (< 15°), group 2 (15-30°) and group 3 (> 30°). The vertical distance to the canine cusp tip was measured perpendicular to the occlusal plane. The occlusal plane was determined by drawing a line through the incisal edge of the central incisor and the mesiobuccal cusp of the first molar. The vertical height was divided into four levels as described by Stivaros et al[25]: level 1 (vertical position of the canine cusp tip at the level of the cemento-enamel junction, CEJ, of the adjacent incisor), level 2 (canine cusp tip between the CEJ and the middle of the root of the adjacent incisor), level 3 (canine cusp tip within the apical half of the adjacent incisor) and level 4 (canine cusp tip above the apex of the adjacent incisor).[24] Ericson and Kurol introduced a classification system describing the antero-posterior position of the tip of the canine crown related to the neighboring teeth according to five sectors: 1 = normal position (primary canine), 2 = distal to the long axis of the lateral incisor, 3 = mesial to the long axis of the lateral incisor, 4 = distal to the long axis of the central incisor, or 5 = mesial to the long axis of the central incisor.[26]

Digital tracings on panoramic radiographs were repeated with a one-month interval by the same trained operator (KG) on 25 subjects randomly selected. Intra-observer reproducibility for the image analysis was measured using the intraclass correlation coefficient (ICC) for the identification of antero-posterior sector, angulation and vertical height. Disagreements were resolved through discussion between two observers (KG and MS).

Statistical analysis

The analysis was performed in S-Plus for Linux version 8.0 (Tibco, Palo Alto, CA, USA). Univariate relations with outcome variables were fit by means of a generalized linear model for binary responses using a logit-link for binary variables and a general linear model for variables that are normally distributed around their mean. The normality of the residual values of the general linear model was assessed by a normal quantile plot. If an explanatory variable consisted of more than two groups, the groups were compared with each other and a correction for simultaneous hypothesis testing according to Tukey was applied. A stepwise model selection procedure was applied to find the combination of explanatory variables that have the closest relation to the outcomes.

RESULTS

Patients and maxillary canine characteristics

A total of 259 patients with 319 impacted maxillary canines were eligible for inclusion in the study. Unfortunately, many patients were excluded because of (a) no follow-up (53 canines), (b) absence or poor quality of post-treatment photographs (41 canines) and (c) missing preoperative radiographs (72 canines). After exclusion, a total of 153 impacted maxillary canines from 132 patients remained and were included in the analysis. Cases with missing post-treatment photographs or preoperative radiographic imaging were excluded as both parameters are fundamental in the assessment of the relation of the initial position of the canine and the main outcome of this survey: success, failure rate and aesthetic outcome. Patients characteristics are described in Table 2.

Distribution of the 153 impacted maxillary canines according to the classification as described by Ericson and Kurol and Stivaros et al, is also presented in Table 2.25,26 Impacted maxillary canines were most frequently found in sector 1 at the level of the deciduous canine (n: 52; 34%), canine angulation > 30° (n: 77; 50%) and level 2 vertical position (canine cusp tip between the CEJ and the middle of the root of the adjacent incisor; n: 70; 46%).

A closed approach was more frequently performed (n: 113; 74%) than an open approach (n: 40; 26%).

Table 2. *Patient characteristics in relation to canine impaction.*

Variable		Impacted canines (n)	Percentage (%)
Patient age	≤ 16	122	80
	> 16	31	20
Patient gender	M	47	31
	F	106	69
Unilateral vs, bilateral	Unilateral	111	73
	Bilateral	42	27
Buccopalatal position	Buccal	35	23
	Mid-crestal	31	20
	Palatal	87	57
Angulation	0-15°	31	21
	15-30°	45	29
	> 30°	77	50
Sector	1	52	34
	2	33	22
	3	33	22
	4	25	16
	5	10	7
Vertical position	1	12	8
	2	70	46
	3	59	39
	4	12	8
Choice of treatment	Open technique	40	26
	Closed technique	113	74

The mean treatment time was 22.2 months (SD +/- 8.9; range 4-48.2). Success of treatment was defined as achieving a fully functional eruption of the canine, with an aesthetically excellent result, without the need for re-interventions. Out of the 153 impacted canines included in the study population, 147 canines (96%) achieved a fully functional eruption with excellent or good aesthetic outcome.

Failure of treatment was defined as the need for re-intervention and/or the removal of the canine. In the course of the orthodontic treatment, 19 surgically exposed canines (12%) needed re-intervention. Six canines (4%) were removed due to failure of eruption after a mean of 21 months of treatment (range 15-30) and multiple attempts of surgical re-exposure. These failed canines did not receive a MCAI score.

Table 3. *Relationship age and initial canine position with the treatment duration.*

		Treatment duration			
		Number of canines	Mean (months)	SD	P-value*
Patient characteristics					
Age (years)	< 16	122	21,5	8,3	0,05
	≥ 16	31	25,0	10,6	
Position	Unilateral	111	21,1	9,2	0,01
	Bilateral	42	25,2	7,4	
Canine characteristics					
Buccopalatinal position	Buccal	35	21,5	8,9	0,05
	Mid-crestal	31	19,6	8	
	Palatal	87	23,5	9,1	
Sector	I	52	17,9	6,6	0
	II	33	22,1	9,1	
	III	33	23,7	8,3	
	IV	25	27,9	9,3	
	V	10	25,9	9,8	
Angulation	I	31	18,6	7,6	<0.01
	II	45	19,7	8	
	III	77	25,2	9	
Vertical height	I	12	16,9	6,5	<0.01
	II	70	21,2	9,2	
	III	59	23,2	7,9	
	IV	12	28,7	10,2	

* P-values ≤ 0,05 are considered statistically significant.

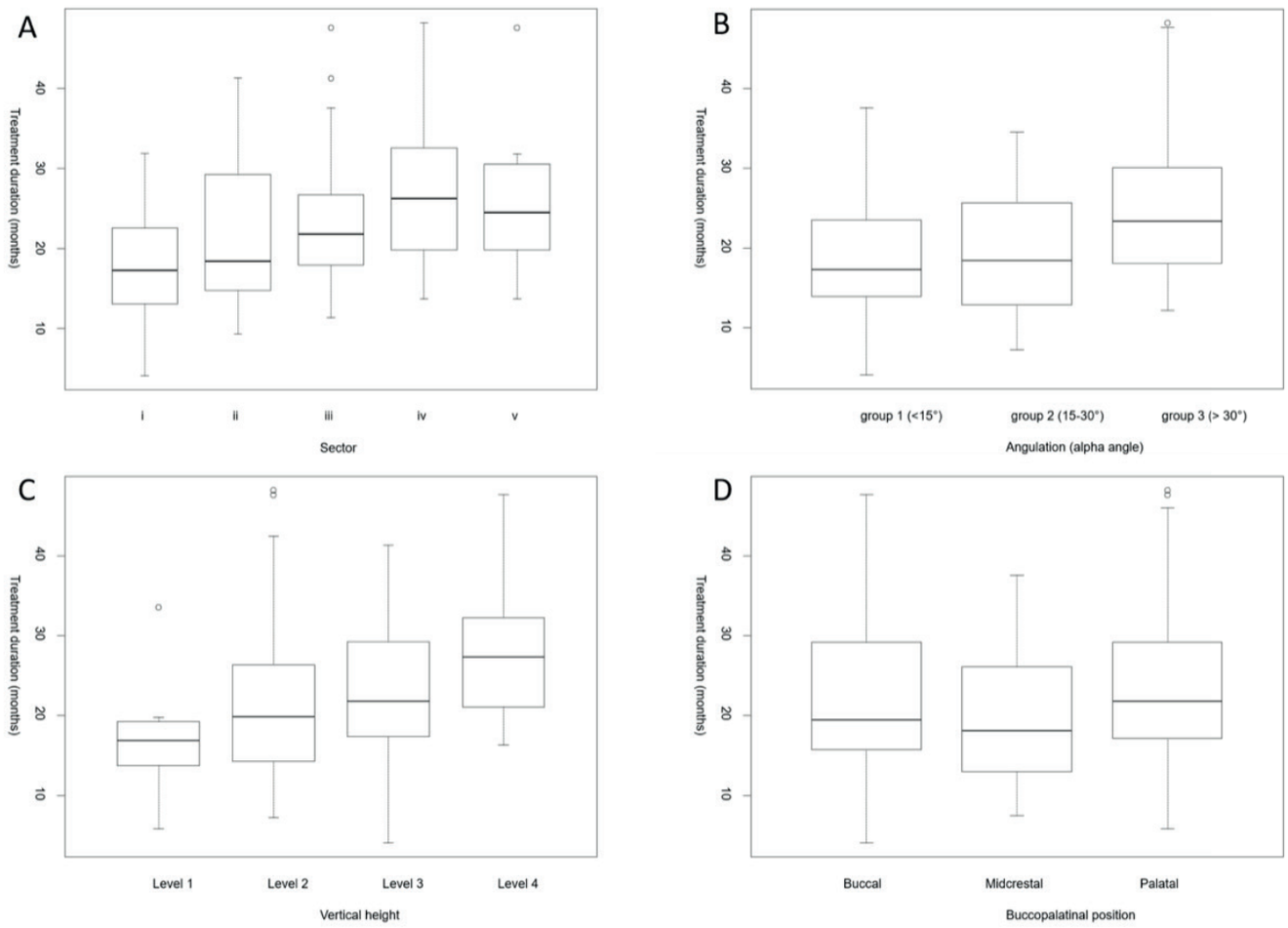


Figure 3. *Radiographic canine position and relationship with treatment duration.*
Figure 3A: *Relationship antero-posterior sector position and treatment duration.*
Figure 3B: *Relationship angulation and treatment duration.*
Figure 3C: *Relationship vertical height and treatment duration.*
Figure 3D: *Relationship buccopalatal position and treatment duration.*
All findings were observed with p<0,05.

Table 3 and Figure 3 demonstrate the significant (p<0,05) relationship between duration of treatment and antero-posterior sector position, angulation, vertical height and buccolingual position. A high vertical position, anterior sector position, angulation >30° and palatal location were significant predictors of prolonged treatment duration.

Angulation and vertical height were found to have a significant relationship (p<0,05) with the aesthetic outcome as defined by the MCAI. A high vertical position and angulation >30° were good predictors of suboptimal aesthetic results as defined by the MCAI (Table 4).

The vertical height and buccolingual position of the canine were significant predictors (p <0,05) of the need for re-intervention. Impacted canines with a high vertical position and buccal location needed a second surgical intervention significantly more often in this study. No significant correlation was found between initial maxillary canine position and the need for removal of the canine (Table 4).

Stepwise model selection partially confirmed the significant relations of the univariate model. Significant results are presented in Table 5. A high vertical position, anterior sector position (sectors 4 and 5 versus the rest) and palatal location were confirmed as significant predictors of prolonged treatment duration. High vertical position (level 4 versus level 3) was confirmed to have a significant relationship (p<0,05) with the aesthetic outcome as defined by the MCAI. The stepwise model selection did not find any significant relationships between the initial maxillary canine position and the removal of the canine.

Table 4. *Relationship age and initial canine position with outcomes of treatment.*

	Initial canine position																			**Age**		
	Sector							Vertical height					Angulation				Buccolingual position						
Outcome		1	2	3	4	5	P-value **	1	2	3	4	P-value **	1	2	3	P-value **	P	MC	B	P-value **	< 16	≥ 16	P-value **
MCAI*	≤3	47	32	29	21	9	0,2	12	67	50	9	0,05	29	43	66	0,05	87	31	29	0,3	117	5	0,08
	> 3	1	1	3	3	1		0	0	7	2		0	1	8		6	0	3		27	4	
Need for re-treatment	No	45	30	27	22	10	0,7	12	63	51	8	0,05	28	42	64	0,2	78	29	27	0,05	111	23	0,03
	Yes	7	3	6	3	0		0	7	8	4		3	3	13		9	2	8		11	8	
Removal of canine	No	48	33	32	24	10	0,5	12	67	57	11	0,7	29	44	74	0,7	84	31	32	0,2	119	28	0,1
	Yes	4	0	1	1	0		0	3	2	1		2	1	3		3	0	3		3	3	

*6 removed canines did not receive a MCAI score
** P-values ≤ 0,05 are considered statistically significant.

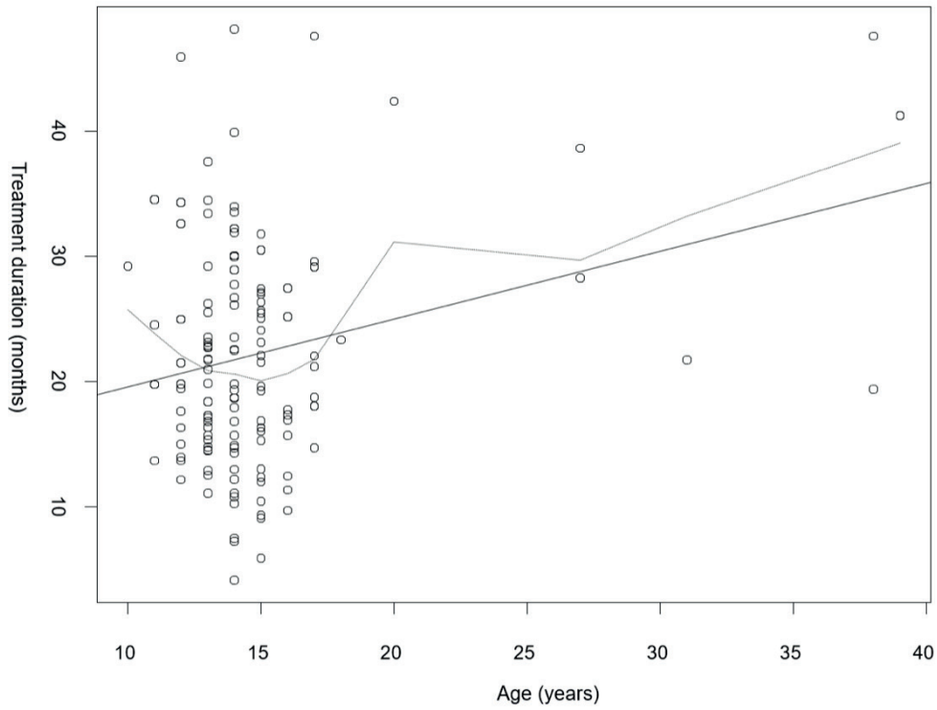


Figure 4. *Age and relationship with treatment duration. All findings were observed with p<0,05. Both the linear and the variable relation of treatment duration with increasing age is visualized.*

A significant relationship was found (p<0,05) between increasing age and treatment duration and the need for re-intervention (Figure 4). A cutoff at the age of 16 was used due to the expectancy of complete canine root development at this age. A significant relationship was found (p<0,05) between prolonged treatment duration and need for re-intervention, and aged 16 or above (Tables 3 and 4). The odds for the need for re-intervention were more than three times as high for patients aged 16 or above (odds ratio, 3,51; 95% CI; p=0,03).

Stepwise model selection confirmed the significant relations of the univariate model. Significant results are presented in Table 5. A significant relationship was found (p<0,05) between increasing age, treatment duration and need for re-intervention. Moreover, the stepwise model selection demonstrated a significant relationship between increasing age and a suboptimal aesthetic result as defined by the Maxillary Canine Aesthetic Index MCAI (Table 5).

Orthodontic alignment of bilateral impacted canines required significantly prolonged treatments (mean: 25 months +/- 7; range 16-41) compared to orthodontic alignment of unilateral impacted canines (mean: 21 months +/- 9; range 4-48). Stepwise model selection confirmed the univariate model (Table 5).

DISCUSSION

The permanent canine has a key position in the dental arch. It is a strong tooth with an important function in occlusion, lateral articulation movements and aesthetic appearance. Hence, one of the goals in every treatment protocol is a well-positioned canine in the dental arch. In the informed consent and decision-making process with patients and parents, orthodontists have to give information regarding expected treatment duration, risk factors, treatment outcome and alternative treatment options. To this end, this study investigated treatment duration and aesthetic outcome as defined by the Maxillary Canine Aesthetic Index MCAI. The MCAI is an index that was developed for evaluating maxillary canine aesthetics. This index can be used in both research and clinical settings, taking into account twelve different soft tissue and tooth characteristics.[24] Characteristics of the gingiva are included in the overall aesthetic evaluation of the canine. The advantage of the MCAI is not only that future results can be compared, but that the system combines visible soft tissue (gingival) and hard tissue (tooth) parameters into one comprehensive scoring system. Further information is found in Table 1.

Table 5. *Stepwise model selection.*

Outcome	Variable	OR	Coefficient	P-value ***	CI lower 95%	CI upper 95%
Need for re-intervention						
	Age	-	0,14	0,01	0,05	0,2
	Buccal vs. palatal position	4,27	-	0,05	1	18,3
MCAI index ≤ 3						
	Age	-	0,1	<0.01	0,01	0,2
	Level of vertical height (level 3 vs, level 4) *	0,2	-	<0.01	0,1	0,5
Treatment duration						
	Age	-	0,49	<0.01	0,2	0,8
	Unilateral/bilateral position	-	4,39	<0.01	1,6	7,2
	Sector position (sectors 4 and 5 vs, sectors 1, 2 and 3) **	-	-5	<0.01	-8,1	-1,9
	Level of vertical height	-	0,56	<0.01	0,2	0,9

* In the subgroup of canines positioned in vertical levels 1 and 2, there are no canines with a MCAI index > 3.

** This is a comparison of sectors 4 and 5 versus the rest. We compare 0 (sector not 4 or 5) with 1 (sector 4 or 5).

*** P-values ≤ 0,05 are considered statistically significant.

Furthermore, we found a significant relationship between the initial position of the impacted canine and the aesthetic outcome as defined by the MCAI.[24] Only a few other studies analyzed the aesthetic outcome of impacted maxillary canines after treatment.[8,18–22] However, there are multiple studies that investigated the pretreatment radiographic features for the periodontal prognosis of treated impacted canines.[5,8,9,12,15,26] Similar findings regarding the position of the maxillary canines were reported by Ericson and Kurol in a population of 125 cases, describing 55% of canines to be impacted palatally, 26% distal in relation to the root of the lateral incisor and 19% buccally.[26]

In the case of buccal impaction, a more advanced root developmental stage, a more anterior position and a high vertical impaction have been associated with worse periodontal outcome.[5] Moreover, a more buccally positioned canine generally has minimal buccal bone support which makes the soft tissue vulnerable for gingival recession. In the case of palatal impaction of the canine, there is some disagreement in the literature. Some authors report excellent periodontal outcomes, regardless of the initial canine position.[15] In contrast, Caprioglio et al reported a relation between gingival recession and visible cemento-enamel junction with a more anterior sector of the palatally impacted canine.[8]

Other studies reported the importance of the initial vertical position, angulation, and antero-posterior sector for the periodontal outcome of palatally impacted canines after treatment.[7,8] High vertical position (level 4 versus level 3) was confirmed to have a significant relationship ($p<0,05$) with the aesthetic outcome as defined by the MCAI in our study. For level 4 positioned canines the odds of suboptimal aesthetic results as defined by the MCAI were five times as high compared to level 3 positioned canines (Table 5).

In our study population, we found no significant difference in the aesthetic outcome of either buccally or palatally impacted canines following orthodontic treatment, nor did we observe a significant difference between the aesthetic outcome after an open or closed approach. We did however, find a significantly less aesthetic outcome with an increased degree of impaction (high vertical position and α-angle >30°). We could not identify the antero-posterior sector of the impacted canine as a predictor of aesthetic outcome.

Crescini et al found a significant relationship between prolonged treatment duration and more severe impaction.[15] This was supported by the findings of Stewart et al and Zuccati et al.[9,12] In line with these studies, we observed that bilateral position and increased impaction severity (sector, angulation and vertical height) were significantly associated with prolonged treatment duration.[9,12,15] Published literature suggests that the duration of treatment for orthodontic patients with palatally impacted canines is on average 18 to 30 months, with a wide range for individual cases. With an average treatment duration of 22 months, our findings are comparable to those in the literature.[5,9,11–15,27]

For the treatment of mid-crestal impaction of maxillary canines, Crescini et al suggested the application of the tunnel technique.[28] In our study population, we found that approximately half of the mid-crestal impacted canines were

treated with the closed tunnel technique. Retrospective evaluation of these cases demonstrated that the surgical procedure was converted to an open technique when there was adequate palatal exposure of the canine crown for the application of a bracket or cleat. Cassina et al stated in their recent systematic review that a closed approach to surgical exposure and the alignment of palatally impacted canines, took significantly longer overall than the treatment of buccally impacted canines.[29] Our study observations only partially support those findings.

We did observe a significantly longer treatment duration associated with palatal impaction of canines. However, no relationship with the chosen treatment modality was observed. Besides the role of the location of the impacted canine on treatment duration and the number of visits, Crescini et al also found that patients older than 25 require remarkably longer treatments than younger patients.[15] In line with these findings, Iancu Potrubacz et al found that the shortest treatment time was observed in eleven- to twelve-year old patients.[14] These findings were confirmed in our study population, where we observed prolonged treatment times with increased age (Figure 4). This relation between increased difficulty of treatment and increased age has also been reported by Becker et al.[30] These authors stated that the success rate among patients over 30 years of age was 41%, whereas the success rate for those 20 to 30 years of age was 100%.[30] Although we did not observe such a dramatic difference in success rates, we did observe a significant impact of age on prolonged treatment duration, suboptimal aesthetic results as defined by the MCAI and the need for re-intervention (Figure 4; Tables 3, 4 and 5). In the literature, there are few reports concerning the failure of treatment. Koutzoglou et al reported that for both buccal and palatal impaction of canines, the severity of impaction is a significant predictor of ankylosis.[6] In the study of Motamedi et al, about 30% of the impacted canines had to be surgically removed because of ankylosis and no movement after eight to nine months of 50 to 60g traction via elastic chains.[11] They identified a relationship between root dilaceration, anterior sector, and angulation greater than 45°, and an unsuccessful outcome, and concluded that the decision to expose or remove a canine with palatal impaction can be supported with these variables.

The position of the impacted canine is a major factor in the overall treatment duration. Other patient related factors to consider are: relation of the canine to adjacent teeth, presence of a follicle and condition of the surrounding bone. On the other hand, some orthodontist related factors to consider are: force used to support eruption, sequence of alignment of the maxillary dental arch, additional orthognathic surgery and overall retention period.[5,9,11–15,27]

In the course of the orthodontic treatment, 19 surgically exposed canines (12%) needed re-intervention. This was mainly caused by a lack of movement after an initial closed approach, loosening of the bracket or post-operative wound infection. The mean treatment time in this subgroup was 25 months (range 12-48). Of those canines, 13 canines reached a successful outcome after these surgical interventions. Initial canine position (vertical height and

angulation) was a significant predictor for the need for re-intervention Buccal position was confirmed as a significant predictor for the need for re-intervention. For buccally impacted canines the odds of re-intervention were more than four times as high compared to palatal or mid-crestal positioned canines (Table 5). The optimal position for placement of a bracket is the top of the canine crown. In severely impacted teeth, the exposure of the tip can be difficult and a proper fixation of the bracket with composite is not always easy to perform. An improper position of the bracket might result in suboptimal orthodontic traction. In some cases, this is an indication for re-intervention.

A panoramic radiograph is available and useful for the localization of the impacted canine. In this study, the vertical, antero-posterior sector position of the impacted canine and its angulation were analyzed. This two-dimensional interpretation was based on current guidelines regarding the assessment of given variables in the position of the canine. In adults with a high, more horizontally angulated, canine that is positioned close to the roots of the adjacent teeth, a CBCT might provide additional information to predict feasibility and efficacy of exposure and ligation of this tooth. This statement is supported by a recent systematic review comparing CBCT and conventional radiography in the localization of maxillary impacted canines.[31] Also, according to Becker et al, this is the only way to reduce the number of failures.[30]

In about four percent of the included canines, orthodontically assisted eruption was not possible and the canine had to be surgically removed. In all of these cases, a clinical diagnosis of ankylosis and failure of eruption was made. Increased age was the only significant predictor for surgical removal of the canine. Alternative treatment options in adults are autotransplantation of the impacted canine into the dental arch followed by an endodontic treatment, placement of a dental implant or rehabilitation with a conventional bridge.[4]

LIMITATIONS OF THE STUDY

The main limitation of this study is its retrospective design. As a consequence, many patients were excluded due to lack of pre-treatment panoramic radiographs and/or photographs between one and two weeks after debonding. This may have resulted in a significant selection bias and this high dropout rate undermines the statistical value of our study.

However, no significant difference was found between the excluded and included groups when it comes to the age of patients, which was an important predictive variable for the outcomes addressed in this study. Although not all baseline characteristics of the excluded patients could be addressed, we believe that the large number of excluded patients did not affect the outcome of the results of this study.

CONCLUSIONS

According to the present results, the following conclusions could be drawn when considering the treatment of impacted maxillary canines:

- Even when considering a broad study population with impacted canines (no age limitations, no positional limitations), this study suggests a high number of canines will achieve full eruption at the end of the treatment (96%), with or without the need for surgical re-intervention.
- Excellent aesthetic outcomes, as defined by the MCAI, are to be expected when treating impacted maxillary canines with surgical exposure and orthodontic traction based on the given results.
- Radiographic variables of the canine position (vertical height and angulation) are valuable tools for the prediction of the aesthetic outcome.
- Radiographic variables of the canine position (vertical height, angulation, and antero-posterior sector), buccopalatal position, increased age and bilateral impaction are valuable tools for the prediction of treatment duration.
- Increased age is an important predictor for unsuccessful treatment (suboptimal aesthetic result and need for re-intervention).

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CHAPTER 7

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Chaabouni D, Romero LPG, Vandendriessche T, Politis C, Jacobs R. Autogenous transalveolar transplantation of maxillary canines: A systematic review and meta-analysis. Eur J Orthod. 2018 Nov 30;40(6):608-616. doi: 10.1093/ejo/cjy026. PMID: 29860316; PMCID: PMC6265659.

AUTOGENOUS TRANSALVEOLAR TRANSPLANTATION OF MAXILLARY CANINES: A SYSTEMATIC REVIEW AND META-ANALYSIS

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ABSTRACT

OBJECTIVES: The objective was to systematically review transalveolar transplantation of maxillary canines and the long-term outcome for an average follow-up period of two years or more.

MATERIAL AND METHODS: A systematic review of the currently available literature until December 2017 was conducted, using Medline, Cochrane Central, Web of Science and PubMed. Articles were screened for 1) indications, 2) contra-indications, 3) surgical planning, 4) surgical technique, 5) associated risk factors and 6) long-term outcome for transalveolar transplantation of maxillary canines with the following outcome measures: bone related outcomes, tooth related outcomes, soft tissue related outcomes and aesthetic outcome measures. Descriptive statistics, as well as a quality assessment of included articles, were performed. Following study retrieval and selection, relevant data was extracted and the risk of bias was assessed using the Methodological Index for Non-Randomized Studies (MINORS).

RESULTS: Twelve articles were included in this review. These studies included outcome data for 783 autotransplanted maxillary canines, with long-term studies indicating a clinically acceptable overall outcome.

CONCLUSION: There is sufficient evidence to justify the transalveolar transplantation of maxillary canines as a legitimate treatment technique for impacted maxillary canines deemed difficult to treat with surgical exposure and subsequent orthodontic alignment. Long-term studies have shown that a good overall outcome is to be expected. There is no clear agreement in the literature on the indications and contra-indications for transalveolar transplantation of

maxillary canines. It is highly desirable that further research on this issue be undertaken; high quality observational studies are recommended.

INTRODUCTION

Impaction is defined as 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.[1]

Permanent maxillary canines are the second most frequently impacted teeth with an incidence ranging from 0.9 to 2.2 percent, the most frequent being wisdom teeth.[2] Impaction of permanent maxillary canines occurs three times more often in females than in males. Eight to ten percent of these cases are bilateral.[3] Untreated partially erupted or impacted canines may result in several complications such as displacement and loss of vitality of the adjacent incisors, shortening of the dental arch, formation of follicular cysts, canine tooth ankylosis, recurrent infections, pain, internal resorption, external resorption of the canine and adjacent teeth, or combinations of these factors.[4]

Initially, diagnosis of impacted maxillary canines is clinical, with attention for distal displacement or distal inclination of the lateral incisor (ugly duckling), lateral incisor mobility, retention of the primary canine in the dental arch beyond the age of 14 to 15, local palatal swelling or absence of the typical vestibular prominence.[5] Further radiographic analysis with panoramic radiographs (PR) and cone-beam computed tomography (CBCT) is essential for the assessment of canine position and to detect canine root malformations, local obstructing pathology or incisor root resorption.

Traditional treatment options for impacted canines are 1) interceptive removal of the deciduous canine, 2) surgical exposure with or without orthodontic traction to align the malpositioned tooth, 3) no treatment, 4) autotransplantation of the permanent canine or 5) removal of the permanent canine and prosthetic or restorative treatment. When surgical exposure and subsequent orthodontic realignment are difficult or impossible because of an unfavorable canine position, autotransplantation is a valuable alternative to extraction or other treatment options. High positioning or an angulation larger than 45° relative to the occlusal plane are known selection criteria for autotransplantation.[6] Orthodontic treatment is not always accepted by patients because treatment time may increase to two to three years, depending on many factors such as the canine position, aesthetic and economic considerations. In such cases, and with sufficient diastema, autotransplantation of the maxillary canine may be a good treatment.

So far, no systematic reviews assessing indications for transalveolar transplantation of maxillary canines and their outcomes over the long-term have been reported in the literature. In the present study, the aim was to systematically analyze the scientific literature regarding transalveolar transplantation of maxillary canines considering 1) indications, 2) contra-indications, 3) surgical planning, 4) surgical technique, 5) associated risk factors and 6) the long-term outcomes for transalveolar transplantation of maxillary canines with: bone related outcomes, tooth related outcomes, soft tissue related outcomes and aesthetic outcome measures. The ultimate purpose is to better define indications for maxillary canine transplantation, avoiding failure of surgical exposure with orthodontic alignment while also preventing unnecessary maxillary canine transplantations.

MATERIALS AND METHODS

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines were followed to ensure transparency and comprehensiveness in this systematic review.[7] A search protocol was specified in advance and registered at PROSPERO (International Prospective Register of Systematic Reviews) nr. CRD42017056348.

Objective

To review transalveolar transplantation of maxillary canines considering 1) indications, 2) contra-indications, 3) surgical planning, 4) surgical technique, 5) associated risk factors and 6) long-term outcome for transalveolar transplantation of maxillary canines: bone related outcomes, tooth related outcomes, soft tissue related outcomes and aesthetic outcome measures. Criteria for including studies in this systematic review are shown in Table 1.

PICO question

Eligibility criteria were determined a priori according to the PICOS (Participant–Intervention–Comparison–Outcome–Study design) scheme (Table 1).

Table 1. *Criteria for including studies in this systematic review.*

Types of studies (S)	
Prospective and retrospective studies that assessed transalveolar transplantation of maxillary canines with a minimum follow-up period of two years.	
Participant characteristics (P)	
Studies on human participants of any gender or malocclusion in the permanent dentition with full or incomplete development of the roots.	
Intervention (I)	
Transalveolar transplantation of maxillary canines.	
Comparison (C)	
Studies assessing outcome after transalveolar transplantation of maxillary canines.	
Outcome (O)	
Bone related outcomes	▪ Presence of lamina dura ▪ Alveolar bone resorption ▪ Vestibular thickness, height and prominence of the bone ▪ Vertical bone loss
Tooth related outcomes	▪ Root resorption ▪ Changes in pulp chamber ▪ Tooth vitality ▪ Change of canine color ▪ Tooth mobility and ankylosis ▪ Endodontic treatment
Periodontal outcomes	▪ Periodontal attachment: pocket depth ▪ Periodontal space ▪ Gingival recession
Aesthetic outcome	▪ Patient satisfaction ▪ Objective criteria

SEARCH STRATEGY FOR THE IDENTIFICATION OF STUDIES

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 December 2017. The search strategy used a combination of controlled vocabulary and free text terms and was run with the recommended EMBASE and MEDLINE filters to identify randomized controlled trials.[8]

The full search protocol for the different databases is displayed in Supplemental Table 1. No language or data restrictions were applied when searching the electronic databases. Additionally, all references of selected full-text articles were manually screened for potentially useful articles.

DATA COLLECTION AND ANALYSIS

Selection of studies

Titles and abstracts of relevant studies identified through the electronic searches were screened by three authors (KG, DC and LPGR). Full-text articles were obtained from the studies that fulfilled the inclusion criteria. These full-text

articles, together with full-text articles found through the manual search, were independently assessed by these authors to determine if they were in line with the inclusion criteria. Disagreements were resolved through discussion. After selection, data extraction and a risk-of-bias assessment were performed.

Inclusion and exclusion criteria of eligible studies

- Main inclusion criteria
  - Studies investigating the indication, success/survival rate, and surgical procedure of autogenous transplantation of maxillary impacted canines
  - Controlled trials or prospective/retrospective studies, case series with at least ten transplanted maxillary canines
  - Studies reporting at least one of the following: survival rate (short or long-term), success rate, pulp condition, tooth mobility, presence of ankylosis and root resorption of autotransplanted teeth with complete or incomplete root formation
  - Mean follow-up period should be at least two years
  - No restrictions on language were made
- Main exclusion criteria
  - Studies including autogenous transplantation other than maxillary canines
  - Case reports, case series with less than ten transplanted maxillary canines, opinion articles, and review articles
  - Studies reporting teeth autotransplantation in patients with systemic diseases, syndromes, or cleft lip and palate
  - Animal studies
  - Studies without specified transplantation protocol
  - Studies referring to transplantation of traumatized maxillary canines
  - Studies reporting autotransplantation of teeth with a history of cysts, tumors, or trauma
  - Studies including sterilized teeth, cryopreserved teeth or teeth maintained in culture media
  - Studies with oro-antral fistula
  - Studies examining tooth autotransplantation associated with maxillary sinus lifting
  - Studies examining autotransplantation of canines subjected to endodontic treatment during transplantation surgery
  - Studies with patients that have genetic or systemic diseases
  - Studies not including information about follow-up

Data extraction and management

Data extraction was independently performed by two researchers (DC and LPGR) according to a modified version of the Cochrane data extraction form.[8] Data extraction forms were subsequently compared and a final form was constructed by two researchers (KG and DC). Authors of potentially eligible articles were contacted for clarification in case of doubts or missing data.

Data recorded:

- Methods: study design, location/setting, recruitment period
- Participants: inclusion and exclusion criteria, demographics, number of participants and autotransplanted maxillary canines
- Intervention: details regarding type of intervention
- Outcomes: bone related, tooth related, periodontal and aesthetic outcome and average follow-up time

Methodological quality assessment

The assessment of the methodological quality of the articles, in accordance with the Methodological Index for Non-Randomized Studies (MINORS), is shown in Supplemental Table 2. An item was scored as '0' when not reported, '1' when it was inadequately reported, and '2' when it was adequately reported. The articles were classified according to their methodological quality into low (>17), medium (10-17), and high risk of bias (<10).

Statistical analysis

Studies were divided into two groups: short follow-up (two to five years) and long-term follow-up (five years or more). For every group and success parameter, a meta-analysis based on a generalized linear mixed model for binary outcomes was built using a logit-link.

Forest plots for survival analysis for two to five years and five years or more were performed (Figure 2 and 3). Horizontal lines next to article names reflect the confidence interval for the parameter of interest for individual studies. The size of the quadrangle in the middle reflects the weight of each individual article in the meta-analysis. The figure in the lower part of the graph shows the confidence interval of the parameter, as obtained by meta-analysis of all mentioned studies.

Risk of bias in included studies

On the basis of the MINORS quality assessment, one study had a low risk of bias, six studies a moderate risk, and five studies a high risk (Supplemental Table 2).

RESULTS

Description of the studies

Results of the search

After screening titles and abstracts of 132 unique papers, 35 potentially eligible articles were selected (Figure 1). Each title and abstract were independently reviewed by two researchers (KG and DC), and the obtained information was compared. Inter-examiner disagreements were resolved in a consensus meeting. Of the 35 potentially eligible articles, 23 were excluded. These articles were excluded for the following reasons: study with histological analysis; studies

concerning autotransplantation without specific results or conclusions about maxillary canines; short paper about general reasons, requirements, treatment plans and techniques of autotransplantation of maxillary canines without clinical outcomes; studies with preoperative endodontic treatment techniques; studies with systematic surgical exposure of the maxillary canine before autotransplantation; studies focusing on root anomalies of impacted maxillary canines; case series with less than ten transplanted maxillary canines; literature reviews; studies without information about survival and/or success rates and one study with no report of the surgical procedure, follow-up modalities or even outcomes.

Included studies

A total of twelve articles was identified for inclusion in this review.9-18 This systematic review was based on prospective and retrospective cross-sectional studies and case series due to the absence of controlled trials. The reported final outcomes, ankylosis and root resorption rates from individual studies are summarized in Table 2. Information on pre-operative assessment, operative protocol and post-operative assessment is provided in Supplemental Table 3. For the meta-analysis considering endodontic treatment analysis, four studies were excluded.[12-14,19] For the analysis of resorption and ankylosis, four [16,17,19,20] and six studies [10,14,16,17,19,20] were respectively excluded.

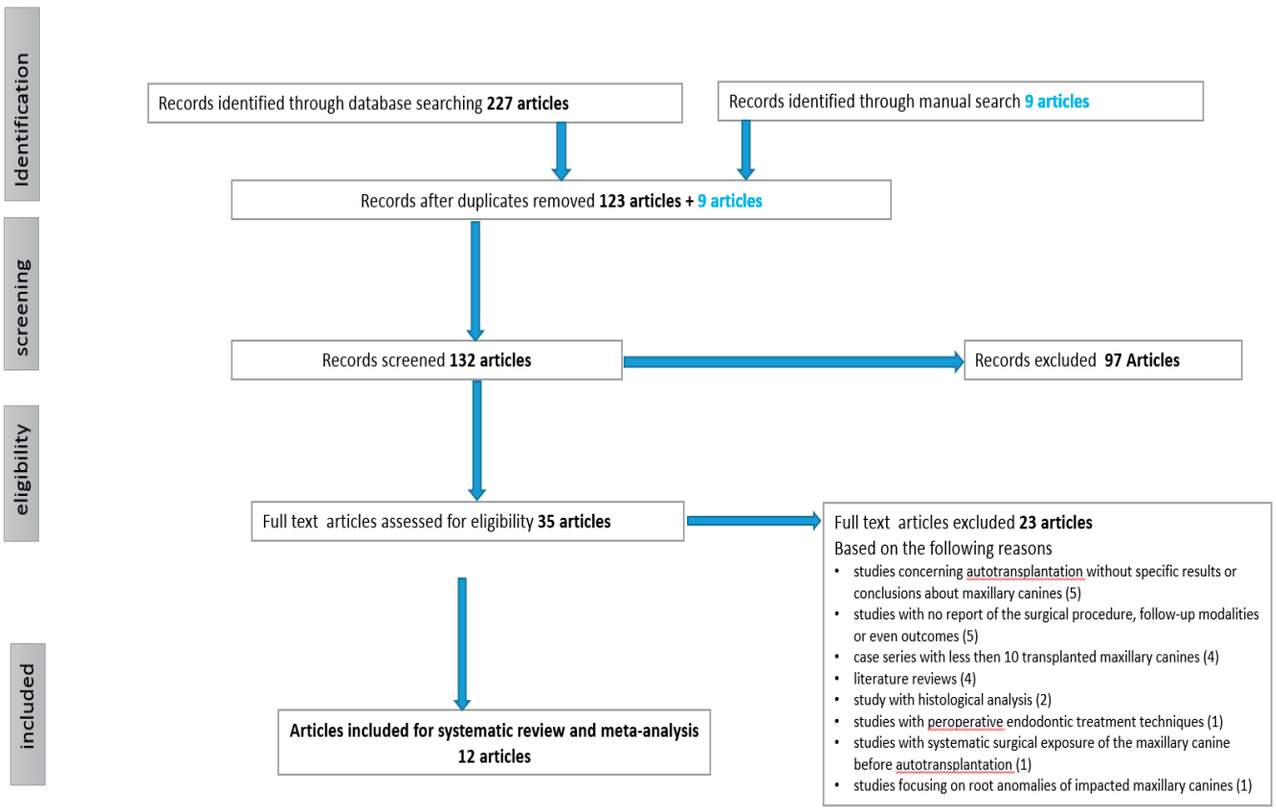

Figure 1. *Flow diagram.*

Table 2. *Summary of study characteristics and outcomes.*

Mean FU	Study	Outcome (%)	Endodontic treatment (%)	Resorption (%)	Ankylosis (%)	Mean FU (y)	Study design	N pt.	N teeth	M	F	Mean age	Min age	Max age
≥ 5 years	Patel et al (2011)	83	65	30,00	6,00	14,5	case control	49	63	-	-	21,8	13	42,1
	Ahlberg et al (1983)	96,7	69,7	75,8	100	6	retrospective	29	33	-	-	27,5	16	54
	Arikan et al (2008)	93,5	100	6,3	-	5,87	cross-sectional	30	32	9	21	34,32	25	55
	Sagne et al (1997)	88,1	100	-	-	9	cross-sectional	85	101	31	54	31	11	76
2 - 5 years	Kvint et al (2010)	90,3	-	3,2	3,2	4,8	retrospective	-	31	-	-	-	-	-
	Lownie et al (1986)	78		19%	-	4	cross-sectional	-	17	-	-	-	-	-
	Pogrel et al (1987)	62	-	-	-	2	cross-sectional	-	162	-	-	-	-	-
	Sagne et al (1986)	100	100	-	-	2	retrospective	12	14	8	4	36,5	23	54
	Schatze et al (1993)	100	65	5	10,00	4,4	cross-sectional	17	19	-	-	24,9	13	48
	Chambers et al (1988)	94	100,00	33	72	2,9	retrospective	35	41	13	22	22	11	42
	Hall et al (1983)	90	31	-	-	4	retrospective	113	141	33	80	20	13	43
	Kallu et al (2005)	89,2	-	37,5	32,1	3,8	retrospective	-	56	-	-	19,8	-	-

Characteristics of the study settings and investigators

Of the twelve included studies, four were performed in Sweden[9,13,16,17] and two in Australia[11,20]. Other studies were performed in Belgium[12], Turkey[10], South Africa[14], UK[15], USA[19], and Switzerland[18]. Studies had a retrospective, cross-sectional, retrospective case series and case-control nature (split-mouth design).

Characteristics of the participants

The mean age of the participants ranged from 19.8 to 36.5 years old (minimum age 11 and maximum age 76). Three studies did not report mean age.[13,14,19] The distribution of men and women was presented in five of the twelve studies. Between twelve and 113 patients were selected for each study, with a median of 33 patients. Four studies mentioned the number of teeth rather than the number of patients.[12-14,19] Fourteen to 162 maxillary canines were selected for each study, with a median of 37 maxillary canines. Nine studies solely reported on the transplantation of maxillary canines.[6,9-11,14-17,20] Three studies reported on the transplantation of maxillary canines as a subgroup.[12,13,19]

Sample size calculation

None of the studies reported sample size calculations.

Characteristics of the interventions

- **Pre-operative assessment**

Most of the studies did not report any details about clinical and radiographic pre-operative assessment. Root development stage was mentioned in three studies and found to be complete in all canines of these studies.[9,10,15] Canine positions were mentioned in two studies.[9,20] Canine angulation and root anomalies were not mentioned in any studies. Pre-operative orthodontic treatment was discussed in three of the included studies.[14,16,17] In three studies, authors mentioned orthodontic treatment pre-operative for widening of the diastema.[14,16,17] Radiographic analysis was mentioned in seven studies and performed with 2D images. None of the included studies discussed 3D imaging with CBCT or 3D planning.

Indications for autotransplantation were vaguely described in two studies.[16,17] These studies mentioned severe impaction and difficult malpositioning, as such that orthodontic treatment was either impossible or would have been complicated and time-consuming.

- Operative protocol

The surgical procedures of maxillary canine transplantation were identical or similar to the protocol demonstrated by Andreasen et al.[21] First of all, the surgical sites are disinfected and a local anesthetic is injected. The remaining primary canine, if still present, is extracted, and a trapezoidal flap incision is made ensuring intact mesial, distal, and palatal gingiva at the graft site. To prepare the recipient socket, an osteotomy is performed using a surgical bur with water cooling and chisels. The socket for the graft should be slightly larger than the graft. Next, the crown of the impacted canine is exposed and the tooth removed with a periosteal elevator. The donor tooth is extracted slowly and as atraumatically as possible. Next, the donor tooth is placed into the recipient socket without any pressure. The trapezoidal flap is repositioned and sutured.

Six studies mentioned the extra-oral time as: <15 minutes, <20minutes, <25 minutes, brief, with minimal delay or without extra-oral time.[10,11,13,14,17,20] Five studies mentioned the storage medium as: cloth saturated with saline[3], in physiological saline or intra-alveolar at the donor site [9,11,13,14,17]. The fixation method was discussed in eleven studies as: attached to the orthodontic wire for 3-6 weeks, 5 weeks, 12 weeks or 3-6 months, to a splint (undefined type) for 2, 4 or 6 weeks, to a plastic vacuform splint or silver splint for 4 weeks, to a metal cap splint for 6 weeks or with sutures for 2-3 weeks.[6,9-12,14-17,19,20] Occlusal positioning of the transplanted maxillary canine was discussed in eleven studies and found to be infra-occlusal in five studies and functional in six studies.[6,9-12,14-17,19,20]

- Post-operative assessment

Most of the studies did not report any details about the post-operative assessment other than including clinical and radiographic examinations. In none of the studies a clear healing protocol was discussed. One study mentioned a minimal delay of one year for instrumentation of the periodontium.[10] The duration and recurrence of clinical and radiological follow-up were mentioned in respectively five and eight studies (Supplemental Table 3). Two studies mentioned orthodontic treatment post-operatively but did not discuss timing.[14,17] Endodontic treatment and indications were discussed in all twelve studies. In four studies, endodontic treatment was a standard protocol after transplantation.[10,11,16,17] In seven studies, endodontic treatment was only indicated in case of signs of periapical infection or inflammatory root resorption.[9,12-15,19,20] In one study, endodontic treatment depended on the patient's age and root formation.[6]

Characteristics of outcome measures

Some studies define outcome differently by using various success and survival criteria in which only teeth without any signs of resorption and/or endodontic treatment can be considered to be successful. However, it should be questioned whether root resorption observed after tooth transplantation constitutes a failure when it is possible to keep the tooth in place for a prolonged time without further bone resorption and on the contrary even maintain the alveolar ridge by the process of replacement resorption.[22,23] As such, authors of this review preferred to use calculation of a general outcome in which successful outcome was defined as the percentage of transplanted teeth still present and functioning well at the time of recall. Failure was defined as loss of the autotransplanted maxillary canine during the observation period.

Infection-related root resorption was defined as the autotransplanted tooth exhibiting resorption signs on a radiograph. Ankylosis was defined as the absence of clinical mobility with or without root resorption on a radiograph. The data of failure, infection-related root resorption, and ankylosis were based on the reported results from the original articles.

Bone related outcomes were seldom explicitly reported, except for vertical bone loss in six studies and the presence of lamina dura in three studies (Supplemental Table 3).

Tooth related outcomes were more frequently reported. Nine studies discussed the prevalence of root resorption, two studies discussed changes in pulp chamber appearance. Seven studies reported testing of tooth vitality, four studies compared tooth color. Four studies tested tooth mobility and subsequently also ankylosis, in nine studies frequency of endodontic treatment was discussed (Table 2).

Soft tissue outcomes were frequently tested by all studies in the clinical follow-up. Nine studies checked the periodontal attachment by controlling the pocket depth.[6,9-12,15-17,20] Only one study mentioned a one-year healing interval

before probing.[10] Four studies evaluated gingival recession levels and two studies evaluated the periodontal space (Supplemental Table 3).

Aesthetic outcome was reported in two studies by means of patient satisfaction.[11,16] No objective criteria were used to score the aesthetic outcome in any of the included studies.

Duration of mean follow-up

The mean duration of follow-up was found in seven studies. In two studies, only a minimal follow-up time was mentioned.[14,19] In those cases, minimal follow-up time was used for further calculations. In three studies, autotransplanted maxillary canines were subdivided according to mean follow-up time.[11,14,20] Only subgroups with a mean follow-up time of minimal two years were included. In the case of multiple subgroups with a mean follow-up time of minimal two years, only the subgroup with the most complete follow-up information was included. The data of the mean follow-up times were based on the reported data from the original articles.

Table 3. *Results of estimated outcome, endodontic treatment, infection-related root resorption rate and ankylosis rate from meta-analysis.*

Variable	Group	Number of included articles	Percentage	Confidence Interval (CI)
Outcome	2-5 years	8	87.5	[77.2;93.6]
Outcome	5 years or more	4	88.2	[81.4;92.7]
Endo	2-5 years	4	82.5	[31;98]
Endo	5 years or more	4	91.5	[53.3;99]
Resorption	2-5 years	5	18.5	[7.4;39]
Resorption	5 years or more	3	32.3	[5.4;79.9]
Ankylosis	2-5 years	4	23.8	[4.8;65.7]
Ankylosis	5 years or more	2	65.2	[0.2;99.9]

Calculations performed on data

Meta-analytic results are summarized in Table 3. The meta-analysis showed a final outcome rate of 87.5% (CI 77.1;93.6) in the short-term follow-up group (2-5 years) and 88.2% (CI 81.4;92.7) in the long-term follow-up group (> 5 years). Endodontic treatment was calculated to be performed in 82.5% (CI 31;98) of the canines in the short-term follow-up group (2-5 years) and 91.5% (CI 53.3:99) of the canines in the long-term follow-up group (> 5 years). The meta-analysis showed the complication rate of root resorption and ankylosis to be respectively 18.5% (CI 7.4;39) and 23.8% (CI 4.8;65.7) in the short-term follow-up group (2-5 years) and 32.3% (CI 5.4;74.9) and 65.2% (CI 0.2; 99.9) in the long-term follow-up group (> 5 years) (Figures 2-3).

Effects of intervention

Twelve studies presented outcome data for 783 autotransplanted maxillary canines. Results for all outcomes are summarized in Table 2.

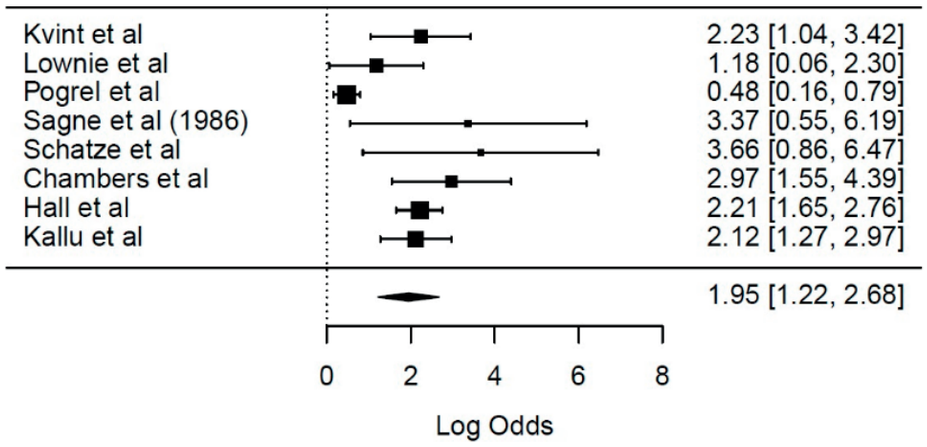

Figure 2. *Forest plot survival 2-5 years.*

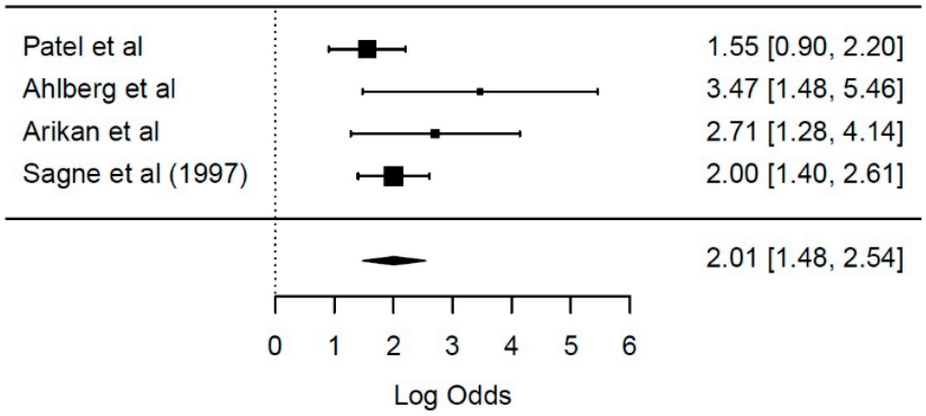

Figure 3. *Forest plot survival 5 years or more.*

DISCUSSION

Summary of evidence

This systematic review is the first comprehensive meta-analysis of autotransplanted maxillary canines. The objective of this study was to review transalveolar transplantation of maxillary canines and long-term outcome. Investigated outcome parameters included degree of mobility, pulp and root conditions and final aesthetic outcome for a follow-up period of two years or more. Prospective and retrospective studies identified in accordance with strict inclusion criteria were included. Information available on indication and follow-up were summarized. In total, twelve studies were included in the review.

In the current review it was evident that the literature lacks sufficiently well-organized studies concerning the topic of autotransplantation of maxillary canines. There was a striking absence of clearly reported diagnostic pathways, pre-operative planning and post-operative follow-up. Concerning the surgical technique, there is more uniformity between the different studies. None of the studies explicitly reported careful handling of the follicle. None of the reviewed studies mentioned 3D planning. None of the reviewed studies mentioned an objective evaluation of the final result.

An effort was done to include high-quality studies. However, most studies were retrospective. The level of bias in retrospective studies may be very high, which indicates the need for better designed studies addressing this subject. Organizing randomized controlled trials about this topic would be difficult as controls have different initials situations.

Overall completeness and applicability of evidence

This review included one case-control, six retrospective and five cross-sectional studies on the transalveolar transplantation of maxillary canines (Table 2). Considering the small number and retrospective study design of most studies, there is still insufficient evidence to support definitive conclusions.

None of the included studies reported adequate guidelines for pre-operative clinical and radiographic assessment and orthodontic pre-treatment. Most of the studies reported the use of 2D radiographs for evaluation of the status of root and apex and canine position. However, none of the included studies reported canine angulation and root anomalies. None of the included studies reported the use of 3D radiographic analysis with CBCT. At the time when most of the referred studies in this systematic review were performed, CBCT data was not yet introduced into clinical routine, with treatment planning and follow-up mostly based on 2D radiographs and clinical examination. Furthermore, for such procedures, the use of 3D data and CBCT is most often not advocated in case of (long-term) follow-up, unless problems arise. More recently, there is a tendency to use 3D planning for autotransplantation enabling accurate positional planning, increasing the ease of surgery, and decreasing the extra-oral time. However, the quality of the existing body of evidence is low. Further research is therefore required to investigate the clinical advantages of this innovative autotransplantation technique. When integrating CBCT examinations in the planning and follow-up, one should be aware of the costs and the radiation patients are exposed to. Also, CBCT does not necessarily provide more information compared to intra-oral radiography.[24]

The surgical protocol was defined in all the included studies. All of the studies followed the same surgical technique, minimizing the extra-oral time of the extracted canine and, when reported, used physiological saline or intra-oral storage. The fixation method varied in length (2 weeks – 6 months) and method (sutures, orthodontic wire, plastic vacuform splint, metal cap splint).

The post-operative assessment was only reported more extensively in a few studies. Most of the studies only mentioned the duration and recurrence of clinical follow-up and the usage of 2D radiographs. Most authors consider endodontic treatment of autotransplanted canines with closed apices mandatory, analog to traumatically avulsed teeth with closed apices. In cases of immature teeth with open apices, a wait-and-see strategy is accepted due to the considerable potential of revascularization. However, some authors suggest a wait-and-see strategy even in cases of closed apices.

Better survival and success rates have been reported with autotransplanted teeth with open apex versus closed apex. However, Chung et al, in their systematic review of transplanted teeth with a closed apex, found high survival rates of 98% at the one-year follow-up point and 90.5% at the five-year follow-up point.[25] Acevedo et al, in their systematic review of teeth with an open apex, found a survival rate of 98% after a mean follow-up period of six years.[26] In a recently published long-term follow-up case series, Murtadha et al concluded that one might need to reconsider the protocol of routinely providing endodontic treatment for transplanted teeth with closed apices, because some might have the potential for revascularization.[27]

None of the included studies discussed orthodontic movement after surgery.

Most of the included studies reported on only tooth related outcomes such as tooth survival, root resorption and ankylosis. However, only the minority of the included studies reported a complete clinical evaluation including changes in pulp chamber, canine color and mobility. Only two studies evaluated more extensively the soft tissue outcome. As mentioned before, CBCT was not available or routine use of it was not yet established at the time when the studies included in this systematic review were conducted. Thus, none of the included studies reported 3D evaluation of tooth related and bone related outcomes. Previous studies have proven that regular follow-up with clinical checkup and intraoral radiographs are sufficient in clinical practice. However, in a research setting it might be interesting to use 3D imaging to evaluate tooth related and bone related outcomes in the short and long-term.

None of the included studies reported objective criteria for aesthetic outcome evaluation.

Although there is a lack of consensus regarding a set of universally accepted outcome criteria, studies of transalveolar transplanted canines should make an effort to describe parameters of clinical outcome. The criteria used for the assessment of final outcome in autotransplantation are quite variable, ranging from the tooth simply being present intra-orally to present and completely free from resorption, discoloration, and pocketing, while maintaining vitality.[15] It should be questioned whether ankylosis and replacement resorption observed after tooth transplantation constitute failure. Although the tooth is eventually lost, the root structure is replaced by bone during the root resorption process. At the end of the resorption process, the bucco-palatal width of the bone

may be sufficient for intraosseous dental implant insertion, even if it was not sufficient prior to tooth transplantation. Thus, transplantation failure may result in successful alveolar ridge augmentation. Therefore both survival (still present in the arch) and success (positive evaluation according to certain set of criteria defining success) are valid to report.

Meta-analysis showed a mean effect of 87.5% (CI 77.1;93.6) for the final outcome with a mean follow-up of two to five years and 88.2% (CI 81.4;92.7) with a mean follow-up of more than five years. This is considered to be an excellent prognosis.

Six studies reported ankylosed teeth. The numbers varied from 3.2% to 100%. A high ankylosis rate could have been caused by traumatic injuries either from donor tooth extraction or from extraoral root canal treatment. A low ankylosis rate might have resulted from minimizing the trauma from surgical procedures. Ankylosis may be caused by large injury to the root surface of a donor tooth during surgery. The bone directly contacts the dentin without an intermediate attachment apparatus. Subsequently the root is resorbed and replaced by bone.[28] According to Andreasen et al, clinical signs of ankylosis can be observed within a year of tooth autotransplantation.[29] Tsukiboshi concluded that ankylosis is irreversible and will progress until the loss of the tooth.[30] However the gradual progressive resorption in ankylosed teeth can vary with age, with high activity observed in children and significantly lower activity seen in adults, where the affected teeth may survive ten, 20 or more years.

Inflammatory root resorption was observed in eight studies, varying from three to 76%. The high rate in the latter study might be caused by delays in endodontic treatment. Inflammatory resorption is a progressive dentin resorption process in which a tooth with a damaged periodontal ligament surface and infected pulp is transplanted or replanted.[28,30] In general, radiographic signs of infection-related root resorption can be observed one to two months after tooth autotransplantation or explantation.[21]

CONCLUSIONS

Implications for practice

Based on the findings of the current study, it became clear that the literature is deficient in high-quality clinical studies. There is sufficient clinical experience to justify transalveolar transplantation of maxillary canines, with open and closed apices, as a legitimate treatment alternative considering the proper indication. Long-term studies have shown that a good overall success and survival rate is to be expected. However, since long-term complications such as progressive root resorption and ankylosis with replacement resorption can occur, the clinician should always consider the emotional cost, oral health related improvement in quality of life, treatment fatigue with having to endure the current procedure and possibly even another one in the future. There is a need for clear selection

criteria specifying requirements when to select transalveolar transplantation of maxillary canines, in order to reduce occurrence of the aforementioned complications.

Implications for research

Since the lack of randomized controlled trials considering this topic, the quality of the evidence in the present review is low. It is highly desirable that further research on this issue be undertaken based on larger samples and RCT designs to support the conclusions of the current literature. However, since impacted maxillary canines are a rare anomaly and different aspects, such as position of the impacted canine, patient's age and patient's demands and expectations must be taken into account, it is practically impossible to randomize treatment. In this case, high quality observational studies are recommended.

It is suggested that future studies should focus on indications for autotransplantations of maxillary canines, long-term clinical success parameters, revisit surgical techniques, 3D planning, (long-term) aesthetic results and patient satisfaction.

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SUPPLEMENTAL MATERIAL

Supplemental Table 1. *Search strategy.*

PubMed	Concept 1: maxillary and canines ((“Maxilla”[Mesh] OR maxilla*[tiab] OR “upper jaw”[tiab] OR “upper jaws”[tiab]) AND (“Cuspid”[Mesh] OR cuspid*[tiab] OR canine*[tiab]))
	Concept 2: autotransplantation (“Transplantation, Autologous”[Mesh] OR “transplantation autologous”[tiab] OR “autologous transplantation”[tiab] OR “autologous transplantations”[tiab] OR autotransplantation*[tiab] OR autograft*[tiab] OR “transalveolar transplantation”[tiab] OR “trans alveolar transplantation”[tiab] OR “canine transplantation”[tiab] OR “canine transplantation”[tiab])
Embase	Concept 1: maxillary and canines ((‘maxilla’/exp OR maxilla*:ti,ab OR ‘upper jaw’:ti,ab OR ‘upper jaws’:ti,ab) AND (‘canine tooth’/exp OR ‘canine tooth’:ti,ab OR ‘canine teeth’:ti,ab OR cuspid*:ti,ab OR canine*:ti,ab))
	Concept 2: autotransplantation (‘autotransplantation’/exp OR ‘transplantation autologous’:ti,ab OR ‘autologous transplantation’:ti,ab OR ‘autologous transplantations’:ti,ab OR ‘autotransplantation’:ti,ab OR autograft*:ti,ab OR ‘transalveolar transplantation’:ti,ab OR ‘trans alveolar transplantation’:ti,ab OR ‘canine transplantation’:ti,ab OR ‘canine transplantation’:ti,ab)
Web of Science	Concept 1: maxillary and canines ((maxilla* OR “upper jaw” OR “upper jaws”) AND (cuspid* OR canine*))
	Concept 2: autotransplantation (“transplantation autologous” OR “autologous transplantation” OR “autologous transplantations” OR autotransplantation* OR autograft* OR “transalveolar transplantation” OR “trans alveolar transplantation” OR “canine transplantation” OR “canine transplantation”)
Cochrane	Concept 1: maxillary and canines (maxilla* OR “upper jaw” OR “upper jaws”) AND ([cuspid] OR cuspid* OR canine*))
	Concept 2: autotransplantation (“Transplantation, Autologous” OR “transplantation autologous” OR “autologous transplantation” OR “autologous transplantations” OR autotransplantation* OR autograft* OR “transalveolar transplantation” OR “trans alveolar transplantation” OR “canine transplantation” OR “canine transplantation”)

Supplemental Table 2. *Score of each article selected with the inclusion criteria according to the items of MINORS*

Items of MINORS	Ahlberg et al (1983)	Arikan et al (2008)	Chambers et al (1988)	Hall et al (1983)	Kallu et al (2005)	Kvint et al (2010)	Lownie et al (1986)	Patel et al (2011)	Pogrel et al (1987)	Sagne et al (1986)	Sagne et al (1997)	Schatz et al (1993)
a clearly stated aim	2	2	1	1	2	2	2	2	1	2	1	2
inclusion of consecutive patients	1	2	1	1	2	2	2	1	1	1	1	2
prospective collection of data	2	2	1	2	2	2	2	2	1	2	1	2
endpoints appopriate to the aim of the study	2	2	1	2	0	2	1	2	1	1	1	2
unbiased assessment of the study endpoint	0	1	0	0	0	0	0	1	0	0	0	0
follow-up period appropriate to the aim of the study	2	1	1	1	2	2	2	2	0	1	1	2
loss to follow-up less than 5%	2	2	0	1	2	2	2	2	0	0	2	1
prospective calculation of the study size	1	0	1	1	2	1	0	2	0	0	1	1
an adequate control group	NA	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
contemporary groups	NA	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
baseline equivalence of groups	NA	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
adequate statistical analyses	NA	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
Total score	12	12	6	9	12	13	11	18	4	7	8	12
Risk of bias	medium	medium	high	high	medium	medium	medium	low	high	high	high	medium

Supplemental Table 3. *Summary of study interventions: pre-operative assessment, operative protocol and post-operative assessment.*

	Ahlberg et al (1983)	Arikan et al (2008)	Chambers et al (1988)	Hall et al (1983)	Kallu et al (2005)	Kvint et al (2010)	
Types of interventions and comparisons (I & C)							
Pre-operative assessment							
Status of root and apex (complete developed root or open apex)	complete	complete	NM	NM	NM	NM	
Canine position	23 palatal + 10 vestibular	NM	NM	72% palatal and 28% midcrestal	NM	NM	
Canine angulation	NM	NM	NM	NM	NM	NM	
Root anomalies	NM	NM	NM	NM	NM	NM	
Pre-operative orthodontic treatment	NM	NM	NM	NM	NM	NM	
Radiography	NM	NM	NM	not specified	NM	NM	
Operative protocol							
Surgical procedure	standard	standard	standard	standard	standard	Standard	
Extra oral time of the extracted canine	NM	< 15 min	brief'	<25 minutes	NM	minimal delay	
Storage	physiological saline	NM	Saline-soaked gauze	NM	NM	cloth saturated with saline	
Fixation method and length of fixation	5 weeks splint or orthodontic wire	4 weeks splint	6 weeks splint	6 weeks splint	sutures, 2-3 weeks	NM	
Contact with antagonist and adjacent teeth	in occlusion	occlusion	occlusion	occlusion	infra occlusion	NM	
Medication after surgery	NM	AB, mouth rinse	NM	NM	AB	AB	
Post-operative assessment							
Healing protocol	NM	no instrumentation	NM	NM	NM	NM	
Duration and recurrence of clinical follow up	NM	1w-2w-3w-4w-3/6/12m-2/3/4y	NM	NM	NM	6,12M and yearly for 5Y	
Radiological follow up (2D, 3D, recurrence)	2D rx apical; 1-2-3-5-6 years	2D rx apical 2-5y	NM	NM	NM	NM	
Orthodontic movement after surgery	NM	NM	NM	NM	NM	NM	
Endodontic treatment	only when symptoms	4 weeks, always	2 weeks , always	only when symptoms of resorption	only when symptoms of resorption	only when symptoms of resorption	

	Lownie et al (1986)	Patel et al (2011)	Pogrel et al (1987)	Sagne et al (1986)	Sagne et al (1997)	Schatz et al (1993)
	NM	complete	NM	NM	NM	NM
	NM	NM	NM	NM	NM	NM
	NM	NM	NM	NM	NM	NM
	MN	NM	NM	NM	NM	NM
	yes	NM	NM	yes	yes	NM
	OPG, periapical xray	not specified	NM	OPG and periapical rx	OPG and periapical rx	OPG and periapical rx
	standard	standard	standard	standard	standard	standard
	<20 min	NM	NM	NM	none	NM
	saline soaked gauze	NM	NM	NM	intra-alveolar	NM
	metal cap splint, 6w	splint, 2 weeks	plastic vacuform splint, silver splins for 4 weeks	orthodontic wire, 3-6 months	orthodontic wire, 3-6 weeks	orthodontic wire, 12 weeks
	infra occlusion	infra occlusion	occlusion	infra occlusion	infra-occlusion	occlusion
	AB and mouth rinse	AB	AB	AB	AB	AB and mouth rinse
	NM	NM	NM	NM	NM	NM
	weekly follow up-6w-6/12M-4Y	NM	NM	2-3-6-12-18M 1/jaar	1w-2/6/12/18M 1/y 5y	NM
	2D xrays	2D radiographs	6/12/18/24/36/48/60M	2-3-6-12-18M 1/jaar	1w-2/6/12/18M 1/y 5y	1w - 1/3/6m 1/year
	NM	NM	NM	NM	yes	NM
	only when symptoms of resorption	only when symptoms of resorption	only when symptoms of resorption or periapical abcess	always	always	related to age (preventive or only when symptoms of resorption)

	Ahlberg et al (1983)	Arikan et al (2008)	Chambers et al (1988)	Hall et al (1983)	Kallu et al (2005)	Kvint et al (2010)	
Types of outcome measures (O)							
Bone related outcomes							
Presence of lamina dura	Yes	NM	NM	yes	NM	NM	
Alveolar bone resorption	Yes	NM	NM	NM	NM	NM	
Vestibular thickness, height and prominence of the bone	NM	NM	NM	NM	NM	NM	
Vertical bone loss	Yes, 2D	yes	NM	NM	NM	NM	
Presence of lamina dura	Yes	NM	NM	yes	NM	NM	
Tooth related outcomes							
Root resorption	Yes, 2D	yes	yes	yes	yes	NM	
Changes in pulp chamber	NM	NM	NM	NM	NM	NM	
Tooth vitality	Yes	NM	NM	NM	yes	NM	
Change of canine colour	Yes	NM	yes	NM	yes	NM	
Tooth mobility and ankylosis	Yes	NM	NM	NM	yes	NM	
Endodontic treatment	Yes	NM	yes	NM	yes	1 month postop	
Root resorption	Yes	yes	yes	yes	yes	NM	
Periodontal outcomes							
Periodontal attachment: pocket depth	Yes	yes	yes	yes	yes	NM	
Periodontal space	Yes	yes	NM	NM	NM	NM	
Gingival recession	Yes	yes	NM	yes	NM	NM	
Periodontal attachment: pocket depth	Yes	yes	yes	yes	yes	NM	
Aesthetic outcome							
Patient satisfaction	NM	NM	yes	NM	NM	NM	
Objective criteria	NM	NM	NM	NM	NM	NM	

NM: not mentioned
AB: antibiotics

	Lownie et al (1986)	Patel et al (2011)	Pogrel et al (1987)	Sagne et al (1986)	Sagne et al (1997)	Schatz et al (1993)
	yes	NM	NM	NM	NM	NM
	NM	NM	NM	NM	yes	NM
	NM	NM	NM	NM	NM	NM
	NM	yes	NM	yes	yes	yes
	yes	NM	NM	NM	NM	NM
	yes	yes	NM	yes	NM	yes
	yes	NM	NM	NM	NM	yes
	yes	yes	yes	yes	NM	yes
	NM	yes	NM	NM	NM	NM
	yes	yes	NM	NM	NM	NM
	yes	yes	NM	2 months postop	3-6w	yes
	yes	yes	NM	yes	NM	yes
	NM	yes	NM	yes	yes	yes
	NM	NM	NM	NM	NM	NM
	NM	yes	NM	NM	NM	NM
	NM	yes	NM	yes	yes	yes
	NM	NM	NM	yes	NM	NM
	NM	NM	NM	NM	NM	NM

CHAPTER 8

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Nys M, The V, Vrielinck L, Schepers S, Jacobs R, Politis C. Long-term outcome of autogenously transplanted maxillary canines. Clin Exp Dent Res. 2019 Jan 17;5(1):67-75. doi: 10.1002/cre2.159. PMID: 30847235; PMCID: PMC6392819.

LONG-TERM OUTCOME OF AUTOGENOUSLY TRANSPLANTED MAXILLARY CANINES

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ABSTRACT

OBJECTIVES: The aim of this study was to determine the long-term outcome of autotransplanted maxillary canines and to investigate the influencing parameters.
MATERIAL AND METHODS: Seventy-one patients (84 transplanted canines) volunteered to participate in this study. The mean follow-up time was 21 years. In case of tooth survival and when patients were found willing for recall, teeth were investigated clinically and radiographically. Transplanted teeth were compared to the contralateral canine and scored with an aesthetic and radiographic index.
RESULTS: The survival rate was 67.9%, considering that 27 transplanted teeth were lost before examination. The mean survival time was 15.8 years.
CONCLUSION: Maxillary canine autotransplantation may have a successful outcome up to 21 years after transplantation requiring minimal patient compliance and low financial costs. The survival rate can be considered favorable given that autotransplantation is a treatment option in a selected group of cases.

INTRODUCTION

Permanent maxillary canines are essential considering aesthetics and lip support.[1,2] However, apart from the wisdom teeth, upper canines are the most frequently impacted teeth (incidence 0.9 to 2.2 percent).[3] Impaction of the permanent maxillary canine occurs two times more often in females.[3] Eight to ten percent of the cases are bilateral.[4]

Canine impaction has been reported to increase orthodontic treatment time, with complicated orthodontic treatment mechanics and increased treatment costs.[5,6]

The traditional treatment options for impacted canines are interceptive removal of the deciduous canine, surgical exposure with or without orthodontic traction to align the malpositioned tooth, no treatment, autotransplantation of

the permanent canine or removal of the permanent canine and prosthetic or restorative treatment.

When surgical exposure and subsequent orthodontic realignment are difficult or impossible due to an unfavorable impaction position of the impacted maxillary canine or the patient refuses prolonged orthodontic treatment, autotransplantation is a valuable alternative. Autogenous tooth transplantation can be defined as the surgical movement of a tooth from one position in the mouth to another in the same individual.[7] Few long-term follow-up studies have been published in the literature.[8] The present study aimed to determine the long-term outcome and survival of autotransplanted canines.

MATERIAL AND METHODS

Subjects

In 71 patients, 84 teeth, maxillary canine transplantation was performed. All these procedures were performed between 1995 and 2002. Equal gender distribution was found (33 males, 41 teeth and 38 females, 43 teeth; Table 1). At the time of transplantation, the mean age was 20.7 years (range 10.9 – 46.3 years), and the mean follow-up period was 21 years (range 19.9 – 23.9 years). The same surgeon performed all transplantations (CP), following the same protocol. All transplanted teeth reported here were maxillary impacted canines. Pre- and perioperative parameters were retrieved from the medical files (Table 2). Through observation of previous radiographs (intra-oral and panoramic), the stage of root development at time of transplantation was evaluated with Moorrees et al's classification.[9]

Table 1. *Number of patients, number of transplanted teeth, and age at time of transplantation subdivided by gender.*

	N	Number of transplanted teeth	Age at time of transplantation, mean (SD)
Male	38	46	21.5 (+/- 9.9)
Female	33	38	19.9 (+/- 9.5)
Total	71	84	20.7 (+/- 9.7)

Table 2. *Pre- and postoperative parameters which could influence the outcome of transplantation.*

Preoperative parameter	Total (n)	Survival (n)	Failure (n)	p-value
Position of the canine				
Palatal	82	57	25	0.21
Labial	2	0	2	
Sufficient space for transplantation				
Yes	79	53	26	0.56
No	5	4	1	
Stage of root development				
1/2 - 3/4	3	3	0	
>3/4	23	14	9	
Complete	58	40	18	
Condition of apex				
Open	26	20	6	0.31
Closed	58	37	21	
Apical anomaly				
Curved apex	22	15	7	0.97
No curved apex	62	42	20	
Baseline ankylosis of the transplanted tooth				
Yes	19	7	12	<0.005
No	65	50	15	
Damage of the periodontal ligament				
Yes	15	5	10	<0.005
No	69	52	17	
Fixation				
Orthodontic wire	65	46	19	
Trauma splint	18	10	8	
No fixation	1	1	0	

All patients were contacted by telephone and survival of the transplanted canine was checked for. In case the transplanted canine was still in situ, patients were invited for a recall visit to the department for further clinical and radiographic analysis. Out of the 47 patients (57 surviving autotransplanted maxillary canines) who were eligible for a recall visit, 23 patients (27 surviving autotransplanted maxillary canines) decided to participate in the present study. Clinical and radiographic examination of these 27 autotransplanted maxillary canines was performed by the same examiner. This involved evaluation of the transplanted canine and the contralateral canine using aesthetic and radiographic indexes as described by Grisar et al.[11,12] In case of bilateral autotransplantation, both teeth

were evaluated and compared with the contralateral canine. In case of absence of the contralateral tooth, only the transplanted tooth was evaluated.

The mobility of the transplanted tooth was tested by means of the Periotest (Medizintechnik Gulden, Modautal, Germany). Periotest measurements were taken and interpreted according to the manufacturer's instructions. Negative Periotest values indicate lower mobility, pointing toward ankylosis. [10]

The 24 patients (27 failed autotransplanted maxillary canines) that reported a failure of the transplanted canine via telephone were further questioned concerning the timing of failure and the current treatment or treatment plan (no plan, resin retained bridge, prosthesis, dental implant with or without bone augmentation procedure).

The study protocol was approved by the Ethics Committee of the St. John's Hospital, Genk.

Surgical procedure

The same surgeon performed all transplantations (CP), following the same protocol. This protocol, including the surgical technique and criteria for endodontic treatment, has been described in the previous study of Gonissen et al (Figure 1).[10] Prior to carrying out the actual surgery, a radiographic presurgical analysis was carried out identifying the specific location and donor site characteristics.

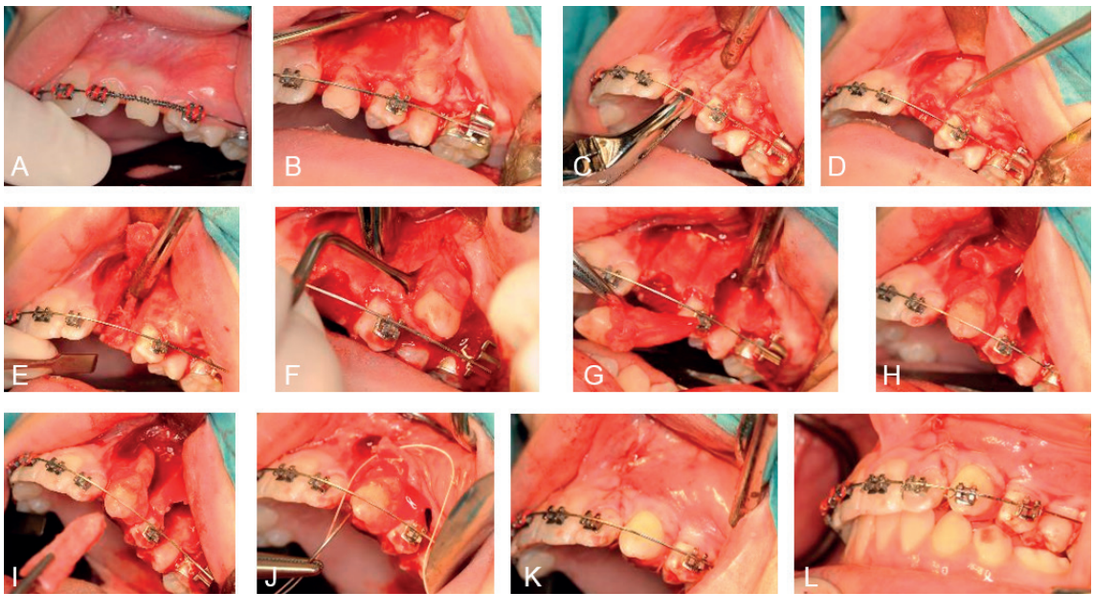

Figure 1. *Transplantation of an ectopic maxillary canine. A, Vestibular location. B, trapezoidal incision. C-D, Osteotomy with a fine surgical drill and chisels. E, Preparation of the recipient socket with chisels. F-G, Removal of the graft with careful handling of the periodontal ligament. H-K, Positioning of the donor tooth into the recipient socket and suturing of the trapezoidal flap. L, Fixation in the orthodontic arch with a bracket and orthodontic wire in infra occlusion position.*

CLINICAL AND RADIOGRAPHIC EXAMINATION

All transplanted teeth that were still in place were eligible for recall and further evaluation. Each patient signed a written informed consent form approved by the St. John's Hospital Ethics Committee (B371201733373). Clinical evaluation was performed according to the protocol described in the publication by Gonissen et al.[10] Tooth vitality, tooth mobility (Periotest), gingival inflammation, pocket status and aesthetic outcome were scored. Aesthetic outcome was assessed with the Maxillary Canine Aesthetic Index (MCAI) as described by Grisar et al.[11]

Intraoral radiographs (Sirona, 70 kV, 0.06s, 7 mA) and Cone Beam Computerized Tomography (CBCT) images of all transplanted teeth were taken. At the OMFS department of the St. John's Hospital, the cone-beam scanner Galileos (Sirona, 85 kV, 7 mA, 14s, 15 cm^3) was used. Radiological examination allowed evaluation of root resorption, periodontal ligament and lamina dura formation, ankylosis, alveolar bone loss, and apical inflammation. Radiographic outcome of the transplanted canine was assessed with the Autotransplanted Maxillary Canine Radiographic Index (AMCRI) as described by Grisar et al.[12]

Statistical analysis of the results

The ratio between failed and succeeded canines was first compared between different groups by means of a generalized linear model. Subsequently, survival analysis was performed by means of Kaplan-Meier graphs and survival regression for censored normally distributed data.

RESULTS

Clinical investigation

Twenty-seven transplanted maxillary canines were examined. Almost half of the teeth (17 teeth) showed negative Periotest values. Periotest values higher than the normal values were found with two teeth. The remaining eight teeth had normal Periotest values. Two transplanted teeth showed grade two tooth mobility. None of the contralateral canines showed altered mobility.

Almost half of the teeth (13 teeth) had root canal treatment after transplantation. Tooth vitality was examined in the remaining teeth (14 teeth). Five teeth showed a positive result for the cold test. Overall, almost half of the teeth (13 teeth) showed a deepened (>3 mm) clinical pocket depth. Mean pocket depth of the autotransplanted maxillary canines was 3.0 mm (SD 1.5). Mean pocket depth of the contralateral maxillary canines was 3.0 mm (SD 1.78). Seven transplanted teeth showed bleeding on probing, meaning moderate inflammation. Six teeth were clinically suspected of ankylosis due to the onset of an open bite (Figure 2, A). On clinical examination, major discoloration was seen in four teeth. Minor discoloration was seen in five teeth. All other transplanted teeth showed normal color.

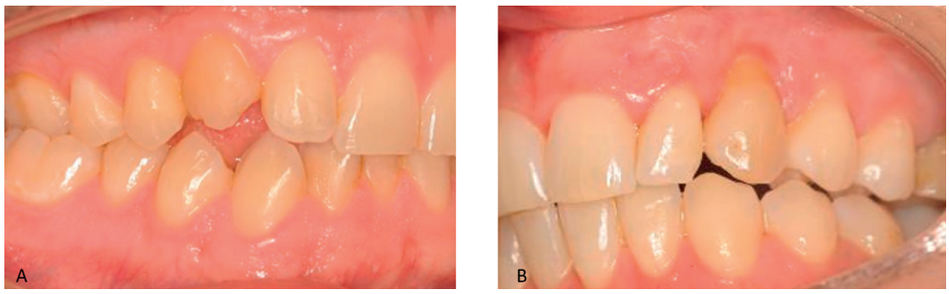

Figure 2. *A, Clinical picture of case with ankylosis and infra-occlusal position of transplanted canine. B, Clinical picture of case with gum recession.*

Aesthetic index

Aesthetic outcome of the transplanted canine was assessed with the Maxillary Canine Aesthetic Index (MCAI).[11] Sixteen of the transplanted maxillary canines were scored to have an excellent outcome, nine good, one with an acceptable outcome and one having a poor aesthetic outcome (Figure 3,4). Two teeth showed extensive recession of the gums (Figure 2, B). Six teeth were found to have a major deviation of the buccolingual inclination when compared to the contralateral maxillary canine.

Figure 3. *Aesthetic outcome of one case, 18 years after autotransplantation of the left maxillary canine. The tooth had root canal treatment six weeks after transplantation. The final functional, aesthetic and radiographic outcomes are excellent.*

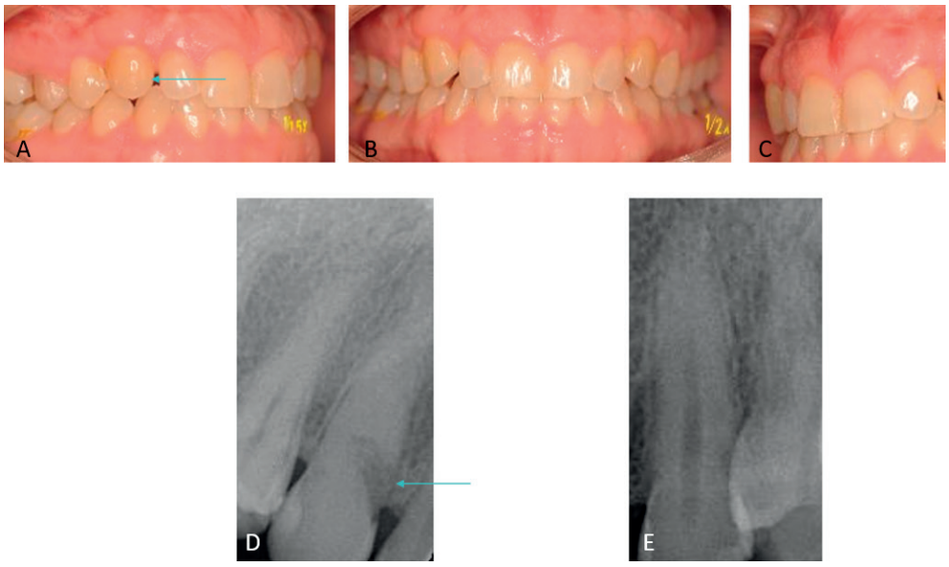

Figure 4. *Case of transplanted maxillary canine with sign of resorption. There is an excellent aesthetic outcome with nice gums around the transplanted tooth and good position. However, on intraoral imaging we can see an external resorption. Also, there is obliteration of the root channel and ankylosis.*

Radiographic index

Radiographic outcome of the transplanted canine was assessed with the Autotransplanted Maxillary Canine Radiographic Index (AMCRI).[12] Twelve of the transplanted maxillary canines were scored to have an excellent outcome, three good, seven with an acceptable outcome and four to have a poor radiological outcome (Figure 2, 3, 4).

External root resorption was the predominant type of resorption as nine transplanted teeth showed some sign of external root resorption on 2D and 3D imaging (Figure 4). Three teeth showed apical infection on 2D and 3D imaging. None of the transplanted teeth showed internal root resorption. Four teeth showed signs of ankylosis on 2D and 3D imaging. Three teeth showed apical pathology on 2D and 3D imaging.

Survival rate

Since 27 transplanted teeth were lost prior to end stage examination, the survival rate was 67.9%. Because of a delayed root canal treatment, one transplant was lost six months after surgery. Figure 5 represents the Kaplan-Meier risk curve for the overall survival rate over 21 years. The mean survival time was 15.8 years (min 0.5 – max 23.9; SD 6.6). Figure 6 shows the relation between age at time of transplantation and survival of the transplanted canine (p=0.0966).

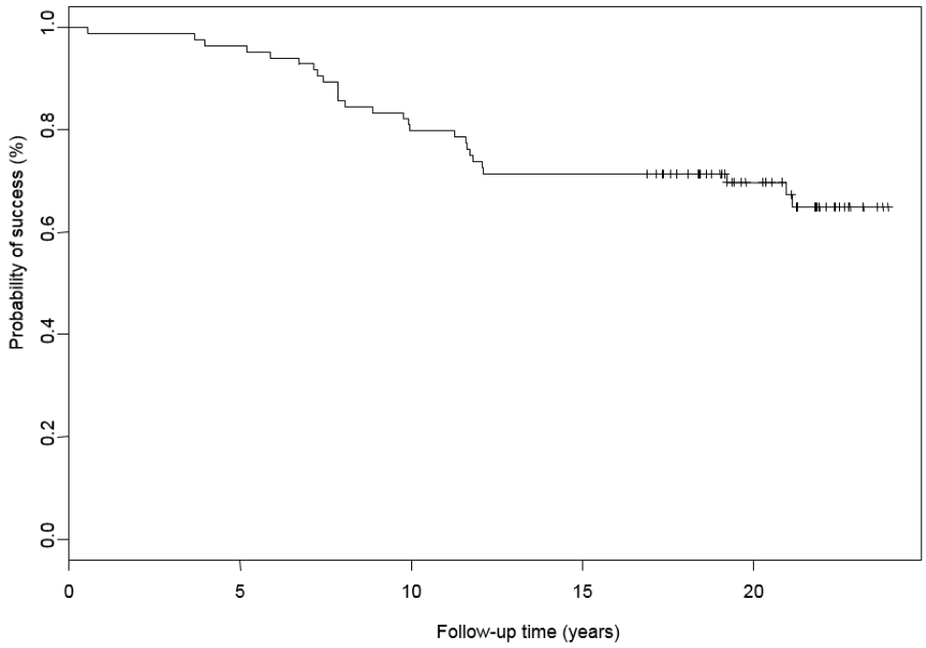

Figure 5. *Kaplan-Meier estimation describing the probability of survival for a follow-up period of 21 years showing a survival rate of 67.9% after 21 years, because 27 transplanted teeth were lost before examination.*

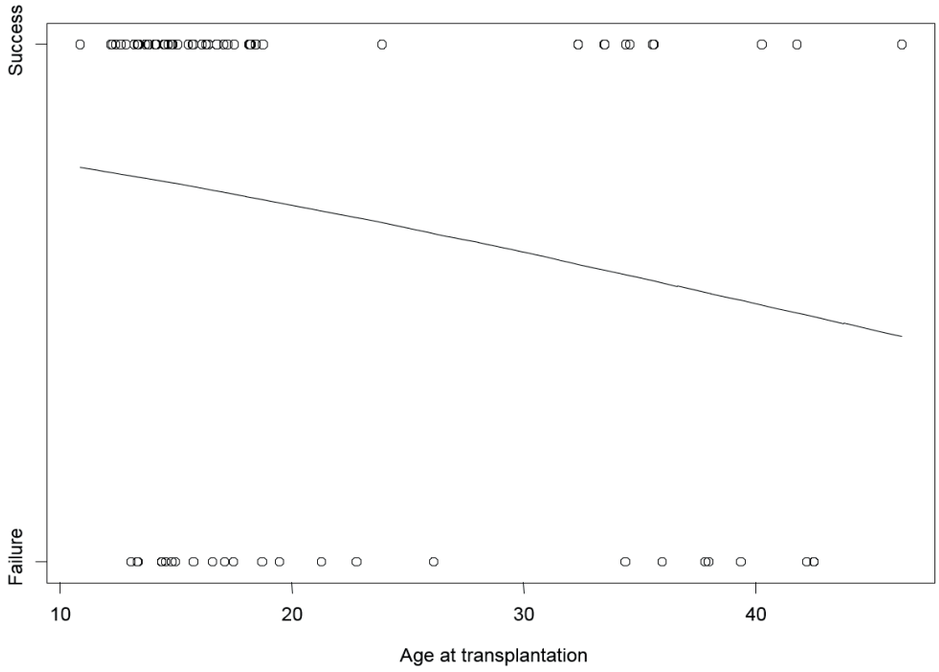

Figure 6. *Probability of success as a function of age at transplantation. The probability of success decreased when the age at time of transplantation increased (p=0.0966).*

Investigating baseline variables and their influence on final outcome showed a significant correlation between ankylosis of the impacted maxillary canine and failure ($p<0.005$). Survival analysis correlated with ankylosis as shown in Figure 7.

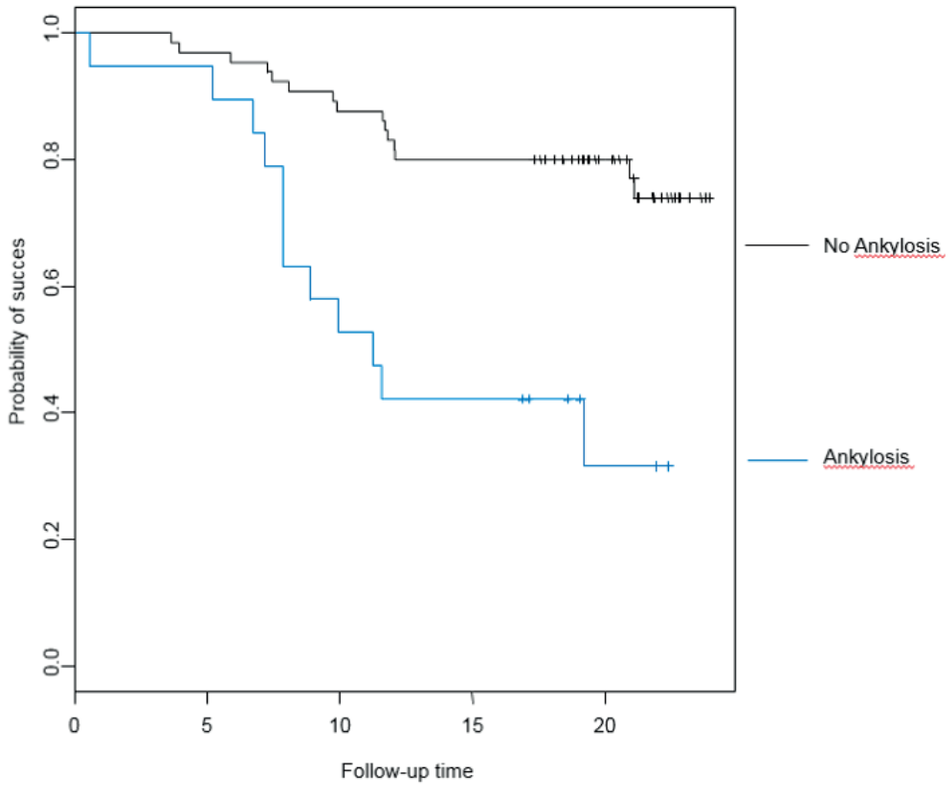

Figure 7. *Baseline ankylosis and survival. When preoperative investigations uncover ankylosis one should be aware of a higher possibility of failure. Twelve out of 19 ankylosed canines failed after transplantation.*

Furthermore, damage to the periodontal ligament during surgical removal of the impacted canine was significantly associated with a worse long-term outcome ($p<0.005$) (Figure 8).

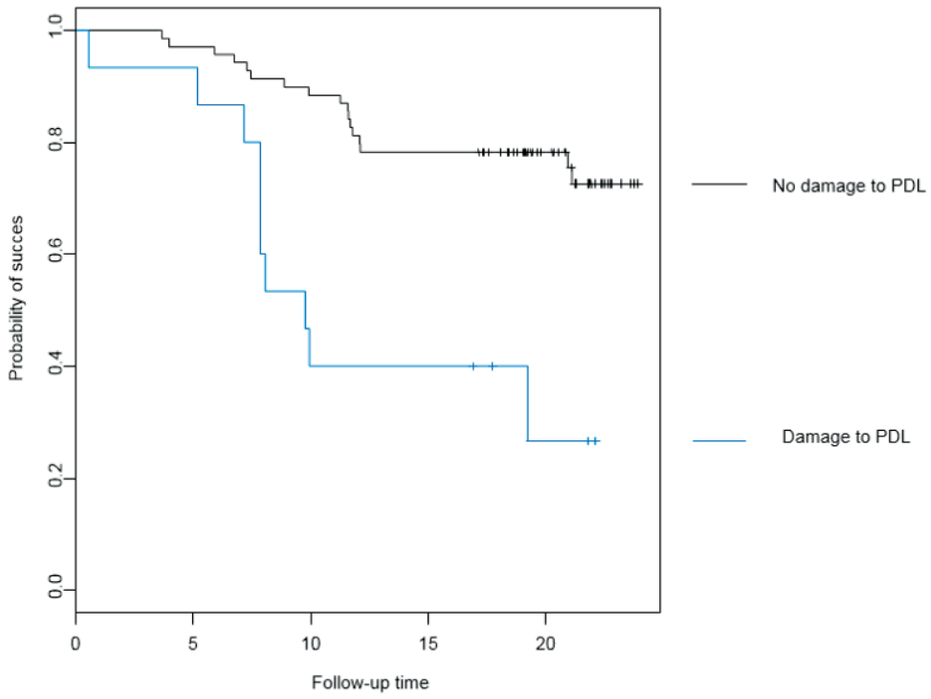

Figure 8. *Baseline damage of the PDL and survival.*

Success rate

The success rate was only calculated for the transplanted teeth that were evaluated on recall visits. In this study, 22 of the 27 surviving transplanted teeth on recall were evaluated as successful after clinical aesthetic and radiological evaluation.[11,12]

Patients were questioned using a VAS (Visual Analogue Scale) scoring system consisting of 7 questions:

- Q1: Judge retrospectively the overall treatment protocol regarding the inherent therapy and the length of treatment
- Q2: Does the treatment result fulfill the general expectations?
- Q3: Satisfaction with the treatment outcome from a general aesthetic point of view?
- Q4: Satisfaction with the treatment outcome from a general functional point of view?
- Q5: Satisfaction with the treatment outcome regarding color of the tooth?
- Q6: Satisfaction with the treatment outcome regarding morphology (length and width) of the tooth?
- Q7: Satisfaction with the treatment outcome regarding position of the tooth?

All patients reported high individual scores (average 8.6, range 6.7-9.6), demonstrating a high long-term patient satisfaction. Lower VAS scores were related to lower scores on the Maxillary Canine Aesthetic Index (MCAI).

Failed transplantations

Further questioning was possible with 18 out of 24 patients with a failed transplanted maxillary canine. Five patients currently have no replacement for the failed transplanted maxillary canine. Seven patients reported successful implant replacement while three patients had implant surgery planned. In three out of ten cases with (future) implant treatment, a bone augmentation procedure was necessary (Figure 9). Three patients needed replacement with a resin retained bridge.

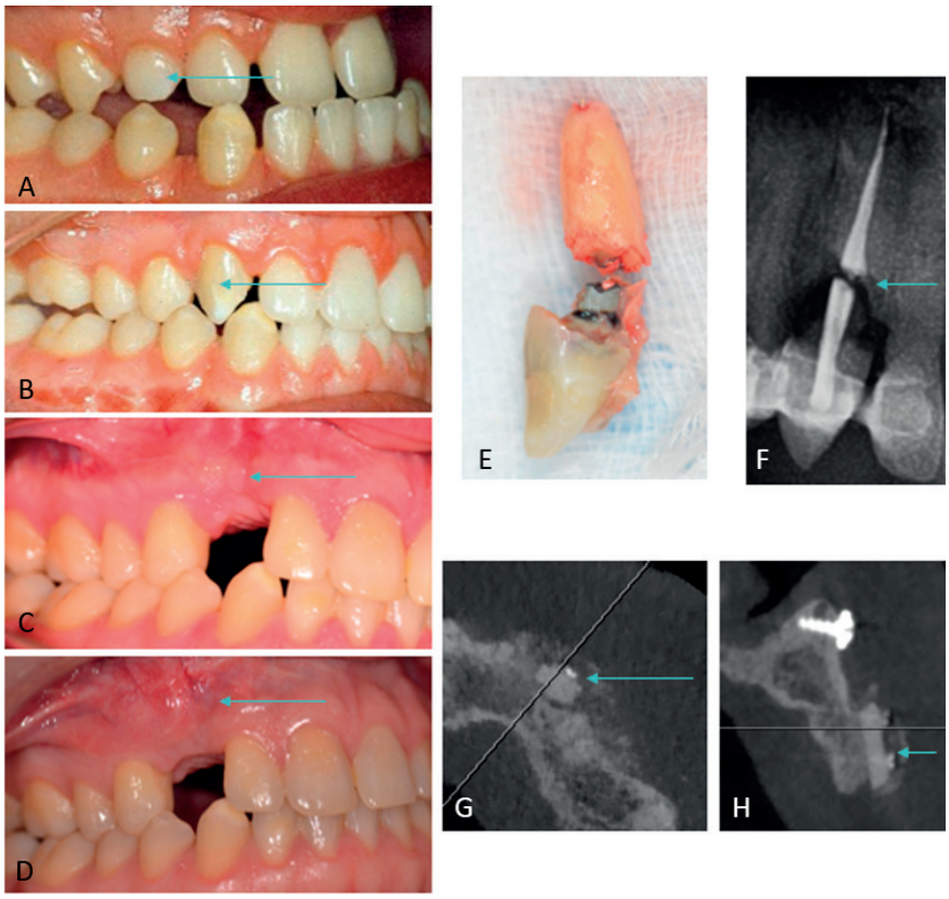

Figure 9. *Follow-up of a case with failure of the transplanted canine, 19 years after the initial procedure. A, Initial presentation of the patient with primary canine in situ (arrow). B, Clinical outcome 10 years after initial autotransplantation of the impacted right maxillary canine (arrow). C, Clinical image of the gingiva ten weeks after removal of the failed transplanted tooth with appearance of insufficient bone volume of the alveolar ridge (arrow). E-F, Clinical and radiographic images of the failed transplanted tooth with clear signs of resorption (arrow). D-G-H, Clinical and radiographic images after reconstruction of the alveolar ridge with a ramus bone graft and recovery of vestibular bone volume (arrow).*

DISCUSSION

The survival rate of transplanted maxillary canines in this study, with an average follow-up of 21 years, was 67.9%. The mean survival time was 15.8 years. A recent systematic review reported survival ranges to be 88.2% after 5 years or more.[8] However, none of the included studies had a follow-up longer than 15 years. A progressive loss of transplanted teeth is to be expected with increasing follow-up time since it has been proven that with increasing time after transplantation, significantly more root resorption can be expected.[10]

When comparing the outcome rate of this study with the literature, it is important to consider the difference in criteria for success, because there are no common success criteria. This study used established criteria for clinical assessment of transplanted teeth.[2,14,15]

Moreover, the transplanted canines were clinically and radiographically compared with the contralateral canine using previously developed indices. Subsequently, only transplanted canines with an excellent, good or acceptable final aesthetic result, no signs of infection or root resorption and sound periodontal tissues were classified as successful.

Significant parameters in determining outcome of autotransplantation were baseline ankylosis of the impacted canine and damage of the PDL during surgery as reported by the surgeon.

By questioning the patients with a failed autotransplanted maxillary canine, information was obtained of treatment possibilities after autotransplantation. In the current literature, there are no studies investigating the treatment possibilities after loss of autotransplanted maxillary canines. Thus, there is no knowledge of the real complexity of those treatments. In our study population, most patients with failures were enrolled in a non-complex follow-up treatment, such as implant surgery without bone grafting or prosthetic replacement. In almost a third of the cases with a dental implant, a separate bone augmentation procedure proved to be necessary (Figure 8).

In the present study, the authors did not consider transient root resorption, ankylosis or endodontic treatment to be a failure. This is because even in case of eventual loss of the tooth, autotransplanted teeth may have been retained for considerable lengths of time, providing an aesthetic and functional solution. However, poor aesthetic or radiological outcomes were considered to be a failure.[11,12]

Among the surviving teeth, the longest duration was 23.9 years and the shortest 0.5 years, with an average of 15.8 years. Tooth transplantation is not usually the first line of treatment for patients with impacted canines.[2] However, given a survival percentage of 67.9% after a mean follow-up period of 21 years, it should be considered an option in selected cases.

The use of autogenous transplantation as an alternative for both osseointegrated implants and Maryland bridges can be assessed by comparing success rates and survival times for each procedure. The benefits of

autotransplantation include the provision of a natural biological tooth and periodontal environment, ensuring maintenance of the normal exteroceptive function of the tooth to guarantee peripheral feedback and physiological function.[2] In addition, there is the potential to induce alveolar bone growth, proprioceptive function, a normal PDL, the potential to erupt with neighboring teeth during continued facial growth while maintaining a normal interdental papilla and allowing orthodontic movement.[2,16,17] Moreover, transplantation is possible during growth, in contrast to implant treatments. Viable transplanted teeth have the capacity to further erupt and do not require initial incorporation into the bone, when there is sufficient periosteum surrounding the tooth.

The present study demonstrated an outcome of 67.9%, 21 years after transplantation of impacted canines. Baseline ankylosis of the impacted maxillary canine and damage to the periodontal ligament during surgical removal were found to be important prognostic factors, emphasizing the importance of proper patient selection.

Autotransplantation of impacted maxillary canines may be indicated in selected circumstances; an acceptable long-term survival rate can be expected. Individual success is difficult to predict and patients must be informed of the potential for failure and associated risks before undergoing such a procedure.[2] If this is met, high patient satisfaction can be expected. If the transplanted tooth is lost, replacement can be achieved by means of a dental implant potentially and additionally requiring a bone augmentation procedure.

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CHAPTER 9

THIS CHAPTER IS BASED ON THE FOLLOWING MANUSCRIPT

Grisar K, Smeets M, Ezeldeen M, Shaheen E, De Kock L, Politis C, Jacobs R. Survival and success of autotransplanted impacted maxillary canines during short-term follow-up: A prospective case-control study. Orthod Craniofac Res. 2020 Aug 10. doi: 10.1111/ocr.12422. Epub ahead of print. PMID: 32777135.

SURVIVAL AND SUCCESS OF AUTOTRANSPLANTED IMPACTED MAXILLARY CANINES DURING SHORT-TERM FOLLOW-UP: A PROSPECTIVE CASE CONTROL STUDY

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ABSTRACT

OBJECTIVES: This prospective clinical trial aimed to examine the predictability of maxillary canine transplantation as compared to biological canine eruption. Additional objectives were to examine hard and soft tissue outcomes, including aesthetic outcome, compared to outcomes with the contralateral canines.

MATERIAL AND METHODS: The Maxillary Canine Aesthetic Index (MCAI) and the Autotransplanted Maxillary Canine Radiological Index (AMCRI) were scored for all upper canines. Successful transplantation was considered to be the absence of pathology during intermittent clinical and radiographic controls and a good-to-excellent outcome compared to the contralateral biological erupted canine, as defined by the MCAI and AMCRI.

RESULTS: The mean follow-up period was 28 months (±9; range 12–40 months). The overall survival rate was 100% and the success rate reached 68% one year postoperatively. Significant predictors of success were the extra-oral time during transplantation, amount of damage to the root surface, quality of surrounding tissues, and immediate postoperative oral hygiene.

CONCLUSION: Standardized measurements demonstrated clinically satisfactory outcomes with maxillary canine autotransplantation compared to outcomes of the contralateral canine during one to three years of follow-up. The potential predictors of success identified here should be confirmed with long-term follow-up studies.

INTRODUCTION

Surgical exposure and subsequent orthodontic realignment are largely considered to be the standard treatment strategy for an impacted maxillary canine. When this option fails or is considered too difficult or impossible because of a critical impaction or local pathology, treatment options include preservation of the deciduous canine or removal of the impacted canine and orthodontic closure of the gap. In addition, canine autotransplantation can be considered as an alternative to tooth removal.[1-4]

When a maxillary canine is autotransplanted, it is carefully removed from its impacted or ectopic site. A socket is then created, and the tooth is re-implanted into the correct position within the alveolus. Long-term studies have shown good overall success and survival rates.[1] Autogenous teeth can allow for the preservation of alveolar bone and attached gingiva. The cost is considered to be comparatively low, orthodontic movement is possible, and the procedure can be performed in patients who are still in the growth stage.[1]

A recent systematic review investigating autotransplantation of maxillary canines concluded that sufficiently well-designed studies on this topic are lacking. There was a striking absence of clearly reported diagnostic methods, pre-operative planning, and postoperative follow-up. Moreover, almost all studies were retrospective.[1] High-quality observational studies were recommended that focus on indications for autotransplantation of maxillary canines, predictors of outcome, clinical success parameters, surgical techniques, three-dimensional (3D) planning, aesthetic results, and patient satisfaction.

The present prospective split-mouth study was designed to address these gaps. Canine autotransplantation was performed using a standardized treatment protocol with pre-operative 3D planning, a strict surgical protocol, and postoperative follow-up with standardized indices, and outcomes were compared to the contralateral canines.[5,6]

MATERIAL AND METHODS

Study design

The outcome of autotransplantation of impacted maxillary canines was evaluated in comparison to outcomes of the contralateral canine, using standardized indices.5,6 The study design and clinical procedures were performed in accordance with the Declaration of Helsinki. All patients signed an informed consent form prior to commencing treatment, and the local ethical committee approved the study.

A protocol for tooth transplantation was designed to evaluate the data concerning patient information, treatment, and outcome without bias (Supplemental Figure 1). All patients who visited the clinic for tooth autotransplantation and agreed to participate in the study were registered in the study database, and the treatment protocol was explained at the first visit. The

present reporting considered the checklist items as proposed in the STROBE statement.[7]

Study population

The study population included 17 consecutively autotransplanted maxillary canines in 17 patients between August 2016 and January 2019. Patients were initially included in the study if they were candidates of any age for autotransplantation of a maxillary canine and had sufficient mesiodistal space. Patients were not included in the study if a bilateral autotransplantation procedure was needed. Bilateral procedures were excluded to avoid heterogeneity of data and to allow comparison with the contralateral canine using the standardized indices.[5,6] All patients were regularly followed up (Supplemental Figure 1).

In all cases, the choice of tooth autotransplantation was made based on a discussion between the surgeon and the orthodontist. This discussion included a Cone Beam Computed Tomography (CBCT) based analysis of the deciduous canine and canine position to assess the feasibility of the transplantation procedure versus other treatment options (e.g. preservation of the deciduous canine, extraction of the impacted canine with orthodontic space closure). All upper canines selected for tooth autotransplantation were assessed as having a critical impaction according to the classification described by Ericson and Kurol: a high alpha angle (>30°) with high sector, high vertical position, and/or root dilaceration (Supplemental Figure 2). In the presence of these characteristics, conventional treatment of these teeth could be considered to be quite challenging with a doubtful, if not impossible, prognosis.[8]

Pre-operative protocol and 3D planning

At the intake visit, an examination of general health and dental status was performed, with special attention given to underlying diseases (e.g. primary failure of eruption) that could be related to maxillary canine impaction. Patients were screened for previous surgical or orthodontic treatments. Then, clinical and radiographic examinations (orthopantomogram and 3D CBCT) were performed.[9] If the deciduous canine was present, the possibility of preserving it was assessed through evaluation of the crown, root, and supporting alveolar bone. Special attention was given to the apical root morphology of the impacted maxillary canines to predict the difficulty of careful removal. The stage of root development for all included teeth was evaluated according to the Moorrees scale.[10] Angulation, mesiodistal position, and vertical position were checked according to the Ericson and Kurol classification.[8] A Digora phosphor plate system (Soredex, Tuusala, Finland) was used for intraoral radiography with a Heliodontent Plus intraoral x-ray tube at 70 kV, 7 mA, and 0.06 s (Sirona, Bensheim, Germany). Panoramic images were acquired with a VistaPano (Dürr Dental AG, Bietigheim-Bissingen, Germany) panoramic radiography device, operating at 70 kV and 8–12 mA, with an exposure time of 13.5 s. CBCT imaging

was performed using the Newtom VGI Evo (QR Verona, Verona, Italy) at 95 kV with a voxel size of 0.2 mm (field of view 75 × 100 mm), allowing for patient-specific low-dose imaging via tube current modulation.

This low-dose CBCT scan was followed by donor tooth segmentation and digital 3D model creation of the donor tooth and recipient site (Figure 1). A virtual autotransplantation procedure was then performed to determine the surgical feasibility (enough vertical and mesiodistal space) and the best positioning and orientation for the donor tooth (Figure 1).[11,12] The method for CBCT-guided surgical planning and tooth replica fabrication has been previously validated and described in detail.[11,12]

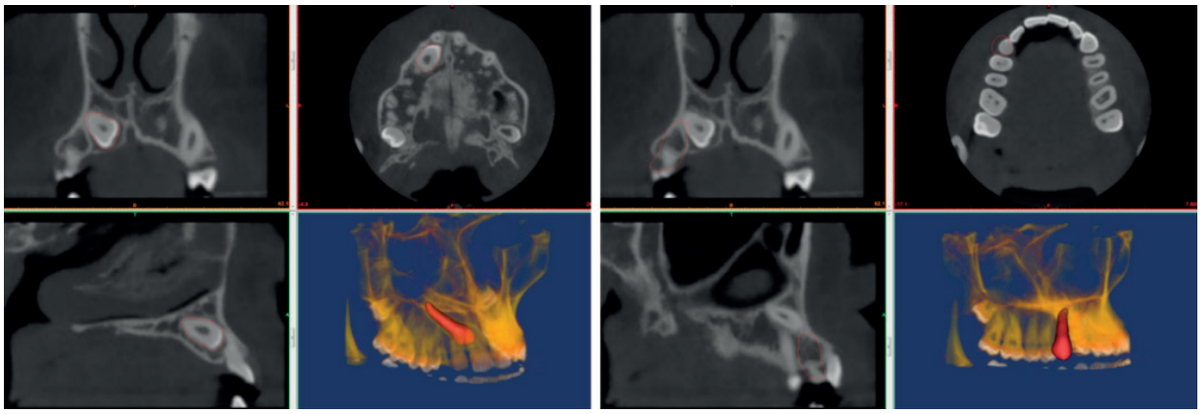

Figure 1. *CBCT-based 3D planning of canine transplantation.*

Surgical procedure

The surgeons performing the procedure were instructed to follow a standardized surgical technique. The surgical team included a senior surgeon who was familiar with the autotransplantation procedure, and a trainee. All surgeries were performed with the patient under general anesthesia supplemented with local anesthesia (2% lidocaine with 1:80,000 epinephrine). All patients received prophylactic antibiotic coverage (cefazolin 2 g intravenously or 50 mg/kg according to standard surgical prophylaxis guidelines) at the start of the operation. If a deciduous canine was present, it was extracted at the beginning of the surgery.

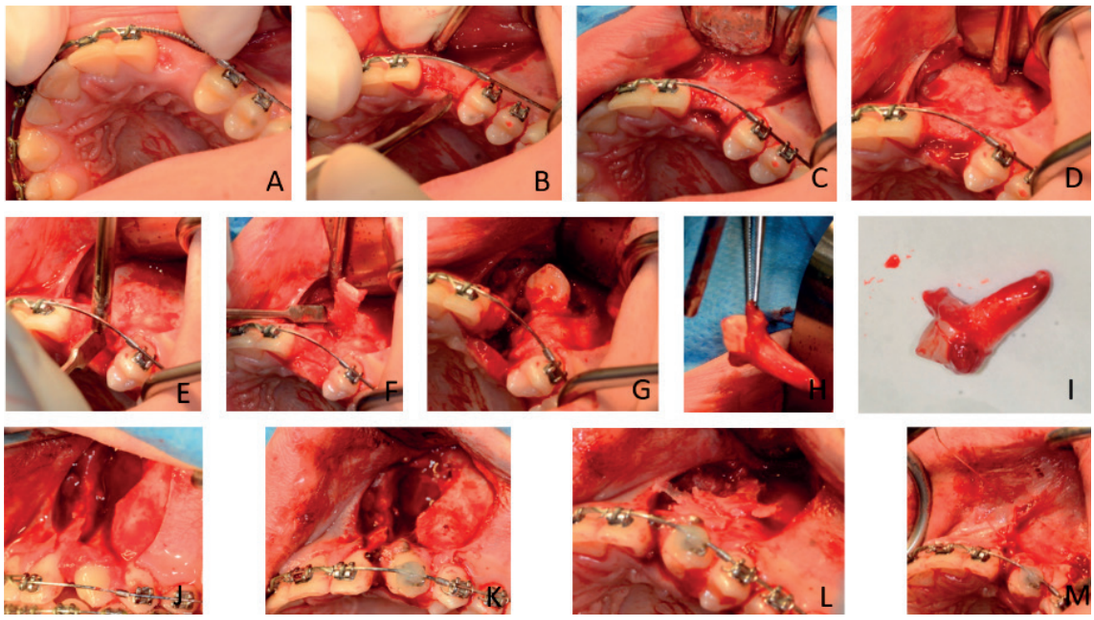

Figure 2. *Transplantation of a maxillary canine. A–C, Vestibular location and trapezoidal incision. D–G, Osteotomy and preparation of the recipient socket with chisels. H-I, Removal of the graft with careful handling of the transplant. J, Positioning of the donor tooth into the recipient socket. K-L, Fixation in the orthodontic arch with a bracket and orthodontic wire in the infra-occlusive position and covering with harvested bone chips. M, Suturing of the trapezoidal flap.*

The surgical procedure varied by the site of impaction, but the general approach is described in Figure 2. In case of vestibular or mid-crestal impaction, surgical access was achieved from the buccal region. A mid-crestal incision was made and extended over the sulcus of the first premolar and lateral incisor. The flap was raised carefully, preferably with a chisel rather than a bur, and the cortical bone was removed to expose the crown of the impacted canine. The procedure was performed carefully to avoid damage to the periodontal ligament (PDL) and root cementum, while preserving the dental follicle. While the donor tooth was stored intra-orally or briefly extra-orally in sterile saline at room temperature, the recipient socket was prepared and checked with the help of a 3D-printed dummy according to the protocol described by Ezeldeen et al and Shahbazian et al[11,12] (Figure 3). The donor tooth was then placed in an infra-occlusal position and bonded with orthodontic wire.

In case of a palatal location, surgical access was achieved with a palatal intrasulcular incision adjacent to the second premolar and central incisor. During the surgical procedure, the donor tooth was checked for damage to the root surface after removal. Surrounding soft and hard tissues were also evaluated for potential issues, such as buccal bone defects or insufficient keratinized mucosa to achieve complete wound closure around the donor tooth. The total extra-oral time of the transplant was also recorded.

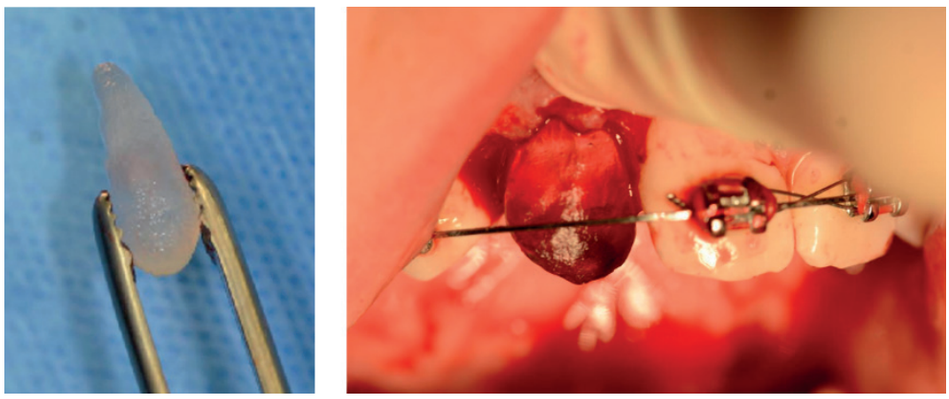

Figure 3. *3D-printed dummy of a maxillary canine.*

Postoperative protocol

All patients received a mouth rinse (chlorhexidine gluconate 0.12%, 7 days), and good oral hygiene was encouraged. The splint (orthodontic wire and resin) was removed two to four weeks postoperatively. The following clinical measurements were recorded at every follow-up consultation: oral hygiene, occlusal tooth contacts, bleeding on probing, and gingival inflammation. Pocket depth (PD), tooth mobility, and percussion were scored only at the three-month visit. To measure PD, a calibrated periodontal probe (Hu-Friedy, Leimen, Germany) was inserted with light pressure into the gingival pocket. A PD ≥3 mm was rated as pathological. The mobility of the transplanted tooth was tested using the Periotest (Medizintechnik Gulden, Modautal, Germany). Periotest measurements were taken and interpreted according to the manufacturer's instructions. Negative Periotest values indicate lower mobility, suggesting ankylosis. Gingival inflammation was scored according to the gingival index of Löe.[13]

Intra-oral radiographs were taken of all transplanted teeth following a strict paralleling technique during follow-up at one week, six weeks, and twelve months. Panoramic radiographs were also taken at the one-week visit. In addition, CBCT images were collected for all patients during a recall visit at twelve months postoperatively. Radiological examination contributed to the evaluation of the PDL and postoperative bone healing and to exclude apical infection and inflammatory or internal root resorption (Supplemental Figure 1).

ENDODONTIC AND ORTHODONTIC TREATMENT

One-stage endodontic treatment was performed in all transplanted canines with a closed apex, just before removal of the fixation wire, at two to four weeks postoperatively and always by the same operator.[14] The timing of these procedures is crucial because early endodontic treatment could damage the PDL and late endodontic treatment could provoke inflammatory resorption.[15]

If necessary, a restart of the orthodontic treatment was scheduled from four weeks postoperatively onwards, after removal of the splint. In our treatment protocol, the orthodontic treatment was resumed after removal of the splint and execution of the endodontic treatment. This practice is in line with the findings and recommendations of Jang et al, who showed that early application of orthodontic force could increase the survival rate of autotransplanted teeth without ankylosis.[16]

Outcomes

The primary outcomes were tooth survival and success of the autotransplanted canine. Tooth survival was defined as the presence of the transplanted tooth during the evaluation. Treatment success was assessed using intermittent clinical and radiographic controls to rule out the presence of any pathology (e.g. periapical pathology, periodontitis, inflammatory root resorption, or ankylosis) and using an assessment based on two validated indices: the Maxillary Canine Aesthetic Index (MCAI) and the Autotransplanted Maxillary Canine Radiological Index (AMCRI).[5,6] These standardized indices compare the aesthetic appearance and the soft and hard tissue health of the transplanted canine with those of the contralateral biologically erupted canine.[5,6] All observations and scorings were performed by three observers independently (KG, MS and LDK), trained and calibrated to use the MCAI and AMCRI systems using a reference training data set. Disagreements were resolved through discussion. Further information on these indices is presented in Supplemental Tables 1 and 2.

Because of the root development stage of the impacted canines at baseline, endodontic treatment was not considered as indicative of unsuccessful treatment.

Statistical analysis

Sample size planning was performed for a non-inferiority test. Limits considered were the worst side of the confidence interval (CI) identified in a meta-analysis by Grisar et al.[1] This value was used to test if the current intervention was not worse than conventional treatment strategies, as reported in that meta-analysis.[1] Cut-off values were set as follows: inflammatory root resorption <39%, ankylosis <66%, and survival 100% after twelve months.[1] With an expected survival percentage of 99%, resorption percentage of 10%, and ankylosis percentage of 20%, a power analysis based on the binomial test indicated that for a study power of 80%, a minimum of twelve canines needed to be included for the

survival analysis, eleven canines for the resorption analysis, and seven canines for analysis of ankylosis.

For patient characteristics and analysis at distinct points in time, the relation with success was modeled using a generalized linear model for binary data with a logit link for continuous predictor variables and Fisher's exact test for categorical predictor variables. The relation between success and specific variables measured at distinct time points was also assessed by a generalized linear model for binary outcomes using a logit link and the variable under consideration and time as crossed factors. P-values were calculated for contrasts that compared the levels of the variable under consideration per time point and changes between time points for the different levels of the variable under consideration. P-values were corrected for simultaneous hypothesis testing according to Sidak.[17]

RESULTS

Study population

The study population included 17 consecutively autotransplanted maxillary canines in 17 patients (10 females, 7 males). The mean age at the time of surgery was 18 years and one month (SD±6; range 11–29 years). At the time of intake, all but one of the patients were undergoing active orthodontic treatment with orthodontic appliances bonded on all teeth except the impacted canine. Six deciduous canines had been removed as an earlier treatment, and eleven deciduous canines were still in place. An Ericson and Kurol evaluation of the angulation demonstrated that all alpha angles exceeded 30°, with an average angulation of 56°.[8] More than half of the canines were situated in sectors 4 and 5, and more than half had a high vertical position (3 and 4).[8] All canines but one (Moorrees stage 4) had fully developed roots at the initial presentation. No significant relations between baseline characteristics and outcome were found (Table 1).

Table 1. *Demographic and donor tooth characteristics.*

		Canines, n	Success, n (%)	*P*
Patient age	≤18 y	12	9 (75)	1
	>18 y	5	4 (80)	
Patient sex	M	7	6 (86)	1
	F	10	9 (90)	
Active orthodontic treatment	Yes	16	13 (81)	1
	No	1	0	
Primary canine	Yes	11	8 (73)	1
	No	6	5 (83)	
Buccopalatal position	Vestibular	8	6 (75)	1
	Mid-crestal	0	0	
	Palatal	9	7 (78)	
Angulation	0–15	0	0	1
	15–30	0	0	
	>30	17	13 (77)	
Sector	1	4	3 (75)	1
	2	1	1 (100)	
	3	3	2 (67)	
	4	4	3 (75)	
	5	5	4 (80)	
Vertical position	1	0	0	0.07
	2	6	5 (83)	
	3	9	8 (89)	
	4	2	0	
Root dilaceration	Yes	8	5 (63)	1
	No	9	8 (89)	
Root resorption of neighboring teeth	Yes	1	1 (100)	1
	No	16	12 (75)	
Ankylosis	Yes	3	1 (33)	0.12
	No	14	12 (86)	

Assessment during surgery

Three teeth showed damage to the root surface after surgical removal. The average extra-oral time was 5.5 minutes (±6.8; range 1–30). Four canines had an extra-oral time of more than five minutes, with a maximum time as high as 30 minutes. Three canines were found to have defects of the surrounding soft tissues, making it more difficult to properly seal the gingival tissue around the transplanted tooth. All transplanted teeth were positioned in an infra-occlusive position (Table 2).

Table 2. *Clinical and radiographic parameters.*

		Canines, n	Success, n (%)	*P*
During surgery				
Root surface	Intact	14	13 (93)	0.01*
	Damaged	3	0	
Extra-oral time of transplanted tooth	≤5 minutes	13	12 (92)	0.02*
	>5 minutes	4	1 (25)	
Primary stability	Yes	13	11 (85)	0.20
	No	4	2 (50)	
Soft tissue quality	Normal	14	13 (93)	0.01*
	Defects	3	0	
Bone quality	Normal	12	11 (92)	0.05*
	Defects	5	2 (40)	
1 Week				
Oral hygiene	Good	12	11 (91.7)	0.05*
	Average	5	2 (40)	
	Poor	0	0	
Palpation	Not painful	15	12 (80)	0.4
	Painful	2	1 (50)	
2 Weeks				
Oral hygiene	Good	15	12 (80)	0.4
	Average	2	1 (50)	
	Poor	0	0	
Palpation	Not painful	16	13 (81.3)	0.2
	Painful	1	0	
6 Weeks				
Oral hygiene	Good	14	10 (71.4)	0.50
	Average	1	0	
	Poor	0	0	
Palpation	Not painful	17	13 (76.5)	/
	Painful	0	0	
12 months				
Oral hygiene	Good	16	12 (75)	1
	Average	1	1 (100)	
	Poor	0	0	
Palpation	Not painful	17	13 (76.5)	/
	Painful	0	0	
Color	Normal	14	12 (85.7)	0.12
	Discoloration	3	1 (33.3)	
Gingival inflammation (Loë Index)	Yes**	15	13 (86.7)	0.04*
	No	2	0	

Pathological pockets (≥3 mm)	Yes	1	0	0.24
	No	16	13 (81.3)	
Mobility	Yes	2	0	0.04*
	No	15	13 (86.7)	
Peri-apical radiolucency	Yes	1	0	0.24
	No	16	13 (81.3)	
Inflammatory root resorption	Yes	2	0	0.04*
	No	15	13 (86.7)	
Periodontal ligament	Yes	13	11 (84.6)	0.22
	No	4	2 (50)	

* P value is significant for $\alpha \leq 0.05$.
** All canines with gingival inflammation were scored as Löe Index 1 (mild inflammation, no bleeding)

Postoperative examination

At the one-week visit, twelve canines demonstrated good oral hygiene, whereas five had average oral hygiene. Clinical investigation and palpation of the surgical site were painful in two cases one week postoperatively but became painless at two weeks postoperatively. There were no early signs of local bone destruction, and inflammatory root resorption was absent in all cases at one and two weeks postoperatively. However, at six weeks postoperatively, signs of inflammatory root resorption were found in one case (Table 2). On CBCT images, three canines showed no sign of a PDL and lamina dura at twelve months postoperatively (Table 2). These three canines had already presented radiographic signs of ankylosis at the intake investigations. Fifteen canines were found to have gingival inflammation at twelve months (all with Löe score 1) (Table 2).

MCAI and AMCRI

The aesthetic outcome of the transplanted canine was assessed with the MCAI at twelve months after the operation. Regarding the aesthetic outcome, four of the transplanted maxillary canines were scored as excellent, nine as good, and four as acceptable (average score 6; range 2–12). Absence of the mesial papilla, recession, buccolingual angulation, and final vertical position was the most commonly encountered aesthetic problems (Figure 4).

The radiological outcome of the transplanted canines was assessed with the AMCRI at twelve months following the procedure. Five of the transplanted maxillary canines were scored as excellent, nine as good, two as acceptable, and one as poor (average score 9; range 1–37). Lack of vestibular bone height and thickness, disappearance of the lamina dura and PDL, and ankylosis were the most commonly encountered abnormalities.

Figure *4. Clinical examples of transplanted canines. A, Gingival recession. B, Hypoplastic mesial papilla. C, Hypoplastic mesial papilla and mesial angulation of the canine crowns. D, Infra-occlusive vertical position due to ankylosis. E, Transplanted canine with an excellent MCAI score.*

Success and survival

The average follow-up period was 28 months (±9; range 11–40), with a survival rate of 100%. Of the 17 transplanted teeth, 13 were evaluated as successful after clinical aesthetic and radiological evaluation and comparison with the contralateral biologically erupted canine (MCAI; AMCRI) twelve months postoperatively, resulting in a success percentage of 67.5%.

A significant relation was found between several perioperative and postoperative clinical parameters and outcome. Damage to the root surface, prolonged extra-oral time of the transplant (>5 minutes), defects in the surrounding soft tissues and bone, average oral hygiene one week postoperatively, and elevated tooth mobility and gingival inflammation twelve months postoperatively were associated with suboptimal clinical and radiographic results and thus an unsuccessful outcome (Tables 2 and 3).

Table 3. *MCAI and MCRI scores.*

	Patient																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
MCAI																	
Mesial papilla	1	0	0	0	1	0	1	5	1	1	5	0	0	0	1	0	0
Distal papilla	0	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0
Marginal gingiva	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0
Recession	0	1	0	1	0	1	1	1	0	0	0	0	1	1	0	0	1
Marginal gingival thickness	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0
Mesio-distal crown angulation	1	0	0	0	0	1	1	0	0	1	2	1	1	1	0	1	1
Curvature of marginal gingiva	0	0	2	0	0	2	0	0	0	1	0	1	1	1	0	0	1
Soft tissue color and texture	1	1	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1
Root convexity	0	0	0	0	1	0	2	1	0	0	1	0	0	0	1	0	0
Tooth morphology	0	0	0	0	0	2	2	1	0	2	0	1	1	1	0	1	1
Vertical tooth position	0	2	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0
Buccolingual angulation crown acc. neighboring teeth	1	0	0	0	1	1	2	1	1	0	1	0	1	0	0	1	1
Final score	4	5	2	5	6	11	10	12	3	5	10	4	6	4	3	3	6
MCRI																	
MCRI 2D																	
Periodontal ligament	0	1	0	0	0	2	2	1	0	0	1	1	0	0	0	2	1
Lamina dura	2	2	0	1	1	1	2	1	1	1	1	1	0	0	0	1	1
Apical root closure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apical radiolucency	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Ankylosis	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inflammatory root resorption	0	0	0	0	0	5	0	0	0	0	5	0	0	0	0	0	0
MCRI 3D																	
Periodontal ligament	1	1	0	1	0	2	2	1	0	0	1	1	0	0	0	2	1
Lamina dura	1	2	0	1	0	1	2	1	0	1	1	1	0	0	0	2	1
Apical root closure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peritransplant bone volume	1	0	0	0	1	1	0	0	2	1	0	0	2	0	0	0	0
Apical radiolucency	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Ankylosis	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	2	1
Inflammatory root resorption	0	0	0	0	0	5	0	0	0	0	5	0	0	0	0	0	0
Internal root resorption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vestibular bone height	0	1	0	1	1	1	0	1	1	1	1	0	1	1	0	2	1
Vestibular bone thickness	0	0	1	1	1	2	0	1	1	1	1	1	1	1	0	2	0
Vestibular prominence canine	1	1	0	1	1	1	0	0	1	1	1	1	1	1	1	2	0
Final score	6	12	1	6	5	21	10	6	6	6	37	6	5	3	1	15	6

DISCUSSION

Autotransplantation of maxillary canines, with open and closed apices, can be a treatment option in selected cases. As noted, a recent systematic review concluded that the clinical evidence supports this statement but that good-quality clinical studies are lacking, and the authors recommended observational studies.[1] The purpose of the current study was to investigate the short-term outcome of autotransplanted maxillary canines using a strict pre-, peri-, and postoperative protocol to evaluate the reliability of the autotransplantation procedure. Our study population included 17 patients with unilateral maxillary canine impaction. The baseline characteristics of this population led us to conclude that the initial position of the impacted teeth was highly complex (Table 1) and that conventional treatment of these teeth would be challenging, with a doubtful prognosis.

In our study, the survival rate was described as the percentage of the transplanted teeth present at the last follow-up. We found a short-term (28 months; SD ±9; range 11–40) survival rate of 100%. In a recent systematic review and meta-analysis, a survival rate of 87.5% (95% CI 77.2–93.6) was found in the two to five-year follow-up group. In the same meta-analysis, this group was found to have root resorption in 18.5% (95% CI 7.4–39) of cases and ankylosis in 23.8% (CI 4.8–65.7) of cases. In our study population of 17 canines, two had signs of root resorption, and four had signs of ankylosis after a follow-up period of twelve months.[1] Three of the ankylosed transplants had previously been diagnosed with signs of ankylosis when still impacted, so that the surgical removal of these teeth was also more difficult, with prolonged extra-oral time and damage to the root surface.

All included autotransplanted maxillary canines were evaluated at twelve months postoperatively using standardized indices for aesthetic and radiographic evaluation and comparison with the contralateral biologically erupted canine. The success rate was found to be 67.5%. The most common aesthetic problems were absence of the mesial papilla, recession, buccolingual angulation, and final vertical position.

Overall, the study did not reveal significant pretreatment predictors of treatment success (Table 1). In the literature, increasing age and complete root formation are associated with a higher prevalence of inflammatory root resorption and ankylosis and thus worse outcome, yet the current results did not confirm this association (Table 1).[16,18-21] However, the mean age of our study population at the time of the autotransplantation procedure was 18 years, and this relatively older age would likely lower the success rate compared to procedures carried out in patients at younger ages and with partial root development (ideally half to three-quarters complete).[22] Because our entire study population had complete root formation, this variable could not be considered as a pretreatment risk predictor.

Considering the initial position of the impacted maxillary canine, a more severe impaction could be expected to predict a more challenging surgical procedure, with an increased risk of damage to the PDL and cementum. This situation might lead to ankylosis of the donor tooth. We found a nonsignificant ($P = 0.07$) relation between a high initial vertical position and unsuccessful treatment outcome. However, we can assume that the findings of our study were influenced by the baseline characteristics of the study population, i.e. high angulation (>30°; average 56°), complete root formation, high vertical position and mesial sector (Table 1).

During the surgical procedure, several parameters were checked. An intact PDL was a significant predictor ($P < 0.05$) of further treatment success, emphasizing the importance of careful removal of the donor tooth and careful preparation of the recipient socket.[11,23] We found a significant relationship between the extra-oral time of the transplanted tooth and treatment success ($P < 0.05$). Andreasen et al reported that normal periodontal healing would proceed if the extra-oral time of the donor tooth was <18 minutes.[24] This conclusion is consistent with the results of previous studies on intentional replantation.[25] In most guidelines for autotransplantation, however, the tendency is to avoid an extra-oral time exceeding 5 minutes.[23,24]

Both findings draw attention to the importance of careful 3D planning and the usefulness of a slightly oversized 3D dummy. These tools can allow for preparation of the recipient site beforehand with minimal extra-alveolar time. Also, the use of a tooth replica may reduce the number of positioning trials in the recipient socket, thus preserving the viability of the PDL stem cells.[11,23]

Together with PDL and extra-oral time of the transplant, we also found that the quality of the surrounding soft tissue and bone were significant predictors of treatment success. In the experience of the authors, insufficient bone and/or soft tissue volume will complicate the procedure, and the risk of damaging the donor tooth thus increases. Defects in surrounding bone have been described as being associated with failure in autotransplantation procedures.[16,26] The presence of gum recession and defects of the mesial and/or distal papilla are considered to negatively influence the final aesthetic outcome.[6,16]

Wound healing monitoring is an important concern in all surgical procedures because it allows for identification of signs and/or symptoms possibly related to surgical complications. In the case of disrupted or delayed periodontal healing, a deep pocket will form, and plaque accumulation and periodontal inflammation then may ultimately lead to treatment failure.[15,16,27] Jang et al demonstrated that periodontal healing and management to prevent postoperative marginal bone loss are as important as PDL healing for successful autotransplantation.[16] In line with these results, we found that initial oral hygiene and gingival inflammation were significant clinical factors in treatment success.

In light of these findings, autotransplantation of maxillary canines can be considered a reliable treatment option when traditional approaches are not possible. All treatment options for impacted canines should be considered.

Ericson and Kurol described the dubious prognosis of orthodontic traction when the canine is angulated more than 45 degrees, but those findings are relative to the position of the neighboring elements and the morphology of the alveolar process.[8] Aside from autotransplantation, another option is preserving the deciduous canine in complex cases of maxillary canine impaction. The post-treatment stability of a preserved deciduous canine without root resorption has a good prognosis, and other extensive treatment modalities (e.g. autotransplantation) could be avoided. However, this solution is possible only when the crown, root, and supporting alveolar bone are of sufficient quality.[29] Another treatment option might be to extract the canine and achieve orthodontic closure of the gap, along with conversion of the premolar to a canine and a consequent impact on tooth size discrepancy. The variety of potential treatment plan options emphasizes the importance of a multidisciplinary approach that involves orthodontists and surgeons and is based on complete radiological and clinical data.

The short-term success of treatment in this study was significantly associated with extra-oral time during transplantation, damage to the root surface, the quality of surrounding soft and hard tissues, and immediate postoperative oral hygiene. An understanding of these prognostic factors may guide clinicians toward achieving predictable and successful outcomes after tooth transplantation.

The main limitations of this study are the non-randomized design and short follow-up period. The sample size is small but illustrates the difficulties involved in collecting large samples of impacted autotransplanted canines.

The strength of the split-mouth design of this study is its efficiency in terms of sample size because the patients acted as their own controls. Critically impacted maxillary canines are a rare anomaly and different features, such as the position of the impacted canine, patient age, and patient needs and expectations must be considered. It is practically impossible to randomize treatment, and high-quality observational studies therefore are recommended.

CONCLUSIONS

Autotransplantation of critically impacted maxillary canines is a potential treatment option when standard treatment is considered unlikely to be successful. A short-term survival rate of 100% was found, with more than two-thirds being successful. The extra-oral time during transplantation, damage to the root surface, quality of surrounding soft and hard tissues, and immediate postoperative oral hygiene were identified as potential predictors of treatment success. Future studies should focus on long-term follow-up.

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SUPPLEMENTAL MATERIAL

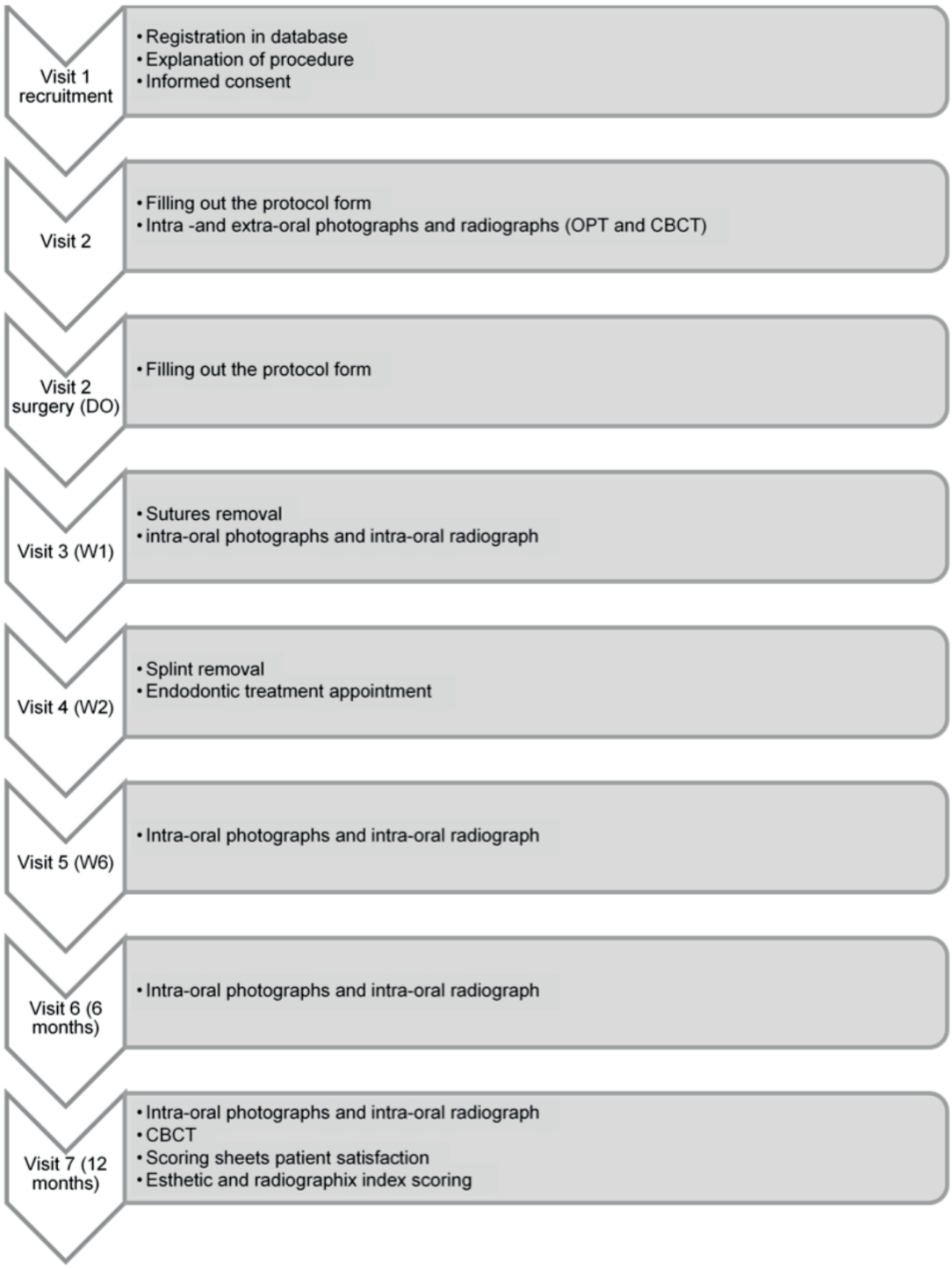
Supplemental Table 1. *The MCAI and parameters.*

Parameters investigating the previously impacted canine			
	Absent	Incomplete	Complete
Mesial papilla	5	1	0
Distal papilla	5	1	0
Marginal gingiva	5	1 (<3mm)	0(>3mm)
Gingival recession	(Apical to MGJ)	(Coronal to MGJ)	(No recession)
	5	1	0
Marginal gingival thickness	Thin	___	Thick
	1	_____	0
Mesio-distal crown angulation	Distal	Straight	Mesial
	2	1	0
Parameters investigating comparison between both canines			
	Major discrepancy	Minor discrepancy	No discrepancy
Curvature of marginal gingiva	2	1	0
Soft tissue color and texture	2	1	0
Root convexity	2	1	0
Tooth morphology	2	1	0
Vertical tooth position	2	1	0
Parameters investigating relation previously impacted canine and neighboring teeth			
Buccolingual angulation crown acc. neighboring teeth	2	1	0
Total score	0–3 points = excellent 4-8 points = good 9-13 points = moderate 14 or more points = poor aesthetics from Grisar et al (2018)		

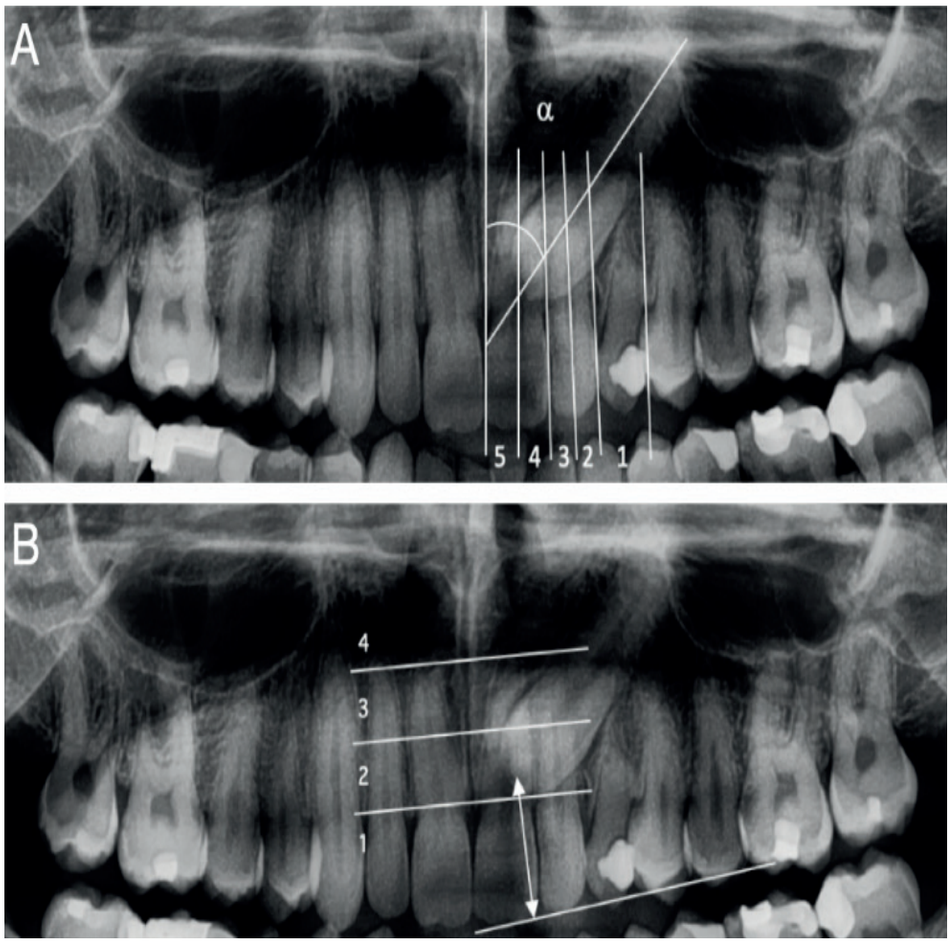
Supplemental Table 2. *The AMCRI and parameters.*

2D radiographic scoring			
Parameter	Absent	Present but incomplete	Present
Periodontal ligament	2	1	0
Lamina dura	2	1	0
Apical root closure	2	1	0
	Present		Absent
Apical radiolucency	10		0
Ankylosis	2		0
Inflammatory root resorption	5		0

3D radiographic scoring			
Parameter	Absent	Present but incomplete	Present
Periodontal ligament	2	1	0
Lamina dura	2	1	0
Apical root closure	2	1	0
Peritransplant bone volume	2	1	0
	Present		Absent
Apical radiolucency	10		0
Ankylosis	2		0
Inflammatory root resorption	5		0
Internal root resorption	5		0
	Major discrepancy	Minor discrepancy	No discrepancy
Vestibular bone height	2	1	0
Vestibular bone thickness	2	1	0
Vestibular prominence canine	2	1	0
Total score	0-5 points = excellent 6-13 points = good 14-20 points = moderate 21 or more points = poor outcome from Grisar et al (2018)		



Supplemental Figure 1. *Study design and follow-up visits. (D = day; W = week)*



Supplemental Figure 2. *Radiographic measurements of initial canine position.*
A, Panoramic radiograph illustrating the antero-posterior sector of the canine, according to Ericson and Kurol's method, and the angular measurement of the canine position in degrees, with an α-angle of maxillary canine to midline.[8]
B, Panoramic radiograph illustrating the vertical position of the canine, according to the method described by Stivaros.[28]

DISCUSSION

This thesis aimed to compose recommendations that will help to identify critically impacted maxillary canines and at the same time support the decision-making process for further treatment options. This should help clinicians to avoid failure with the technique of surgical exposure and orthodontic alignment, while also help to prevent unnecessary maxillary canine transplantations, contributing to a patient-specific treatment.

In research regarding impacted maxillary canines, we see that the authors rarely include standardized assessment of treatment outcome, and when they do, the heterogeneity in outcome variables makes comparisons among studies impossible.

New approaches, that are based upon standardized indices for aesthetic and radiographic variables, are required for objective evaluation. Chapters 1 and 2 propose two novel indices (AMCRI and MCAI) to evaluate the outcome after treatment of maxillary canine impaction. Validation of these indices illustrates a good inter- and intraobserver agreement, confirming measurement reproducibility.

The MCAI is an index that was developed for evaluating maxillary canine aesthetics. Twelve different soft tissue and tooth characteristics are included in the overall aesthetic evaluation of the canine. The main advantage of the MCAI is not only that future results can be compared, but that the system combines visible soft tissue (gingival) and hard tissue (tooth) parameters into one comprehensive scoring system. One of the main strengths of the MCAI, the comparison with the contralateral canine, is also an important disadvantage with bilateral cases. In these cases, both teeth should be evaluated and compared with the contralateral canine if possible. When the contralateral tooth is absent or in the event of severe aesthetic failure, a hypothetical ideal canine can be used as a reference. And while currently the MCAI only includes an evaluation of the tooth morphology, it should in the future also include an assessment of the tooth color. The MCAI does not assess the condition or presence of the neighboring lateral incisor, although this is also essential for the final aesthetic outcome and related to the treatment of maxillary canine impaction.

The AMCRI was developed in response to the lack of a standardized method for evaluating and measuring radiographic outcomes after autotransplantation of impacted maxillary canines. The goal was to develop an index that could be used in both research and clinical settings, allowing standardized reporting for diagnosis and outcome. However, one must be aware that this index only judges the radiographic and not the functional outcome of the canine. A poor radiographic result does not imply malfunction. Results of the AMCRI may

suggest a potential correlation to the final outcome. The AMCRI is based upon 2D and 3D imaging, which could pose a problem in practices where they do not have a CBCT scan. However, it is the author's opinion that 3D imaging is essential for proper evaluation of these canines. When there is access to a CBCT scan, one could even consider 2D imaging to be unneccesary for radiographic evaluation.

Although the initial results with both indices are very promising, we must remain aware that these initial validation studies contained rather small patient populations. Their practical use as a standard procedure should be confirmed in a large-scale clinical study and with an increased umber of observers. This should increase the inter- and intraobserver agreement.

In Chapter 3 we described the different variables that contribute to the notion of critical impaction of maxillary canines. The tendency for impacted upper canines to fail to respond to conventional orthodontic and/or surgical treatment options, is what describes a critical maxillary canine impaction. There are five categories of variables that determine the probability of critical impaction of the maxillary canine:

- The impacted canine position
- Associated pathology
- Root resorption of the neighboring teeth
- Relationship with neighboring anatomic structures
- Age

When assessing a patient with maxillary canine impaction, the medical history, clinical examination and additional imaging (2D and 3D) will help the clinician to evaluate whether any of these five sub-areas has increased complexity.

Most of the literature on the classification of impacted maxillary canines contains results based on 2D images. Recently suggested 3D classifications do not consider possible root anomalies, interactions with surrounding anatomical structures or associated pathology. Moreover, they require multiple measurements and are time consuming.[8,30,31] Therefore, Chapter 4 introduces a 3D based classification for describing impacted canine position and associated pathology. Some important findings that may affect the choice of treatment can only be obtained from CBCT images. Among them is the buccolingual position, the real proximity of the roots to the floor of the sinus or nasal cavity, the root developmental stage, the anatomy of the apical part of the root, signs of ankylosis and root resorption of neighboring teeth.[32,33]

In this study population, we observed a significant relation between mesiodistal position and the choice of treatment. A horizontal position was more frequently associated with autotransplantation of the maxillary canine. In case of mesial angulation or vertical position, surgical exposure and orthodontic traction was the treatment of choice. This is to be expected, considering that autotransplantation is most often associated with a more complex localization of the impacted maxillary canine.

To support our definition of critical canine impaction we systematically reviewed the literature in Chapter 5 and performed a retrospective study in Chapter 6. Evidence from the reviewed studies in Chapter 5 suggests, albeit with a low level of certainty, that some impaction characteristics (e.g. angulation, the vertical dimension of impaction, sector, root developmental stage) can be used as predictors for treatment duration, complexity and outcome.

In Chapter 6 we confirmed these findings from Chapter 5 in our own study population using our standardized aesthetic index (MCAI). It is important to consider the limitations of the retrospective design of this study: MCAI evaluation of the canines was performed on intraoral photographs from one to two weeks after debonding and the study population consisted of patients from multiple orthodontic practices which might imply different orthodontic treatment techniques and materials. Many patients were excluded due to a lack of pre-treatment panoramic radiographs and/or photographs from between one to two weeks after debonding. This may have resulted in a significant selection bias which undermines the statistical value of our study.

According to the results presented in Chapter 6, the following conclusions can be drawn when considering the treatment of impacted maxillary canines with surgically assisted orthodontic traction:

- Even when considering a broad study population with impacted canines (no age limitations, no positional limitations), a high number of canines will achieve full eruption at the end of treatment (96%), with or without the need for surgical reintervention.
- Excellent aesthetic outcomes, as defined by the MCAI, are to be expected when treating impacted maxillary canines with surgical exposure and orthodontic traction.
- Radiographic variables of the canine position (vertical height, angulation and anteroposterior sector), buccopalatal position and age are valuable predictors for aesthetic outcome, the need for surgical reintervention and orthodontic treatment duration.

The findings of the studies as presented in Chapters 5 and 6, confirming our definition of critical canine impactions, motivated us to look for studies which considered alternative treatment options when confronted with the limitations of the traditional treatments in this subpopulation of impacted maxillary canines: high vertical, horizontal and/or mesial position, increased age and/or root malformations.

The literature addressing this subgroup mainly consists of case reports and usually revolves around successful treatments whereas failures are rarely mentioned. It can be assumed that there is an underreporting of the amount of critical maxillary canine impactions and attempts to treat them. Oftentimes, these teeth will be surgically removed or not treated at all. As discussed in Chapter 3, treatment or re-treatment with surgical exposure and orthodontic traction, autotransplantation, apicotomy, segmental osteotomy, removal of the impacted canine with partial maxillary osteotomy, removal of the deciduous

canine and monitoring, and also removal of both canines followed by orthodontic mesialization of maxillary posterior teeth, are among the different treatment options found in these case reports.

In the specific case of extensive root resorption of the maxillary incisors, a decision must be made whether to extract the resorbed tooth and orthodontically align the impacted canine, whether to move the impacted canine away from the resorbed tooth, or whether to remove or autotransplant the impacted maxillary canines and prevent further root resorption. One of the most important factors in this decision will be the severity of the incisor root resorption, ideally examined with CBCT.

Based upon the findings of Chapter 3, one can conclude that, next to surgical exposure and orthodontic traction, autotransplantation is the most widely accepted alternative treatment option. In Chapter 7, the objective was to review the literature for transalveolar transplantation of maxillary canines and long-term outcomes. It became evident that there is a lack of sufficiently well-organized studies concerning the topic of autotransplantation of maxillary canines. There was a striking absence of clearly reported diagnostic pathways, pre-operative planning and post-operative follow-up. Questions regarding the indications for autotransplantation, planning of the procedure and guidelines for post-operative endodontic and orthodontic treatment remained mostly unanswered.

When it comes to surgical technique, there is more uniformity among the studies, although none explicitly reported careful handling of the follicle, 3D planning or an objective evaluation of the final result.

The heterogeneity in outcome assessment in the reviewed studies of Chapter 7 led us to suggest that there is a need for standardized outcome measures in future clinical trials, such as the ones we developed in Chapters 1 and 2. Additionally, since impacted maxillary canines are a rare anomaly and different aspects, such as position of the impacted canine, patient's age and patient's demands and expectations must be considered, it is practically impossible to randomize treatment. Therefore, high quality observational studies are recommended.

In Chapters 8 and 9, we used our validated indices from Chapters 1 and 2. We used the Autotransplanted Maxillary Canine Radiographic Index (AMCRI) to study radiological outcomes of autotransplanted canines and adjacent bone, when compared to the contralateral canine. We used the Maxillary Canine Aesthetic Index (MCAI) for the aesthetic evaluation and periodontal evaluation, including periodontal pocket depth, gingival recession and width of keratinized tissue on the impacted and contralateral canine quadrant.

In the retrospective study in Chapter 8, the main goal was to determine the long-term outcome of autotransplanted maxillary canines and to investigate the influencing parameters. The survival rate of transplanted maxillary canines in this study, with an average follow-up period of 21 years, was 67.9%. The mean survival time was 15.8 years. Significant parameters in determining the outcome of autotransplantation were baseline ankylosis of the impacted canine and damage of the periodontal ligament during surgery as reported by the surgeon, emphasizing the importance of proper patient selection and a careful surgical technique. Based upon the findings of this study, we can consider impacted maxillary canines with incomplete root formation and the absence of signs of ankylosis as ideal candidates for an autotransplantation procedure. This implies that there is a higher chance of success when the treatment is carried out at a younger age. This is in line with the findings of other studies on autotransplantation, investigating the root developmental stage and outcome.[34,35,36]

In the prospective study in Chapter 9, the goal was to set up a high-quality observational study to examine the outcome of maxillary canine transplantation compared to biological canine eruption. In addition to and in further exploration of the previous chapter, we tried to identify potential predictors of success, in order to aid patient selection. Canine autotransplantation was performed using a standardized treatment protocol with pre-operative 3D planning, a strict surgical protocol, postoperative follow-up with standardized indices (AMCRI and MCAI), and outcomes that were compared to the contralateral canines. One-stage endodontic treatment was performed in all transplanted canines with a closed apex, just before removal of the fixation wire, at two to four weeks postoperatively and always by the same operator. The timing of these procedures is crucial because early endodontic treatment could damage the PDL and late endodontic treatment could provoke inflammatory resorption.[37] In our treatment protocol, the orthodontic treatment was resumed after removal of the splint and execution of the endodontic treatment, four weeks post-operatively. This practice is in line with the findings and recommendations of Jang et al, who found that early application of orthodontic force could increase the survival rate of autotransplanted teeth without ankylosis.[38] We found a short-term survival rate of 100%. The success rate was found to be 67.5%. An intact periodontal ligament when checked for during surgery and the extra-oral time of the transplanted tooth were significant predictors of further treatment success, emphasizing the importance of careful removal of the donor tooth and careful preparation of the recipient socket. Both findings draw attention to the importance of careful 3D planning and the usefulness of a slightly oversized 3D dummy. Together with the periodontal ligament and the extra-oral time of the transplant, we also found that the quality of the surrounding soft tissue and bone were significant predictors of treatment success. Initial oral hygiene and gingival inflammation were significant clinical factors in treatment success, highlighting

the importance of patient selection, adequate instructions for post-operative oral hygiene and close follow-up.

It is important to emphasize that all but one of the transplanted canines in the study in Chapter 9 had complete root formation. It would be interesting to set up a high-quality observational study to further investigate the outcome of autotransplanted maxillary canines with open apices. As mentioned in Chapter 7, better survival and success rates have been reported with autotransplanted teeth with an open apex versus a closed apex.

In light of the findings of Chapters 7, 8 and 9, autotransplantation of maxillary canines can be considered a reliable treatment option for critically impacted maxillary canines when conventional approaches are not possible or have failed in a previous attempt. In some cases, as we observed in Chapter 4 for canines with a horizontal position, autotransplantation will be the first choice of treatment.

Aside from autotransplantation, there is the option to preserve the deciduous canine and remove the impacted maxillary canine in complex cases of impaction with poor prognosis after autotransplantation. This might be when 3D imaging reveals severe ankylosis and replacement resorption of the impacted canine, when the patient is older or in case of insufficient quality of the surrounding soft tissue and bone. The post-treatment stability of a preserved deciduous canine without root resorption has a good prognosis. However, this solution is possible only when the crown, root and supporting alveolar bone are of sufficient quality.

In Chapter 3, we also found some studies describing the apicotomy technique. An apicotomy is performed when there is evidence of apical ankylosis or dilacerations, or when proximity of the impacted canine to adjacent anatomical structures would resist the movement of the canine.[22] Considering the small number and the types of study design in these papers, there is insufficient evidence for powerful conclusions on the efficiency of the apicotomy technique. Further research is indicated. Another treatment option might be to remove the impacted canine and achieve orthodontic closure of the gap, along with conversion of the premolar to a canine. Although this is only possible if the patient agrees to further orthodontic treatment, it might result in a more predictable final treatment outcome where the patient is not at risk of developing long term complications. If the patient does not wish to start orthodontic treatment and there is a sufficiently wide diastema, whether after removal of the deciduous canine or not, an osseointegrated implant or Maryland bridge would be viable alternatives. In the decision-making process, the clinician will have to consider agenesis or pathology (e.g. root resorption) of the lateral incisor.

Autotransplantation of impacted maxillary canines is only one possible treatment option in case of critical impaction. As suggested, other treatment options are the removal of the impacted canine or apicotomy. Further research could focus on comparing the outcomes of these different treatment strategies whilst also paying attention to patient satisfaction and quality of life.

CONCLUSIONS

From the present thesis, it can be concluded that both the AMCRI and the MCAI are promising indices for the evaluation of the outcome after treatment of impacted maxillary canines. However, their validity should further be confirmed in a large-scale clinical study.

We described a subpopulation of critically impacted maxillary canines with decreased success rates in case of surgically assisted orthodontic extrusion. There are five categories of variables that determine the probability of critical impaction of the maxillary canine: the impacted canine position; associated pathology; root resorption of the neighboring teeth; relationship with neighboring anatomic structures; age.

A high number of impacted maxillary canines (96%) will achieve full eruption at the end of surgically assistend orthodontic traction and excellent aesthetic outcomes are to be expected. Radiographic variables of the canine position (vertical height, angulation and anteroposterior sector), buccopalatal position and age are valuable tools for the prediction of treatment success after surgically assisted orthodontic extrusion.

We demonstrated acceptable short- and long-term outcomes after autotransplantation of critically impacted maxillary canines. Baseline ankylosis, the extra-oral time during transplantation, damage to the root surface, the quality of surrounding soft and hard tissues, and immediate postoperative oral hygiene were identified as potential predictors of treatment success. An understanding of these prognostic factors may guide clinicians towards achieving predictable and successful outcomes after tooth transplantation. However, long-term complications, such as progressive root resorption and ankylosis with replacement resorption, can occur and the clinician should equally consider the emotional cost, oral health-related improvement in quality of life and treatment fatigue. Based upon the findings of Chapters 7, 8 and 9, we can consider impacted maxillary canines with incomplete root formation, absence of signs of ankylosis, sufficient quality of the surrounding soft tissue and bone, and good oral hygiene as the ideal candidates for an autotransplantation procedure.

To conclude, we wonder whether perhaps the real challenge for the clinician should be to recognize maxillary canine impaction early on and to use interceptive treatments to reduce the number of critically impacted canines.

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SUMMARY

Impacted maxillary canines can present themselves in a variety of ways. In the vast majority of cases, the routine treatment approach is sufficient and the clinician will achieve a successful end result. However, there is a subset of critical impactions where this standardized approach may fall short and the choice is ultimately made to remove the canine. The overall aim of this thesis was to compose recommendations that will help to identify critically impacted maxillary canines and at the same time support the decision-making process for further treatment options.

Chapters 1 and 2 introduce reliable and objective indices for the evaluation of the aesthetic and radiographic outcomes of impacted maxillary canines after treatment. In Chapter 3, the existing literature was reviewed for cases of critical maxillary canine impactions and treatment options. A definition for critical maxillary canine impaction is suggested.

In Chapter 4, a retrospective investigation of our own patient population, using 3D imaging, was performed to assess the different locations and associated pathology of impacted maxillary canines.

In Chapter 5, we reviewed the literature for a possible relationship between the initial position of the maxillary canine and the treatment outcome.

In Chapter 6, a retrospective study on the outcome of maxillary canines after surgical exposure and orthodontic traction was performed, in order to investigate possible predictors of treatment success.

In Chapter 7, the literature was systematically reviewed for autotransplantation of impacted maxillary canines. With this study, we aimed to give updated methodological information on the diagnostic and therapeutic pathways for trans-alveolar transplantation of maxillary canines and the long-term outcomes.

Using the indices from the first two chapters, a retrospective study (Chapter 8) was designed to study the long-term outcome following autotransplantation of maxillary canines. Using the same indices, a prospective study (Chapter 9) investigated the short-term outcome, while using standardized intake, surgery and follow-up procedures.

The findings of this doctoral thesis show that there is a subgroup of critically impacted maxillary canines with increased failure rates after standardized treatment. Autotransplantation of these canines has proven to have acceptable short- and long-term outcomes. However, other treatment alternatives should further be investigated.

To summarize, this thesis focuses on autotransplantation as a treatment option for critically impacted maxillary canines. Understanding and defining critical canine impaction will help in clinical practice. The goal was to identify critically impacted maxillary canines and at the same time support the decision-making process for further treatment options.

SAMENVATTING

Geïmpacteerde hoektanden kunnen zich op verschillende manieren presenteren. In de overgrote meerderheid van de gevallen is de vertrouwde aanpak voldoende en zal de behandelende arts een succesvol eindresultaat bereiken. Er is echter een subgroep van kritieke impacties waarbij deze gestandaardiseerde aanpak tekort kan schieten en vaak zal de keuze gemaakt worden om uiteindelijk de hoektand te verwijderen.

Het algemene doel van dit proefschrift is om aanbevelingen op te stellen die helpen bij het identificeren van kritisch geïmpacteerde hoektanden in de bovenkaak en tegelijkertijd het besluitvormingsproces voor verdere behandelingsopties ondersteunen.

In Hoofdstuk 1 en 2 worden betrouwbare en objectieve indices geïntroduceerd voor de evaluatie van het esthetische en radiografische resultaat van geïmpacteerde hoektanden in de bovenkaak na behandeling. In Hoofdstuk 3 werd de huidige literatuur beoordeeld voor gevallen van kritieke impacties van hoektanden in de bovenkaak en behandelingsopties. Een definitie van kritieke impactie van hoektanden in de bovenkaak werd voorgesteld.

In Hoofdstuk 4 werd een retrospectief onderzoek van onze eigen patiëntenpopulatie uitgevoerd om de verschillende locaties en geassocieerde pathologie van geïmpacteerde maxillaire hoektanden te beoordelen, met behulp van 3D beeldvorming.

In Hoofdstuk 5 werd de literatuur bestudeerd op een mogelijke relatie tussen de initiële positie van de hoektand in de bovenkaak en het resultaat.

In Hoofdstuk 6 werd een retrospectieve studie van de uitkomst van geïmpacteerde hoektanden in de bovenkaak na chirurgische blootlegging en orthodontische tractie uitgevoerd om mogelijke voorspellers van behandelsucces te onderzoeken.

In Hoofdstuk 7 werd de literatuur systematisch bekeken voor autotransplantatie van geïmpacteerde hoektanden in de bovenkaak. Met deze studie beoogden wij waardevolle informatie te geven over het diagnostische en therapeutische traject van trans-alveolaire transplantatie van hoektanden in de bovenkaak en de lange termijn uitkomst.

Gebruikmakend van de indices uit de eerste twee hoofdstukken werd een retrospectieve studie (Hoofdstuk 8) ontworpen om de lange termijn uitkomst van autotransplantatie van hoektanden in de bovenkaak te bestuderen. Gebruikmakend van dezelfde indexen werd in een prospectieve studie (Hoofdstuk 9) de korte termijn uitkomst onderzocht bij toepassing van gestandaardiseerde intake, chirurgie en follow-up procedures.

De bevindingen van dit proefschrift tonen aan dat er een subgroep is van kritisch geïmpacteerde hoektanden in de bovenkaak met een verhoogd aantal falingen na behandeling. Autotransplantatie van deze hoektanden heeft bewezen aanvaardbare resultaten te geven op korte en lange termijn. Andere behandelingsalternatieven moeten echter verder worden onderzocht.

Samenvattend, dit proefschrift richt zich op autotransplantatie als een behandelingsoptie voor kritisch geïmpacteerde hoektanden in de bovenkaak. Het begrijpen en definiëren van kritieke hoektand impactie zal helpen in de klinische praktijk. Het doel is om kritisch geïmpacteerde hoektanden te identificeren en tegelijkertijd het besluitvormingsproces te ondersteunen voor verdere behandelingsopties.

PERSONAL CONTRIBUTION

Koenraad Grisar conceived, planned and carried out the experiments, interpreted the results and wrote all manuscripts in consultation with the supervisors and co-authors.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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(2) Long-term outcome of autogenously transplanted maxillary canines.
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Long-term outcome of autogenously transplanted maxillary canines.

Publications incorporated in the PhD thesis chapters

Grisar K, Fransen J, Smeets M, Hoppenreijs T, Ghaeminia H, Politis C, Jacobs R. Surgically assisted orthodontic alignment of impacted maxillary canines: A retrospective analysis of functional and esthetic outcomes and risk factors for failure. AJODO. Am J Orthod Dentofacial Orthop. 2021 Mar 27:S0889-5406(21)00172-4. doi: 10.1016/j.ajodo.2020.12.019. Epub ahead of print. PMID: 33785231.

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Publications related to the PhD thesis

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