OXFORD

Systematic Review

Autogenous transalveolar transplantation of maxillary canines: a systematic review and meta-analysis

Koenraad Grisar[1,2], Dorra Chaabouni[1,2,3], Lesly Paola Gaitan Romero[1,2], Thomas Vandendriessche[4], Constantinus Politis[1,2] and Reinhilde Jacobs[1,2,5]

[1]OMFS IMPATH Research Group, Department of Imaging and Pathology, Faculty of Medicine, University Leuven, Belgium, [2]Department of Oral and Maxillofacial Surgery, University Hospitals Leuven, Belgium, [3]Department of Radiology, University Dental Clinic, Monastir, Tunisia, [4]KU Leuven Libraries – 2Bergen – Learning Centre Désiré Collen, Leuven, Belgium and [5]Department of Dental Medicine, Karolinska Institutet, Stockholm, Sweden

Correspondence to: Koenraad Grisar, Department of Oral and Maxillofacial Surgery, University Hospitals Leuven, Kapucijnenvoer 33, 3000 Leuven, Belgium. E-mail: koenraadgrisar@gmail.com

Summary

Background and objectives: The objective was to systematically review transalveolar transplantation of maxillary canines and the long-term outcome for an average follow-up period of 2 years or more.

Data collection and analysis: A systematic review of the currently available literature until December 2017 was conducted, using Medline, Cochrane Central, Web off 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.

Limitations: Since the lack of randomized controlled trials considering this topic, the quality of the evidence in the present review is considered low. However, 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 expectancies must be taken into account, it is practically impossible to randomize treatment.

Conclusions: 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.

Implication of key findings: It is highly desirable that further research on this issue be undertaken, high-quality observational studies are recommended.

Registration: PROSPERO (CRD42017056348)

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 per cent, 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 per cent 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 14–15, 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 unfavourable canine position, autotransplantation is a valuable alternative to extraction or other treatment options. High positioning or an angulation larger than 45 degrees relative to the occlusal plane are known selection criteria of autotransplantion (6). Orthodontic treatment is not always accepted by patients because treatment time may increase to 2–3 years, depending on many factors such as the canine position, aesthetic, and economical 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 this study, the aim was to systematically analyse 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 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 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.

PICOS question

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

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 Supplementary 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 autologous transplantation of maxillary impacted canines
- Controlled trials or prospective/retrospective studies, case series with at least 10 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 2 years
- No restrictions on language were made

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 2 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 outcome*s*	• Root resorption • Changes in pulp chamber • Tooth vitality • Change of canine colour • Tooth mobility and ankylosis • Endodontic treatment
Periodontal outcomes	• Periodontal attachment: pocket depth • Periodontal space • Gingival recession
Aesthetic outcome	• Patient satisfaction • Objective criteria

Main exclusion criteria
- Studies including autologous transplantation other than maxillary canines
- Case reports, case series with less than 10 transplanted maxillary canines, opinion articles, and review articles
- Studies reporting autotransplantated teeth 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, tumours, or trauma
- Studies including sterilized teeth, cryopreserved teeth, or teeth maintained in culture media
- Studies with oro-antral fistulae
- 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 systematic 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:
o Methods: study design, location/setting, recruitment period
o Participants: inclusion and exclusion criteria, demographics, number of participants, and autotransplanted maxillary canines
o Intervention: details regarding type of intervention
o 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 Methodological index for non-randomized studies (MINORS), is shown in Supplementary 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 ($\geq 10 \leq 17$), and high risk of bias (<10).

Statistical analysis

Studies were divided into two groups: short follow-up (2–5 years) and long-term follow-up (5 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 2–5 and 5 years or more were performed (Figures 2 and 3). Horizontal lines next to article names reflect the confidence interval for the parameter under 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 taking into account 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 (Supplementary 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 was 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 10 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 12 articles were 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 Supplementary Table 3.

For meta-analysis considering endodontic treatment analysis, four studies were excluded (12–14,20). For analysis of resorption and ankylosis, four (16,17,19,20) and six studies (10,14,16,17,19,20) were, respectively, excluded.

Characteristics of the study settings and investigators

Of the 12 included studies, four were performed in Sweden (9,13,16,17) and two in Australia (11,19). Other studies were performed in Belgium (12), Turkey (10), South Africa (14), UK (15), USA (20), 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 (13,14,20). The distribution of men and women was presented in 5 of the 12 studies. Between 12 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 (12–14,20). 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 (6,9–11,14–17,19). Three studies reported on the transplantation of maxillary canines as a subgroup (12,13,20).

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 radiographical pre-operative assessment. Root development stage was
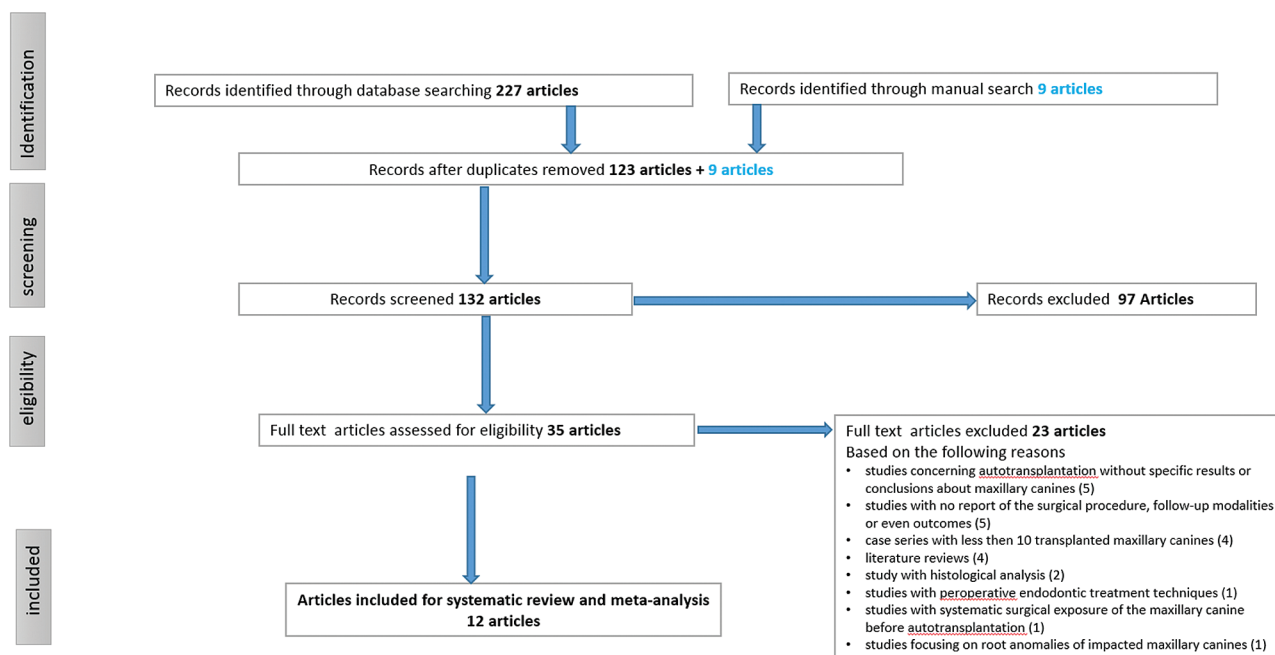

Figure 1. Flow diagram.

Table 2. Summary of study characteristics and outcomes

Mean FU	Study	Outcome (%)	Endodontic treatment (%)	Resorption (%)	Ankylosis (%)	Mean FU (years)	Study design	N pt	N teeth	M	F	Mean age	Min age	Max age
≥5 years	Patel *et al.* (15)	83	65	30.00	6.00	14.5	Case-control	49	63	—	—	21.8	13	42,1
	Ahlberg *et al.* (9)	96.7	69.7	75.8	100	6	Retrospective	29	33	—	—	27.5	16	54
	Arikan *et al.* (10)	93.5	100	6.3	—	5.87	Cross-sectional	30	32	9	21	34.32	25	55
	Sagne and Thilander (17)	88.1	100	—	—	9	Cross-sectional	85	101	31	54	31	11	76
2– years	Kvint *et al.* (13)	90.3	—	3.2	3.2	4.8	Retrospective	—	31	—	—	—	—	—
	Lownie *et al.* (14)	78		19%	—	4	Cross-sectional	—	17	—	—	—	—	—
	Pogrel (19)	62		—	—	2	Cross-sectional	—	162	—	—	—	—	—
	Sagne *et al.* (16)	100	100	—	—	2	Retrospective	12	14	8	4	36.5	23	54
	Schatz and Joho (18)	100	65	5	10,00	4.4	Cross-sectional	17	19	—	—	24.9	13	48
	Chambers *et al.* (11)	94	100,00	33	72	2.9	Retrospective	35	41	13	22	22	11	42
	Hall and Reade (20)	90	31	—	—	4	Retrospective	113	141	33	80	20	13	43
	Kallu *et al.* (12)	89.2	—	37.5	32.1	3.8	Retrospective	—	56	—	—	19.8	—	—

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 (9,19). 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). Radiographical 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, the surgical sites are disinfected and a local anaesthetic 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 slow 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, <20, <25 min, 'brief', 'with minimal delay', or without extra-oral time (10,11,13,14,17,19). 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 11 studies as: attached to the orthodontic wire for 3–6, 5, 12, 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 till 3 weeks (6,9–12,14–17,19,20). Occlusal positioning of the transplanted maxillary canine was discussed in 11 studies and found to be infra-occlusal in 5 studies and functional in 6 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 1 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 (Supplementary Table 3). Two studies mentioned orthodontic treatment post-operatively but did not discuss timing (14,17). Endodontic treatment and indications were discussed in all 12 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 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 (Supplementary Table 3).

Tooth-related outcomes were more frequently reported. Nine studies discussed the prevalence of root resorption and two studies discussed changes in pulp chamber appearance. Seven studies reported testing of tooth vitality and four studies compared tooth colour. 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 (6,9–12,15–17,19). Only one study mentioned a 1-year healing interval before probing (10). Four studies evaluated gingival recession levels and two studies evaluated the periodontal space (Supplementary 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 none of the included studies.

Duration of mean follow-up

The duration of mean follow-up was found in seven studies. In two studies, only a minimal follow-up time was mentioned (14,20). In those cases, minimal follow-up time was used for further calculations. In three studies, autotransplanted maxillary canines were subdivided regarding mean follow-up time (11,14,19). Only subgroups with a mean follow-up time of minimal 2 years were included. In case of multiple subgroups with a mean follow-up time of minimal 2 years, only the subgroup with the most complete amount of follow-up information was included. The data of the mean follow-up times were based on the reported data from the original articles.

Calculations performed on data

Meta-analytic results are summarized in Table 3. The meta-analysis showed a final outcome rate of 87.5 per cent (CI 77.1; 93.6) in the

short-term follow-up group (2–5 years) and 88.2 per cent (CI 81.4; 92.7) in the long-term follow-up group (>5 years). Endodontic treatment was calculated to be performed in 82.5 per cent (CI 31; 98) of the canines in the short-term follow-up group (2–5 years) and 91.5 per cent (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 per cent (CI 7.4; 39) and 23.8 per cent (CI 4.8; 65.7) in the short-term follow-up group (2–5 years) and 32.3 per cent (CI 5.4; 74.9) and 65.2 per cent (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.

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 2 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, 12 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 clear-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

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

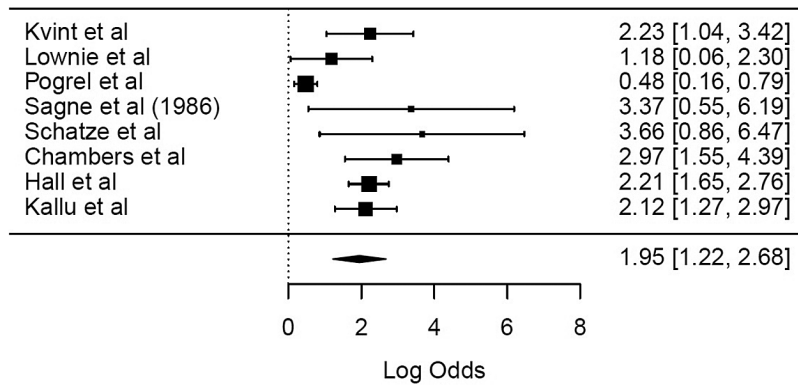| Variable	Group	Number of included articles	Percentage	Confidence interval (CI)
Outcome	2–5 years	8	87.5	[77.2; 93.6]
Outcome	5 years or more	4	88.2	[81.4; 92.7]
Endo	2–5 years	4	82.5	[31; 98]
Endo	5 years or more	4	91.5	[53.3; 99]
Resorption	2–5 years	5	18.5	[7.4; 39]
Resorption	5 years or more	3	32.3	[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]

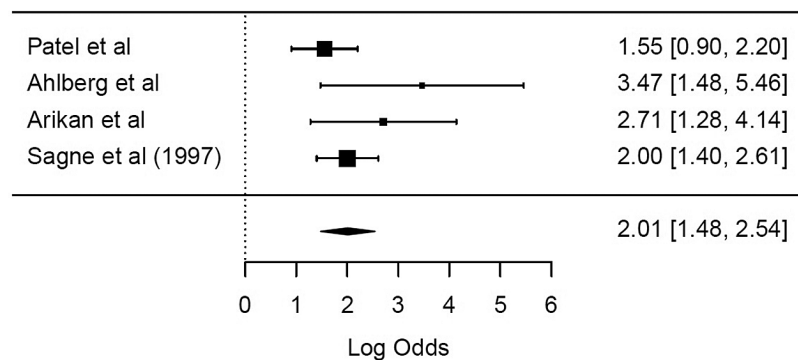**Figure 2.** Forest plot survival 2–5 years.

Figure 3. Forest plot survival 5 years or more.

maxillary canines (Table 2). Considering a 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 radiographical 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 in 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. 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 do 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, minimalized 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 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 as mandatory analogue of 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 also suggest a wait-and-see strategy even in cases of closed apices.

Better survival and success rated have been reported with autotransplanted teeth with open apex versus closed apex. However, Chung *et al.* (25), in their systematic review of transplanted teeth with a closed apex, found high survival rates of 98 per cent at the 1-year follow-up point and 90.5 per cent at the 5-year follow-up point. Acevedo *et al.* (26), in their systematic review of teeth with an open apex found a survival rate of 98 per cent after a mean follow-up period of 6 years. In a recently published long-term follow-up case series, Murtadha *et al.* (27) 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.

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

colour, and mobility. Only two studies evaluated more extensively the soft tissue outcome. As mentioned before, CBCT were not available or the routine use of it was not yet established at the time when the materials for the studies included in this systematic review. 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 check up 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 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, discolouration, and pocketing, while maintaining vitality (15). It should be questioned whether ankylosis and replacement resorption observed after tooth transplantation constitutes a 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 per cent (CI 77.1; 93.6) for the final outcome with a mean follow-up of 2–5 years and 88.2 per cent (CI 81.4; 92.7) with a mean follow-up of more than 5 years. This is considered to be an excellent prognosis.

Six studies reported ankylosed teeth. The numbers varied from 3.2 to 100 per cent. 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.* (29), clinical signs of ankylosis can be observed within a year of tooth autotransplantation. Tsukiboshi (30) concluded that ankylosis is irreversible and will progress until the loss of the tooth. 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 10, 20, or more years.

Inflammatory root resorption was observed in eight studies, varying from 3 to 76 per cent. 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 1–2 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 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 randomized controlled trial (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 expectancies 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.

Supplementary material

Supplementary materials are available at *European Journal of Orthodontics* online.

Conflict of interest

None to declare.

References

1. Kokich, V.G. (2004) Surgical and orthodontic management of impacted maxillary canines. *American Journal of Orthodontics and Dentofacial Orthopedics*, 126, 278–283.
2. Grover, P.S. and Lorton, L. (1985) The incidence of unerupted permanent teeth and related clinical cases. *Oral Surgery, Oral Medicine, and Oral Pathology*, 59, 420–425.
3. Bishara, S.E. (1992) Impacted maxillary canines: a review. *American Journal of Orthodontics and Dentofacial Orthopedics*, 101, 159–171.
4. Alqerban, A., Jacobs, R., Lambrechts, P., Loozen, G. and Willems, G. (2009) Root resorption of the maxillary lateral incisor caused by impacted canine: a literature review. *Clinical Oral Investigations*, 13, 247–255.
5. Becker, A. and Chaushu, S. (2015) Etiology of maxillary canine impaction: a review. *American Journal of Orthodontics and Dentofacial Orthopedics*, 148, 557–567.
6. Schatz, J.P. and Joho, J.P. (1994) Indications of autotransplantation of teeth in orthodontic problem cases. *American Journal of Orthodontics and Dentofacial Orthopedics*, 106, 351–357.

7. Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Gøtzsche, P.C., Ioannidis, J.P., Clarke, M., Devereaux, P.J., Kleijnen, J. and Moher, D. (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Journal of Clinical Epidemiology*, 62, e1–34.

8. Higgins J.P.T., Green S. (2011) *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0*. The Cochrane Collaboration, Table 7.7.a: Formulae for combining groups. Wiley Blackwell.

9. Ahlberg, K., Bystedt, H., Eliasson, S. and Odenrick, L. (1983) Long-term evaluation of autotransplanted maxillary canines with completed root formation. *Acta Odontologica Scandinavica*, 41, 23–31.

10. Arikan, F., Nizam, N. and Sonmez, S. (2008) 5-year longitudinal study of survival rate and periodontal parameter changes at sites of maxillary canine autotransplantation. *Journal of Periodontology*, 79, 595–602.

11. Chambers, I.G., Reade, P.C. and Poker, I.D. (1988) Early post-operative endodontic therapy limits inflammatory root resorption of autotransplanted maxillary canine teeth. *The British Journal of Oral & Maxillofacial Surgery*, 26, 364–369.

12. Kallu, R., Vinckier, F., Politis, C., Mwalili, S. and Willems, G. (2005) Tooth transplantations: a descriptive retrospective study. *International Journal of Oral and Maxillofacial Surgery*, 34, 745–755.

13. Kvint, S., Lindsten, R., Magnusson, A., Nilsson, P. and Bjerklin, K. (2010) Autotransplantation of teeth in 215 patients. A follow-up study. *The Angle Orthodontist*, 80, 446–451.

14. Lownie, J.F., Cleaton-Jones, P.E., Fatti, P. and Lownie, M.A. (1986) Autotransplantation of maxillary canine teeth. A follow-up of 35 cases up to 4 years. *International Journal of Oral and Maxillofacial Surgery*, 15, 282–287.

15. Patel, S., Fanshawe, T., Bister, D. and Cobourne, M.T. (2011) Survival and success of maxillary canine autotransplantation: a retrospective investigation. *European Journal of Orthodontics*, 33, 298–304.

16. Sagne, S., Lennartsson, B. and Thilander, B. (1986) Transalveolar transplantation of maxillary canines. An alternative to orthodontic treatment in adult patients. *American Journal of Orthodontics and Dentofacial Orthopedics*, 90, 149–157.

17. Sagne, S. and Thilander, B. (1997) Transalveolar transplantation of maxillary canines. A critical evaluation of a clinical procedure. *Acta Odontologica Scandinavica*, 55, 1–8.

18. Schatz, J.P. and Joho, J.P. (1993) A clinical and radiologic study of autotransplanted impacted canines. *International Journal of Oral and Maxillofacial Surgery*, 22, 342–346.

19. Pogrel, M.A. (1987) Evaluation of over 400 autogenous tooth transplants. *Journal of Oral and Maxillofacial Surgery*, 45, 205–211.

20. Hall, G.M. and Reade, P.C. (1983) Root resorption associated with autotransplanted maxillary canine teeth. *The British Journal of Oral Surgery*, 21, 179–191.

21. Andreasen, J.O., Paulsen, H.U., Yu, Z., Ahlquist, R., Bayer, T. and Schwartz, O. (1990) A long-term study of 370 autotransplanted premolars. Part I. Surgical procedures and standardized techniques for monitoring healing. *European Journal of Orthodontics*, 12, 3–13.

22. Hammarström, L., Blomlöf, L. and Lindskog, S. (1989) Dynamics of dentoalveolar ankylosis and associated root resorption. *Endodontics and Dental Traumatology*, 5, 163–175.

23. Schätzle, M., Tanner, S.D. and Bosshardt, D.D. (2005) Progressive, generalized, apical idiopathic root resorption and hypercementosis. *Journal of Periodontology*, 76, 2002–2011.

24. Verweij, J.P., Jongkees, F.A., Anssari Moin, D., Wismeijer, D. and van Merkesteyn, J.P.R. (2017) Autotransplantation of teeth using computer-aided rapid prototyping of a three-dimensional replica of the donor tooth: a systematic literature review. *International Journal of Oral and Maxillofacial Surgery*, 46, 1466–1474.

25. Chung, W.C., Tu, Y.K., Lin, Y.H. and Lu, H.K. (2014) Outcomes of autotransplanted teeth with complete root formation: a systematic review and meta-analysis. *Journal of Clinical Periodontology*, 41, 412–423.

26. Atala-Acevedo, C., Abarca, J., Martínez-Zapata, M.J., Díaz, J., Olate, S. and Zaror, C. (2017) Success rate of autotransplantation of teeth with an open apex: systematic review and meta-analysis. *Journal of Oral and Maxillofacial Surgery*, 75, 35–50.

27. Murtadha, L. and Kwok, J. (2017) Do autotransplanted teeth require elective root canal therapy? A long-term follow-up case series. *Journal of Oral and Maxillofacial Surgery*, 75, 1817–1826.

28. Fuss, Z., Tsesis, I. and Lin, S. (2003) Root resorption–diagnosis, classification and treatment choices based on stimulation factors. *Dental Traumatology*, 19, 175–182.

29. Paulsen, H.U., Andreasen, J.O. and Schwartz, O. (1995) Pulp and periodontal healing, root development and root resorption subsequent to transplantation and orthodontic rotation: a long-term study of autotransplanted premolars. *American Journal of Orthodontics and Dentofacial Orthopedics*, 108, 630–640.

30. Tsukiboshi, M. (1993) Autogenous tooth transplantation: a reevaluation. *The International Journal of Periodontics and Restorative Dentistry*, 13, 120–149.