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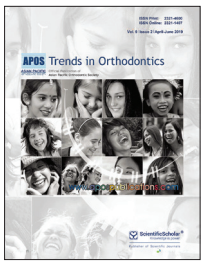

Review Article

Three-dimensional orthodontic anchorage management of impacted maxillary canines: A systematic review

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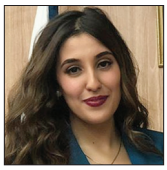

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ABSTRACT

Objectives: Our work aims to provide scientific evidence by conducting a serious systematic review of the efficacy of three-dimensional (3D) anchorage devices for orthodontic traction of impacted maxillary canines.

Material and Methods: An electronic search extending from 2012 to 2022, targeting mainly clinical trials was performed on the following databases PUBMED (MEDLINE), The Cochrane Library, SCIENCE DIRECT, EBSCO HOST DATABASES, and GOOGLE SCHOLAR. The search was established on a well-defined research question following the PICO principle: population, intervention, comparator, and outcome. Search evaluation and the assessment of the risk of bias (RoB) were undertaken in each study following its type and design.

Results: Thirteen studies were included for qualitative analysis, with a low to moderate RoB. Ten studies used only heavy conventional palatal anchorage such as a fixed trans palatal arch (TPA), while one study used skeletal anchorage to manage the orthodontic traction of impacted maxillary canines. Two studies compared trans palatal arch and mini-screws efficiency to treat impacted maxillary canines.

Conclusion: Studies proved that the trans palatal arch (TPA) presents a particular anchorage unpredictability in the sagittal, transversal, and vertical dimensions. Whereas, anchorage management using mini-screws proved to be very beneficial clinically; however, further studies must be implemented to evaluate the 3D efficacy of skeletal anchorage to place an impacted maxillary canine to its rightful position into the arch.

Keywords: Impacted canines, Anchorage, Traction, Orthodontics

INTRODUCTION

Canines, after third molars, are the teeth with the highest prevalence of impaction. It affects women twice as often as men and is more frequently palatally positioned with an 80–90% incidence.[1]

Canine impaction may have detrimental consequences, such as root resorption of the adjacent teeth, dental midline deviation, anterior crowding, arch perimeter shortening, ankylosis, infection, and pain. Thus, early three-dimensional (3D) diagnosis and biomechanical management play an important part in achieving an esthetic and functional placement of the impacted canine while preserving its periodontal integrity.

Orthodontic placement of this tooth is highly recommended in adult patients.[2] Success in the management of maxillary impacted canine (MIC) relies on a good clinical examination, a planned surgical procedure, and a well-considered strategy concerning choosing the best anchorage device and mechanics.

Physiologic force magnitude and correct direction of application must be taken into consideration when displacing an impacted maxillary canine; the goal is to move the tooth vertically (extrusion) and/or sagittally (disalization). The complexity of these movements, therefore, requires accurate anchorage preparation and the use of a reinforced anchorage unit. Lack of attention when choosing the anchorage mechanics may result in unwanted side effects, which makes the treatment more difficult.[3]

Many orthodontic conventional intra-arch anchorage devices have been described in the literature during orthodontic treatment of an impacted canine: Ballista spring, cantilever spring, stainless steel auxiliary arches, and mandibular anchoring. Nowadays, direct or indirect temporary anchorage devices (TADs) have been used as alternative apparatus.[4]

Our work aims to provide scientific evidence by conducting a serious systematic review on the efficacy of 3D anchorage devices for orthodontic traction of impacted maxillary canines.

MATERIAL AND METHODS

Registration of protocol

The search protocol was registered at PROSPERO (Registration # CRD42022311369) to avoid any duplication. PRISMA 2020 guidelines for reporting items for systematic reviews were strictly followed during all phases of the review.

Search strategy

We performed an electronic search extending from 2012 to 2022, targeting mainly clinical trials on the following databases:

- PUBMED (MEDLINE)
- The Cochrane Library
- SCIENCE DIRECT
- EBSCO HOST DATABASES
- And, GOOGLE SCHOLAR.

The following Medical Subject Heading terms used for the search sequence are "Impacted canine," "Tooth impacted," "Dental impaction," "Orthodontic traction," and "Orthodontic anchorage." These keywords were gathered by a Boolean operator "AND"/"OR," forming different search equations:

1/"Impacted canine" AND "Orthodontic anchorage" OR "Orthodontic traction,"

2/"Impacted canine" OR "Dental impaction" OR "Tooth impacted" AND "Orthodontic anchorage" AND "Orthodontic traction."

The search was established on a well-defined research question following the PICO principle: Population, intervention, comparator, and outcome: The main characteristics of the PICO question are summarized in [Table 1]

Inclusion and exclusion criteria

We present in the following [Table 2] the inclusion and exclusion criteria used to incorporate articles into the analysis.

Data extraction method

Two independent reviewers Y.T and Y.O performed a qualitative synthesis; they discussed the result obtained by evaluating the title and summary of the studies, excluding studies that do not meet our criteria of inclusion and eliminating duplicate articles.

Table 1: PICO question.

Population	Patients without age restriction, diagnosed with maxillary included canines, unilaterally or bilaterally, in a buccal or palatal position
Intervention	Surgical - orthodontic treatment with proper anchorage planning: A specific anchorage device (conventional anchorage or mini-screws) or orthodontic anchorage procedure; to move and place the impacted maxillary canine in its rightful position. The anchorage loss will be assessed based on the 3D unwanted movement of arch wire-supported teeth.
Comparison	A comparison between anchorage devices in terms of the type of anchorage used, force application in three directions senses, unwanted movement of arch wire-supported teeth, and clinical efficacy.
Outcome	The success of the anchoring devices in placing the maxillary impacted canines in their rightful position with good periodontal, occlusal, and cephalometric results.

PICO: Population, intervention, comparator, and outcome

Table 2: Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
- Articles in English or French - Full text available - Date of publication from 2012 - Retrospective studies, prospective studies, randomized and non-randomized clinical trials - Clinical trials evaluating only successful orthodontic-surgery approach in treating maxillary included canines - Studies describing precisely the anchorage strategy used	- Animal studies - Simulation or virtual study method - Case reports - Literature review and opinion articles - Studies evaluating interceptive treatment in the management of impacted maxillary canines - Studies including cleft patients in their sample - Articles describing new anchorage system or device in treating impacted maxillary canine

Then, Y.T and Y.O independently extracted data from the retained studies on a data extraction sheet:

- Author name
- Year of publication
- Country
- Study design
- Sample: sex and age
- Situation and localization of the impacted maxillary canines
- Duration of treatment
- Types of appliances used for anchorage reinforcement
- Result.

A third researcher H.B. then, reevaluated the data collected. We illustrate our selection process in the flow chart [Figure 1].

Methodological and risk of bias (RoB) assessment

Search evaluation and the assessment of RoB were made by two researchers independently Y.T and Y.O. In case of any disagreement, the third reviewer H.B. reevaluated the result.

The assessment of RoB was undertaken in each study following its type and design:

- RoB2 tool was used to assess the quality of included randomized controlled trials
- Risk of bias in non-randomised studies of interventions (ROBINS-I) tool was used to assess the quality of included non-randomized trials
- Joanna Briggs Institute (JBI) tool was used to assess the quality of included retrospective case–control and cohort studies.

RESULTS

Study selection

We identified 7110 studies from the primary search, 6929 studies were duplicates or does not fit into our inclusion criteria. We maintained 121 studies for pre-selection studies to undergo abstract screening. After removing irrelevant studies and evaluating the integral text, 14 studies were included in our systematic review.

The summary of the study selection is presented within the flow chart [Figure 1].

Study characteristics and RoB

Our included studies were a combination of one randomized clinical trial, conducted in ITALY and published in 2021,[5] two studies were non-randomized clinical trials published in 2012 and 2016.[6,7] Eight studies were retrospective case–control studies[8-15] and two were retrospective cohort studies.[16,17]

Ten studies used only heavy conventional palatal anchorage such as a fixed trans palatal arch,[8-17] while one study used only skeletal anchorage to manage the orthodontic traction of impacted maxillary canines.[6] Two studies compared trans palatal arch and mini-screws efficiency to treat impacted maxillary canines.[5,7]

Following the RoB2 tool, the randomized clinical trial was considered to have moderate RoB [Table 3]. The ROBIN I tool for non-randomized clinical trials revealed one study with moderate risk while the other is classified as low risk [Table 4].

According to the JBI critical appraisal checklist for retrospective case-control studies, six studies were considered to have low RoB while two were classified as moderate risk [Table 5]. Moreover, the three remaining cohort studies were considered to have moderate RoB [Table 6].

We present a summary of included articles in the following [Table 7].

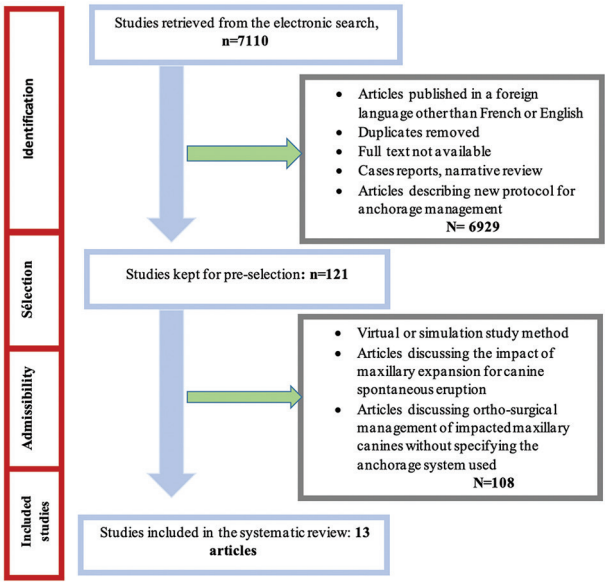

Figure 1: Flow chart.

Table 3: Risk of bias assessment using the RoB2 tool.

	D1	D2	D3	D4	D5	Overall
Migliorati *et al.* (2021) ITALY[5]	+	-	-	+	+	-

Domains:
D1: Bias arising from the randomization process
D2: Bias due to deviation from the intended interventions
D3: Bias due to missing outcome data
D4: Bias in measurement of the outcome
D5: Bias in the selection of the reported result.
Judgment:
X - High
- - Some concerns
+ - Low

Table 4: Risk of bias assessment using ROBIN-I tool.

Study	D1'	D2'	D3'	D4'	D5'	D6'	D7'	Overall risk
Kocsis and Seres (2012)[6]	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Heravi *et al*. (2016)[7]	Moderate	Moderate	Low	Low	Low	Low	Moderate	Low

Domains:
D1': Bias due to confounding
D2': Bias in selection of participants in the study
D3': Bias in classification of interventions
D4': Bias due to deviations from intended interventions
D5': Bias due to missing data
D6': Bias in measurement of outcomes
D7': Bias in selection of the reported result.

Table 5: The JBI critical appraisal for retrospective case control studies.

Checklist questions	1	2	3	4	5	6	7	8	9	10	%yes	Risk
Brusveen *et al*. (2012).[8]	X	✓	✓	✓	✓	?	X	✓	X	✓	60%	Moderate
Silva *et al*. (2016)[9]	✓	✓	✓	✓	✓	X	X	✓	?	✓	70%	Low
Arriola-Guillén *et al*. (2018)[10]	X	✓	✓	✓	✓	X	X	✓	X	✓	60%	Moderate
Arriola-Guillén *et al*. (2019)[11]	X	✓	✓	✓	✓	✓	?	✓	?	✓	70%	Low
Chávez-Alvarez *et al*. (2019)[12]	X	✓	✓	✓	✓	✓	X	✓	✓	✓	80%	Low
Arriola-Guillén *et al*. (2020)[13]	X	✓	✓	✓	✓	✓	X	✓	?	✓	70%	Low
Ruíz-Mora *et al*. (2021)[14]	X	✓	✓	✓	✓	X	✓	✓	✓	?	70%	Low
Rodríguez-Cárdenas *et al*. (2021)[15]	X	✓	✓	✓	✓	✓	?	✓	✓	✓	80%	Low

JBI: Joanna briggs institute

Table 6: The JBI critical appraisal for retrospective cohort studies.

Check list questions	1	2	3	4	5	6	7	8	9	10	11	% yes	Risk
Potrubacz *et al*. (2018)[16]	X	✓	✓	✓	X	?	✓	✓	✓	X	✓	64%	Moderate
Tepedino *et al*. (2018)[17]	X	✓	✓	X	✓	?	✓	✓	✓	X	✓	64%	Moderate

Q1: Q11 indicates questions 1–11 based on the JBI risk assessment. The risk of bias was ranked as high when the study reached up to 49% of "yes" scores, moderate when the study reached from 50 to 69% of "yes" scores, and low when the study reached more than 70% of "yes" scores. "✓" indicates yes, "X" indicates no, and "?" indicates unclear, JBI: Joanna Briggs institute

DISCUSSION

Orthodontic anchorage is defined as the ability to resist unwanted reactive forces and moments related to tooth movements. Our definition goes in line with Newton's 3rd law, which states that, every action had an equal, and opposite reaction.[18]

Impaction of maxillary canines is a frequently encountered clinical problem. The cause of canine impaction can be the result of localized, systemic, or genetic factor(s). The diagnosis and 3D localization of the impacted canines is the most important step in the management of impacted canines based on clinical and radiographic examinations.[19]

Orthodontic treatment of impacted maxillary canines usually requires an interdisciplinary approach, combining a meticulous surgical techniques and orthodontic biomechanical considerations; related to the 3D force system acting on the canines in the horizontal, vertical, and sagittal plane.

Anchorage strategy should adapt to the various changes in the direction of traction of the included canine to achieve proper alignment in the dental arch. Which can be vertical or oblique in the first phase to straighten the axis of the canine and move it away from the roots of neighboring teeth before a second phase of traction, which is often horizontal towards its place on the arch.

Becker *et al*. in his study proved that poor anchorage to be the major cause of failures (in 48.6% of subjects) in the treatment of impacted maxillary canines.[20]

Conventional anchorage devices such as orthodontic arches or transpalatal arches have been used for a long time. However, their effectiveness in providing sufficient orthodontic anchorage is questionable. Meanwhile, the

Table 7: A summary of included studies.

Author, year of publication and country	Study design	Purpose of the study	Sample	Anchorage method	Evaluation Method of impacted canines	Traction mechanics	Results
Kocsis and Seres (2012) Hungary[6]	Non- randomized clinical trial	To evaluate the role of mini-screws in the management of impacted upped canines	63 patients: 69 impacted maxillary canines: • 57 unilaterally • 6 bilaterally • 21 situated buccally • 48 impacted palatally Sex and age: • 27 male, 36 female • Mean age: 22.7 years	Stainless steel 1.5 mm diameter and 8–10 long mini-screws placed in premolar-molar alveolar bone area	Anterior occlusal radiographs and periapical X-rays were taken. The patient was seen at 4-week intervals	Traction was activated with a NITI closed-coil spring The mini-screws were only used to lead the canine to its normal eruption path sagittally, then conventional fixed multibracked therapy was performed	- Of the 69 canines, 61 (88.41%) were successfully guided into occlusion - Traction with mini-screw anchorage lasted 4–10 months. - No root resorption or devitalization of the neighboring teeth
Brusveen *et al.* (2012). Norway and Greece[8]	Retrospective case control study	To evaluate impacted maxillary canines as risk factor for orthodontic apical root resorption	66 patients: Impaction group: 32 patients with unilaterally impacted maxillary canines • 23 palatally • 5 buccally • 4 centrally Age and sex: • 20 females • 12 males • Mean age: 13.9 years Control group: 34 patients with normally erupting canines Age and sex: • 21 females • 13 males • Mean age: 13.4	A transpalatal arch, with a finger spring attached to it.	- Pretreatment orthopantomograms, lateral cephalometric radiographs, and intraoral radiographs. - Periapical radiographs have been routinely - used in the diagnosis of root resorption	The anchorage system was used only to pull the crown of the impacted canine away from adjacent incisor root.	Orthodontic root resorption was not affected by the presence of impacted canines that were distanced from the incisor roots with specially designed anchorage appliance before full bonding
Heravi *et al.* (2016) IRAN[7]	A non-randomized clinical controlled trial study	To evaluate the role of TSAD in moving the impacted canines away from the roots of neighboring teeth	34 palatally impacted canines Experimental group: 19 palatally impacted canines Anchorage used: Two mini-screws (1.4 mm in diameter and 8 mm in length) were inserted in the palatal region for each impacted tooth Control group: 15 palatally impacted canines Anchorage used: A transpalatal arch (TPA) was placed All patients were females with a mean age of 15.6±2.1 years		- Pre and post treatment CBCT scans - VAS score, BOP and GI were recorded - Clinical success rate was also calculated	A palatal cantilever spring made of Beta titanium wire was inserted into the slot of mini-screws in the experimental group NITI overlay were used to guide the canines to the arch in both groups.	- The volume of root resorption of lateral teeth in the control group was significantly greater than in the experimental group (P<0.001) - At the end of treatment, duration of the traction, VAS score, GI and BOP were not significantly different between the two groups - Clinical success rate was 100%. In the experimental group with a survival rate of 94.7%
Silva *et al.* (2016) BRAZIL[9]	Retrospective case-control study	To evaluate the effects of orthodontic traction on root length and alveolar bone level in impacted canines and adjacent teeth.	16 subjects with unilaterally impacted maxillary canines: - Teeth from the impacted- canine side were assigned as Group I - Contralateral teeth as control: Group II - Patients were treated with the same traction protocol Age and sex: • 9 males • 7 females • Mean age: 11.8 years	A stainless steel 0.032" trans palatal arch was used as anchorage	- CBCT scan were taken in a long-term basis of 5 years and 11 months post treatment - Root length and alveolar bone changes were evaluated on cone beam images and assessed by paired *t*-test	Canine traction was performed by using 0.019×0.025" TMA wires exerting a continuous force to guide the canine to its correct position	- All impacted canine erupted successfully - No statistically significant differences in root length and buccal and palatal bone levels of canines and adjacent teeth among groups
Potrubacz *et al.* (2018) ITALY[16]	Retrospective cohort study	To evaluate the time needed for orthodontic extrusion of impactions of different severities, using a device that can predictably apply forces under 0.6 N.	22 patients: A total of 30 impacted maxillary canines: • 8 bilaterally • 14 unilaterally Age and sex: • 10 male, mean age 15.4 years • 12 female, mean age 15 years	A fixed transpalatal arch with a distal loop	- Pretreatment panoramic radiograph, cephalograms and additional measurement were taken. - Statistical analysis was used to detect interactions between treatment time, complexity of impaction, Age, and sex - One year follow up was provided for every patient	A 0.6 diameter stainless steel wire was used to model a cantilever, which was soldered five times around the transpalatal arch This system was used only to extrude the canine	- Transpalatal arch and cantilever system is considered efficient, easy to construct and manage, it offers favorable biomechanics that is easy to activate in a predictable way - Orthodontic extrusion was performed in a mean time of 3.5 months and treatment time was correlated to patient age; the younger the patient, the shorter the time required to extrude the canine, despite its position - Patient sex on treatment time was also observed: there was a shorter treatment time in the boys
Tepedino *et al.* (2018) ITALY[17]	Retrospective cohort study	To evaluate if the different muscular activity correlated to different degrees of facial divergence has an effect on the time needed to extrude a palatally impacted maxillary canine	26 patients with palatally impacted maxillary canines • 17 hypo divergent • 6 normo- divergent • 3 hyper- divergent Age: Mean age: 15.8	A 0.9 mm stainless steel transpalatal arch with a distal loop welded to two molar bands for the upper first molars.	- Pre-treatment lateral cephalograms were collected, tracings were performed by an expert operator and repeated after a 2-weeks interval	A 0.6 mm palatal stainless steel cantilever welded to the transpalatal arch and then rolled around it to create 5 loops was used to extrude orthodontically palatally impacted canines	- Palatally impacted canines can be successfully treated with the described system regardless of the patient's vertical skeletal and muscular pattern. - The mean traction time was 3.6 months
Arriola- Guillén *et al.* (2018) BRAZIL[10]	Longitudinal retrospective case – control study	To compare the RR of maxillary incisors after traction of unilateral versus bilateral impacted canines with reinforced anchorage	30 patients with impacted maxillary canines • 15 unilateral • 15 bilateral Age and sex: • 11 males (6B+5U) • 19 females (9B+10U) • Mean age: 20.97 for unilateral impaction and 16.8 for bilateral ones 60 CBCT scans of patients with MICs: • 30 scans taken before traction • 30 taken after orthodontic traction	a rigid temporary anchor was placed on the permanent first molars with a rigid palatal acrylic button and an arch wire over all palatal surfaces of all maxillary teeth in 1.1-mm or 1.2-mm stainless steel wire with multiple palatal and occlusal vestibular hooks	- Initial lateral cephalometric radiographs and panoramic radiographs were done - CBCT scans were required to complement the diagnosis - Of MIC type. Measurements for this study were made on images - Synthesized from the CBCT scans	An 8- and 12-mm long NITI closed-coil springs linked to the vestibular hooks and extensions of the anchor were used to perform intraosseous traction transalveolarly	- No significant differences in most of the variables evaluated between the 2 impaction groups, except for the canine impaction sector, with greater difficulty for the subjects in the bilateral impaction group. Canine traction required a longer treatment time (3.4 months) in the bilateral group - No subject had RR >2 mm or 5 mm 2, except for the RR of the maxillary right central incisor that was significantly greater (0.86 mm) in the unilateral group
Arriola-Guillén *et al.* (2019) BRAZIL[11]	Longitudinal retrospective case-control study	To determine the influence of the orthodontic traction of impacted canines on the root resorption of adjacent incisors, using CBCT.	45 patients with impacted maxillary canines: • 20 palatally • 18 buccally • 7 bicortically divided into 2 groups: • 20 patients of low complexity cases (10P+10B) • 25 patients of high complexity cases (10P+8B+7BI) Sex and age: • 19 females • 11 males • Mean age 18±7.3 years	Same traction technique: A palatal acrylic button and a modified palatal arch around palatal surfaces of all maxillary teeth with multiple palatal-occlusal vestibular hooks	- Complexity was defined considering impaction sector, eruption inclination angle, and canine position - The amounts of RR were evaluated before and after traction using CBCT images	Vestibular hooks and device extensions allowed regulation of the buckles of closed helicoidal NITI coil springs in an 8 and 13 mm long Activations of 4 to 5 mm were performed every 4–8 weeks	- The amount of RR in both groups (high complexity vs. low complexity) was similar and smaller than 2 mm. This amount of RR does not show any risk for oral or tooth health that could lead to tooth loss. - The influence of sex, indicated by a higher risk of resorption in male patients
Chávez--Alvarez *et al.* (2019) BRAZIL[12]	Longitudinal retrospective case-control study	To compare the inclination and position changes of maxillary incisors after traction of unilateral versus bilateral MICs in no-extraction orthodontic treatment	24 patients with impacted maxillary canines with ANGLE class I malocclusion: • 12 unilaterally • 12 bilaterally Age and sex: • 9 males (5B+4U) • 15 females (7B+8U) • Mean age: 19 years for unilateral impaction and 17.82 for bilateral ones	Heavy palatal anchorage appliance made of 1.1-mm or 1.2-mm stainless steel wires on the permanent first molars reinforced with extensions anteriorly	- Lateral head films and panoramic radiographs were used to evaluate the craniofacial and canine impaction characteristics - CBCTs were obtained before and after canine traction and the inclination and position of both maxillary central incisors were measured - Dental arch, skeletal, and canine impaction characteristics were evaluated	NITI closed coil springs linked to wire hooks were used to distance the canine from the roots of the incisors.	- Incisor change comparisons between the affected and non-affected side, in the unilateral group, showed a greater but statistically insignificant labial inclination in the non-affected side. Furthermore, significant - labial inclination before/after traction were observed on the non-affected incisor, in the unilateral group - Significant labial inclination of central incisors was observed on both sides (right and left) in the bilateral group, and these values were greater than those observed for the non-affected side on the unilateral group and independently of the sides. - A statistically greater labial inclination was only found for the left side of bilateral cases when compared with the affected side of unilateral cases.
Arriola-Guillén *et al.* (2020) PERU[13]	Retrospective case-control study	To study the transverse changes at the level of maxillary premolars after traction of MICs in adolescents and young adults	45 impacted maxillary canines • 15 unilateral cases versus 15 bilateral cases • 20 palatally versus 25 buccally Age and sex: • 11 males • 19 females • Mean age: 18.83	A 1.2 mm stainless steel palatal arch with multiple palatal-occlusal-vestibular soldered hooks	- CBCT scans of all patients were taken in two moments (before treatment and after MIC traction), - transverse changes was evaluated with inter-premolar width measurements in millimeters in the volumetric reconstructions	NITI closed helicoidal coil springs in 8–13 mm were tied to the button of the impacted canines. Activations of 4–5 mm were performed every 4–8 weeks the canines reached the occlusal plane	- The changes in the maxillary premolar-widths (first and second) after impacted canine traction did not show significant differences between unilateral versus bilateral impactions (P=0.917, P=0.724 respectively) - The changes in hemi-arch widths, exclusively in cases of unilateral impaction between the affected side versus unaffected side (control) showed significant differences at the level of first premolars and at the second premolar level - The unilateral impaction cases could have a greater inter premolars width change than bilateral cases if the orthodontist does not use an adequate anchorage to control the side effects of the MIC traction
Migliorati *et al.* (2021) ITALY[5]	Randomized clinical trial	To compare two different anchorage systems efficiency to disinclude impacted maxillary canines	22 patients divided into 2 groups: G1: 11 patients who received TPA as anchorage G2: 11 patients who received mini-screws as anchorage (8 mm long) Sex and age: • 12 females • 10 males • Mean age 13.4		CBCT before treatment, beginning of traction and 3 months after traction were superimposed and canine tip and root movement were evaluated in mm/month ratio	In G2, a beta-titanium cantilever spring was used to apply three-dimensional vector force.	- No significant differences were found between groups as - Regards apex displacement, - None of the mini-screws were lost and the force of traction did not affect TADs stability, while in TPA group significant molars tipping was clinically observed. - The rate of eruption was in average 1.08 and 1.96 mm in 1 month in the TAD and TPA groups respectively. - No evidence that indirect anchorage on mini-screws could make canine disimpaction faster than anchorage on a TPA.
Ruíz-Mora *et al.* (2021) BRAZIL[14]	Retrospective longitudinal case-control study	To evaluate the 3-dimensional changes in alveolar bone morphology after traction of buccally versus palatally unilateral MICs	27 patients with impacted maxillary canines • 14 palatally • 13 buccally 27 contralateral unimpacted served as control sides • Age and sex: • 15 women • 12 men • Aged between 13 and 39	1.1-mm or 1.2-mm stainless steel palatal arch, associated with a palatal acrylic button, and with occlusal-palatal-buccal extensions distal to the lateral incisor and on the proximal sides of premolars and molars	- CBCT scans of 27 patients were obtained before and after canine traction.	NITI closed coil springs of 8 and 13 mm long were used for transalveolar traction of the impacted canines. This system was used to extrude the impacted maxillary canines only	- The traction time in months was similar between - Groups. Sex and age influence these alveolar dimensional changes. - After palatally MIC traction, the buccal, mesial, and distal alveolar heights showed statistically significantly greater decreases (2.52–2.79 mm), and the cervical and mesial widths showed significant increases (0.74–1.36 mm) on the affected side, as compared with the non-affected side - After buccally MIC traction, the palatal, buccal, mesial, and distal alveolar heights showed statistically significantly *greater decreases* (0.28–0.57 mm), and the cervical width showed a significant increase (1.26 mm) on the affected side, as compared with the non-affected side - The anchorage system presented in this study allowed biomechanical control of the magnitude, direction, and x-, y-, and z-axes sense of force. It has a reduced fabrication cost and avoids the use of mini-implants. Thus, it could be considered as an alternative for institutional public health or when the use of mini-implants is refused by patients or are difficult to obtain
Rodríguez-Cárdenas *et al.* (2021) BRAZIL[15]	Retrospective case-control study	three-dimensionally compare the root angulation changes after orthodontic traction of buccally versus palatally MICs	33 patients with 45 MIC selected and divided into 2 groups • 19 buccally • 26 palatally Age and sex: • 16 male mean age 20.38 y • 17 female, mean age 18.37	Stainless steel palatal arch associated with a palatal acrylic button with multiple palatal- occlusal-vestibular soldered hooks	CBCTs taken at pretreatment (T0) and after orthodontic traction (T1)	NITI closed coil-springs were used to deliver physiologic force to the impacted maxillary canines	- The average times of orthodontic traction in the buccal and palatal groups were 9.00±2.69 and 7.67±3.45 months, respectively - The distribution of sex and sector of impaction didn't show any significance difference between both groups (P>0.05) - Intergroup comparison (buccal vs. palatal) showed that the palatal group presented significantly greater mediolateral up righting, medial displacement of the root towards the midsagittal plane, when compared to the buccal. The buccal group showed greater anteroposterior up righting, anterior root displacement, than the palatal group - These findings could indicate that the greater movement of the palatal MIC roots requires an increase in anchorage and greater control of root angulation in their traction process, and this should be carefully considered in cases of bilateral palatally MICs

BOP: Bleeding on probing, GI: Gingival index, VAS: Visual analogue scale, TADs: Temporary anchorage devices, CBCT: Cone-beam computed tomography, MICs: Maxillary impacted canine, RR: Root resorption, NITI: Nickel-titanium, TSAD: Temporary skeletal anchorage devices

current temporary orthodontic anchorage devices such as mini-screws have a potential advantage in terms of 3D absolute anchorage, but the canine traction protocol using mini-screws is not yet perfectly codified.

Conventional anchorage device: A transpalatal arch (TPA).[8-15]

Transversal dimension

Arriola-Guillén *et al*. studied the inter-premolar width changes after traction of MICs using a reinforced conventional anchorage device (transpalatal arch).

The results of this study showed a similar maxillary premolar expansion change that occur without differences between impaction type (unilateral or bilateral) or impaction location (palatal vs. buccal). These comparable results may be explained by the importance of using a heavy anchorage helping to control the Newton's third law.

Moreover, in cases of unilateral impaction, transversal asymmetry mainly in the affected side was reported after traction of MICs. These changes on the affected side were greater regarding the unaffected side (2 mm of expansion vs. <1 mm, respectively, $P < 0.05$). In other words, despite the use of a reinforced transpalatal arch, the authors still noted a loss of transversal anchorage mainly in the unilateral impaction cases.[13]

Sagittal dimension

Chávez-Alvarez *et al*. focused mainly on quantifying the sagittal position change of the incisors after canine traction since it could influence the soft profile and smile esthetics.

It has been pointed out that for each millimeter of change in central incisors position, 0.5 mm change occurs in the upper lip. In non-extraction treatment, canine disimpaction could promote a protrusion of the incisors in a range of approximately 2–3 mm, values that are within acceptable limits of orthodontic treatment.

In the unilateral impaction group, protrusion of central incisors was significant on the non-affected side, while significant greater labial inclination was found independently of the sides in the bilateral group.

Therefore, it is important to evaluate the initial position of the incisors in the diagnosis phase to determine if the patient's profile accepts or not some dental protrusion especially in cases who already have a greater labial inclination of maxillary incisors before treatment.

The results of this study show that, despite the use of a reinforced conventional anchorage for MIC traction, significant inclination and protrusion of maxillary incisors occur, likewise, and a loss of sagittal anchorage.[12]

Vertical dimension

Vertical anchorage control plays an essential role in the management of impacted maxillary canines, anchorage loss is often observed when the traction biomechanics is not respected or not well-planned. It results clinically in the appearance of an anterior or lateral open bite, a mesial tipping of the maxillary molars, which consequently leads to occlusal plane changes and bad treatment results.

TPAs and Nance appliances have routinely been used as adjuncts to enhance the anchorage of the first molars when treating MICs:

A study performed by Migliorati *et al*. (2021) showed that the orthodontic traction of MICs using TPA as anchorage device results in a significant mesial tipping of the first permanent molars. However, this study did not quantify the molars movement nor the amount of anchorage loss in the vertical dimension.[5]

This could explain why, in other studies[10,11,14,15] the authors incorporated a palatal acrylic button to the transpalatal arch, where the anterior palatal vault is used as additional anchorage. The result of these studies did not mention any anchorage loss in the vertical dimension nor molar movement. However, further studies must be done in this line of research to draw more concrete conclusions.

Besides, it has been widely found that a transpalatal arch that connects the upper first molar, experiences intrusive forces produced by the activity of the tongue during deglutition and mastication. At the same time, the extrusive force on the impacted canines produces a reactive intrusive force and a moment that results in a mesial tipping of the molars. This is the reason why the effectiveness of the transpalatal arch remains doubtful.[21-23]

Furthermore, a study performed by Tepedino *et al*. (2018), where they used a transpalatal arch to maintain anchorage during an orthodontic traction of palatally impacted canines. The authors compared different vertical skeletal and muscular pattern of 26 patients (hyper/hypo/normo-divergent) to expect an effect of tongue pressure on the device placed in the palatal vault, and that this effect could be different as the vertical skeletal and muscular pattern changes.

However, results from the present study revealed that no effect on the extrusion of the canine, therefore they concluded that palatally impacted canines can be successfully treated using transpalatal arch regardless of the patient's vertical skeletal and muscular pattern.[17]

Unfortunately, the present study did not specify the change of the FMA angle to assess the vertical anchorage when using a transpalatal arch.

3D cuspid root angulation and alveolar changes

Rodríguez Cárdenas Y.A *et al*. (2021) studied the 3D changes concerning root angulation of buccal versus palatal impacted canines after orthodontic treatment. The anchorage system used in their sample is a conventional fixed transpalatal arch. Using CBCT images, significant root angulation in all senses was observed after traction, with a greatest root inclination towards the midsagittal plane in the palatally impacted maxillary canines than the buccally impacted ones. This reflected a significant convergence of the root towards the midsagittal plane with traction.[15]

Clinically, these findings indicate that the orthodontic traction of palatally impacted maxillary canines requires an increase in anchorage and a great control of root angulation during their traction process.

Therefore, the result of this study showed that even though the use of a transpalatal arch as a heavy anchorage system, a lack of control of root movement is observed and the management of root angulation remains difficult to obtain.

Unfortunately, this study focused only on the relative changes occurring on the impacted canine's root.[15] However, we clearly see the limits of a conventional anchorage device.

Besides, a study performed by Ruíz-Mora *et al*. using CBCT images shows that the orthodontic traction of palatally impacted maxillary canine produced significant changes in width and alveolar height.[14]

A greater alveolar height reduction observed in the traction of palatally MIC compared with buccally MIC; which probably occurred as a side effect of the complex crown-root movement on the X-, Y-, and Z-axes until the achievement of an adequate buccal and occlusal position.[14]

The result of this study indicates that, even though the use of reinforced anchorage side effects in the adjacent structures remains.

Side effects: Root resorption

Brusveen *et al*. in their study compared the amount of apical root resorption of the incisors adjacent to the impacted canines with the incisors on the contralateral side using periapical radiographs. They used posterior teeth as anchorage, via a specially constructed transpalatal arch, that allows moving firstly the canines away from the roots of the incisors to disrupt the aggressive resorptive process.[8]

The study concluded that treating unilateral MIC using reinforced transpalatal arch as anchorage, does not seem to influence the amount of orthodontic apical root resorption of the maxillary incisors.[8]

These findings reinforce the results obtained by Silva *et al*. who used CBCT images to prove that there is no statistically significant difference in the root length measurements of canines and adjacent teeth from impacted group compared with control group. Meanwhile, on the other hand, buccally or palatally displaced canines that suffered traction presented reduced bone levels compared with their contralaterals.[9]

Using the same anchorage device, Arriola-Guillén *et al*. in their work compared root resorption of maxillary incisors before and after orthodontic treatment of impacted unilateral or bilateral maxillary canines; they concluded no significant differences, the resorption in both groups did not exceed 2 mm and 5 mm^2, which is clinically not relevant. The reduced amount of root resorption was mainly due to using heavy anchorage to retrieve direct dental support and the technique used to keep more distance between the impacted canines and the roots of adjacent teeth.[10]

In another study performed by Arriola-Guillén *et al*. they included in their sample high complexity cases: Bicortical canine impaction with close proximity or physical contact with adjacent teeth, where root resorption was observed before starting canine traction. The result of this study showed that root resorption is not apparently a risk factor when efficient biomechanics with optimal forces is used.[11]

Treatment time

Potrubacz *et al*. (2018) demonstrated in their study that transpalatal arch associated with a cantilever system to be efficient and easy to activate in a predictable way. The orthodontic extrusion was performed in a mean time of 3.5 months. The result of this study correlates with the work of Tepedino *et al*. with a mean extrusion time of 3.6 months.[16,17]

Treatment time was correlated to patient age; the younger patient, the shorter the time required to extrude the canine, despite its position. No association between indexes of impacted canine position and time required for orthodontic extrusion was detected in this study.

In addition, an effect of patient sex on treatment time was also observed: There was a shorter treatment time in the boys. This could be explained by the different timing of skeletal maturation between the sexes. Findings for the transpalatal arch characteristics are shown in [Table 8].[16]

Skeletal anchorage

Skeletal anchorage such as mini screws are temporarily fixed to the bone to enhance orthodontic movement, either by supporting the reactive unit (indirect anchorage) or by obviating the need for it (direct anchorage), and is subsequently removed after use. They avoid patient compliance and are easy to place.[24]

Kocsis *et al*. studied the orthodontic traction of unerupted maxillary canines using 1.5 mm LEONE TM mini-screws as anchorage in a sample of 69 canines. The sample included buccally, palatally, unilateral, and bilateral impaction with different level of impaction.

A total success of 88.41% was reported with a mean traction time of 6.8 months. This study proved that the use of skeletal anchorage as a reactive unit can be noteworthy with no anchorage loss reported. The authors in this study used mini-screws and nickel-titanium (NITI) closed-coil spring to guide the canine to its normal eruption path by producing sagittal and vertical forces, then conventional fixed multi-bracked therapy was performed. In other words, the mini-screws were not used in a 3D approach.

In addition, Heravi *et al*. in their study inserted two mini-screws of 8 mm in length and 1.4 mm in diameters in the palatal region for each impacted maxillary canine before the initiation of the orthodontic treatment. Then, the traction force was applied through a palatal cantilever spring of TMA to obtain extrusive and distal forces on canines.[7]

In this study, the cantilever spring was activated to verticalize and expose the canine's crown in the oral cavity, by applying a force mainly extrusive. Afterward, vestibularization of the erupted canine was completed using NITI overlay.[7] The result of this study shows that skeletal anchorage allows controlled movement of the impacted tooth in the vertical and sagittal dimension without the need to bracket the maxillary arch until canine disimpaction.[7] However, no 3D forces using skeletal anchorage were used to treat MIC.

So, is the use of mini-screws sufficient to guide the canine into its rightful position in the arch by applying 3D forces?

Table 8: A summary of the transpalatal arch characteristics.

Transpalatal ARCH	
Sagittal dimension	**Upper molar tipping protrusion of the incisors**
Transversal dimension	Inter-premolar width changes after traction
Vertical dimension	Mesial upper molar tipping occlusal plane changes
3D Cuspid root angulation	Anteroposterior angulation of the root after traction (buccally impacted canine) Significant root angulation toward the midsagittal plane (palatally impacted canine)
3D alveolar changes	Significant changes in width and alveolar height
Root resorption	±
Stability	--
Extrusion mean time	3.5 months

Migliorati *et al*. in their study used 8mm long mini-screw as anchorage in a "canine first" approach where no anchorage preparation was performed. The traction biomechanics included a beta-titanium cantilever spring applying 3D forces on the canines. Mini-screws insertion sites varied depending on the impacted canine position (palatally and buccally).

The results of this study reported no anchorage loss and no significant differences concerning apex and tip displacement of the canines. However, the aim of this article was restricted only on disincluding impacted maxillary canines and not placing them in their correct position in the arch, thus a completion of the study in a larger follow-up is required to confirm the efficiency of the mini-screw anchorage technique.[5]

Daniel CHILLES and Jean-Gabriel CHILLES presented in 2009 an original anchorage system to bring impacted maxillary canines into proper position using two short mini-screws (5 mm long and 2 mm in diameter) placed buccally in cortical bone. The traction biomechanics consisted of an 18 TMA round wire that emerges at the muco-gingival line to exert 3D control on the canine without any dental support.

The skeletal anchorage system proposed is autonomous, it requires the involvement of no other teeth or appliances for anchorage and it moves impacted canines directly into their correct position following the sagittal, transversal, and vertical dimension. The summary of miniscrews characteristics are presented in [Table 9].[25]

Nevertheless, the results of these two studies are not sufficient to conclude the clinical outcome of applying 3D forces on impacted maxillary canines using skeletal anchorage. Further studies must be carried in this path of research.

In addition, complications can arise during mini-screw placement or after orthodontic loading in regard of stability. Cases of failure were identified mainly related to soft tissue irritation and infection due to plaque accumulation, mini-screw bending, or fracture due to increased torsional stress. All precautions should be taken to avoid root injury during drilling or screw insertion. This is why mini-screws of smaller diameter are used in a tooth-bearing area to prevent damage to dental roots.[6]

Asscherickx *et al*. demonstrated that dental roots damaged by orthodontic mini-screws have complete repair of tooth

Table 9: A summary of mini screws characteristics

Mini-screws	
Sagittal dimension	++
Transversal dimension	++
Vertical dimension	++
Root resorption	--
Stability	±
Traction mean time	3 months

and periodontium in 12–18 weeks after removal of the mini-screw.[26]

Limits of the review

The objective of our systematic review was to provide scientific evidence on the efficacy of 3D anchorage devices in the orthodontic traction of MIC by performing a comparison between conventional anchorage appliances such as transpalatal arch and skeletal anchorage for example mini-screws.

Thirteen clinical studies with various anchorage strategies and objectives fulfilled our inclusion criteria, and were included in our paper. However, limitations in our study should be acknowledged.

When comparing the result of the many articles included, true pairing was difficult to achieve due to the different characteristic of each patient. The biomechanics used in the orthodontic treatment was not quite comparable mainly due to variables related to the patient's age, severity of malocclusion, the bone density around the impacted canines, the different locations of the canines, the possibility of extraction, and the clinician's experience… All these parameters could influence our final interpretations in terms of canine displacement speed and treatment efficacy.

CONCLUSION

Maxillary canines play an important aesthetic and functional role; therefore, treatment is essential. The impaction of maxillary canines is considered one of the most frequently encountered surgical-orthodontic problems, characterized with variable axial inclination, and location; they can lead to resorption of neighboring teeth especially lateral incisors, mesial migration of the adjacent premolars, altering the dental intercuspidation and favoring the occurrence of malocclusion.

Frequently, the absence of the permanent canine in the dental arch after its normal eruption timing, leads clinicians to suspect canine impaction. The diagnosis is confirmed only by a clinical evaluation of the patient and a radiographic assessment. Nowadays, the use of CBCT improves diagnostic capabilities as well as the chances of success in difficult cases.

Orthodontic management of impacted canines typically involves surgical exposure and guided orthodontic eruption; it requires the formulation of an adequate treatment strategy. Both patients and clinicians must be aware of the expected duration of treatment, predictable degree of success and side effects that may occur during treatment.

The anchorage method plays a crucial role in the success and guided control of the direction of canine eruption. A transpalatal arch (TPA) corresponds to a custom rigid palatal anchorage, ordinarily used to stabilize the upper arch during canine traction and eruption. It helps to protect adjacent teeth and soft tissues against the effects of action/reaction forces. Owed to its reduced fabrication cost, this device could be considered as substitute for institutional public health or when the use of mini-implants is refused by patients or are difficult to obtain.

TADs such as mini-screw represent an alternative method for anchorage strategy when confronted to impacted maxillary canine; they have become popular because of their ease of placement and removal, as the well as their minimal demand for patient compliance.

The result of our systematic review shows that, anchorage management using mini-screws is very beneficial clinically; they remain comparatively stable in the bone, as they increase anchorage capacity with fewer adverse effects on adjacent teeth or complications that could hinder treatment outcomes. However, concerning their 3D efficacy further studies must be carried in this path to draw more concrete conclusions. Meanwhile, studies proved transpalatal arch to present more side effects and anchorage unpredictability.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

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