

Success Rates of Different Traction Methods for Impacted Canines

Chotwit Khunpradit

Private Dental Practice, Phuket, Thailand

Abstract

AIM: To compare the clinical success rates, biomechanical efficiency and biological safety of orthodontic traction methods for impacted maxillary canines by synthesising available clinical and finite element evidence to inform optimal treatment selection.

METHODS: A systematic literature review of PubMed was performed for clinical and finite element method (FEM)-based studies published from 2000 to 2025. Inclusion criteria required quantitative data on eruption success, force application, root resorption and treatment duration. Sixteen studies met the criteria and were analysed using thematic synthesis and comparative tables.

RESULTS: Traction methods using temporary anchorage devices (TADs), TMA cantilevers, corticotomy-assisted protocols and double-wire techniques demonstrated consistently high success rates (up to 100%) and superior biomechanical control. These approaches were associated with reduced root resorption, improved anchorage stability and shorter treatment duration. Conversely, Kilroy springs and clear aligners exhibited biomechanical limitations and generated elevated stress on adjacent teeth. Patient factors, notably age, impaction depth and compliance, were significant predictors of outcome. FEM studies supported the mechanical advantages of TAD-based and corticotomy-assisted strategies when combined with three-dimensional planning.

CONCLUSION: Individually tailored traction strategies informed by CBCT imaging and biomechanical planning achieve the most favourable outcomes. TAD-based systems and corticotomy-assisted approaches are particularly effective in adult or complex cases. Further randomised controlled trials using standardised force systems and outcome metrics are needed to strengthen clinical guidelines for impacted canine management.

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1 Introduction

Dental impaction refers to a tooth's failure to erupt into its functional position within the expected developmental timeframe, despite full or nearly complete root formation. Tooth eruption generally begins once approximately 75% of the root is formed; if the tooth remains unerupted at this stage, an obstruction whether anatomical, pathological, or mechanical is often suspected (Proffit et al., 2018).

Among permanent teeth, maxillary canines are the second most commonly impacted, with a prevalence ranging from 0.8% to 4.7% depending on the population (Stabryła et al., 2021; Fekonja, 2024). Palatal impactions are more frequently observed in Caucasian populations, while labial impactions are more common in Asian populations (Lee et al., 2018).

The pathophysiology of palatally impacted canines is multifactorial. A prominent explanation is the "guidance theory", which suggests that anomalies or absence of the maxillary lateral incisor eliminate the normal eruption path for the canine. Without the distal surface of the lateral incisor to guide it, the canine deviates medially and superiorly, resulting in a palatal position (Becker, 2012). Genetic predispositions, developmental disturbances, and local mechanical factors such as retained primary teeth, supernumerary teeth, or odontomas also play roles in impeding eruption (Becker, 2012).

Importantly, Becker classifies palatally impacted canines into six groups based on their horizontal distance from the dental arch and vertical height relative to the occlusal plane. These groups provide a framework for prognosis and determine the optimal surgical and orthodontic strategies. For example, Group 1 (close to the arch, low height) offers the best prognosis, whereas Group 6 (far from the arch, high position) presents the greatest difficulty and risk (Becker, 2012).

Diagnosis relies heavily on clinical palpation and radiographic imaging, especially CBCT, to assess the canine's location, angulation, and proximity to adjacent roots. Root resorption of lateral incisors is a frequent complication of delayed diagnosis (Ericson & Kuroi, 1988).

Management strategies for impacted canines depend on several factors, including the degree of displacement, space availability, and patient age. In early-diagnosed cases, interceptive techniques such as extraction of the primary canine or palatal expansion may facilitate spontaneous eruption. Favorable cases have shown success rates ranging from 65% to 78% following timely interceptive intervention (Stabryła et al., 2021; Becker, 2012).

For moderate to severe impactions, surgical-orthodontic traction becomes necessary. Two principal surgical exposure techniques are employed. Open eruption, typically for labial impactions, involves removing gingival and osseous tissue to expose the crown, allowing natural or assisted eruption. Closed eruption, preferred for palatal impactions, includes flap elevation, bonding of an attachment to the impacted tooth, and flap repositioning. This method offers improved aesthetics, better periodontal outcomes, and easier hygiene maintenance (Cassina et al., 2017).

To facilitate traction, multiple biomechanical methods have been developed. Segmental, cantilever springs, ballista loops, and Kilroy springs deliver low continuous forces through stainless steel or TMA wires, enabling controlled movement and moment generation (Başer et al., 2023; Malhab et al., 2023; Sezici et al., 2020). NiTi closed-coil springs have also been shown to apply consistent physiological forces, and are frequently used in daily practice (Xia et al., 2022).

While elastomeric materials are frequently used for their simplicity, they suffer from rapid

force decay and lack the ability to maintain moment vectors, limiting their effectiveness in 3D mechanics (Torres-Rosas et al., 2023). The introduction of temporary anchorage devices (TADs) has provided absolute anchorage, reducing undesired tooth movement and improving directional force control (Kocsis & Seres, 2012).

Corticotomy has emerged as a biologically supported adjunct to improve movement efficiency. Based on the Regional Acceleratory Phenomenon (RAP), described by Frost (1983), corticotomy has been shown to reduce treatment duration without compromising periodontal outcomes (Mousa et al., 2023).

Success in canine traction is assessed by the successful eruption and alignment of the impacted tooth, preservation of periodontal and root integrity, aesthetics, and treatment duration. Failures may result from poor force control, ankylosis, severe displacement, or advanced patient age, where success rates may fall below 70% (Becker & Chaushu, 2003).

Despite the numerous options available, there is no consensus on the most effective approach to impacted canine management. Heterogeneity in study designs, force systems, and outcome definitions impedes direct comparison. Few high-quality randomised trials assess biomechanics, periodontal health, or long-term stability under uniform conditions (Stabryła et al., 2021; Lee et al., 2018).

The aim of the study is to compare the success rates, movement velocity and biological safety (root resorption, periodontal damage and anchorage loss) of different orthodontic canine-traction modalities for retrieving impacted maxillary canines and synthesise evidence on long-term stability.

2 Methods

A comprehensive electronic search was conducted using the PubMed database to identify eligible studies on the management of impacted canines.

The PICO elements were defined as follows: Population: Patients with impacted maxillary canines; Intervention/Exposure: Orthodontic retrieving methods (e.g. cantilever spring, Kilroy spring, NiTi closed coil spring, TAD, corticotomy, etc.); Comparison: Comparative evaluation across different orthodontic and surgical traction modalities; Outcomes: Eruption success rate, velocity of tooth movement (mm/month), periodontal health, root resorption, anchorage stability, and treatment duration.

The electronic search was restricted to articles published between January 1, 2000 and April 1, 2025 and to full-text articles written in English the following search strategy was employed in PubMed: ("impacted tooth" OR "unerupted tooth") AND ("Maxilla") AND ("orthodontic traction" OR "forced eruption" OR "canine extrusion") AND ("NiTi spring" OR "cantilever" OR "TAD" OR "aligner" OR "corticotomy" OR "anchorage").

Studies were included if they were clinical or FEM-based investigations involving orthodontic traction of maxillary impacted canines studies that reported measurable outcomes such as eruption success, velocity of movement, or root/periodontal response were included. Only in vivo human studies (retrospective, prospective, or pilot trials) with full-text availability in English were considered.

Non-English language articles, animal studies, and purely in vitro studies lacking clinical correlation were excluded. Case reports and narrative reviews without original data or defined outcomes were also excluded.

Study selection was conducted in three phases: titles and abstracts were screened for rel-

evance, full texts of potentially eligible studies were assessed against the predefined inclusion and exclusion criteria, and disagreements regarding eligibility were resolved through discussion with the academic supervisor. In total, 245 records were identified through the initial database search, of which 33 full-text articles were retrieved and assessed; 13 studies met the eligibility criteria and were included for data extraction and qualitative synthesis, and a further 3 relevant articles were identified by manual searching of reference lists (**Figure 1**).

A standardized data extraction form was developed in Microsoft Excel and variables such as author(s), year of publication, country, study design, sample size, traction method or appliance used, magnitude and type of orthodontic force applied, treatment duration, eruption velocity (mm/month), success rate, complications (e.g. root resorption or ankylosis), and assessment tools (e.g. CBCT, FEM simulation) were extracted. Data extraction was performed independently and verified by the primary reviewer, and owing to heterogeneity in methodology, outcome measurement, and force systems, a quantitative meta-analysis was not performed and a qualitative narrative synthesis was conducted.

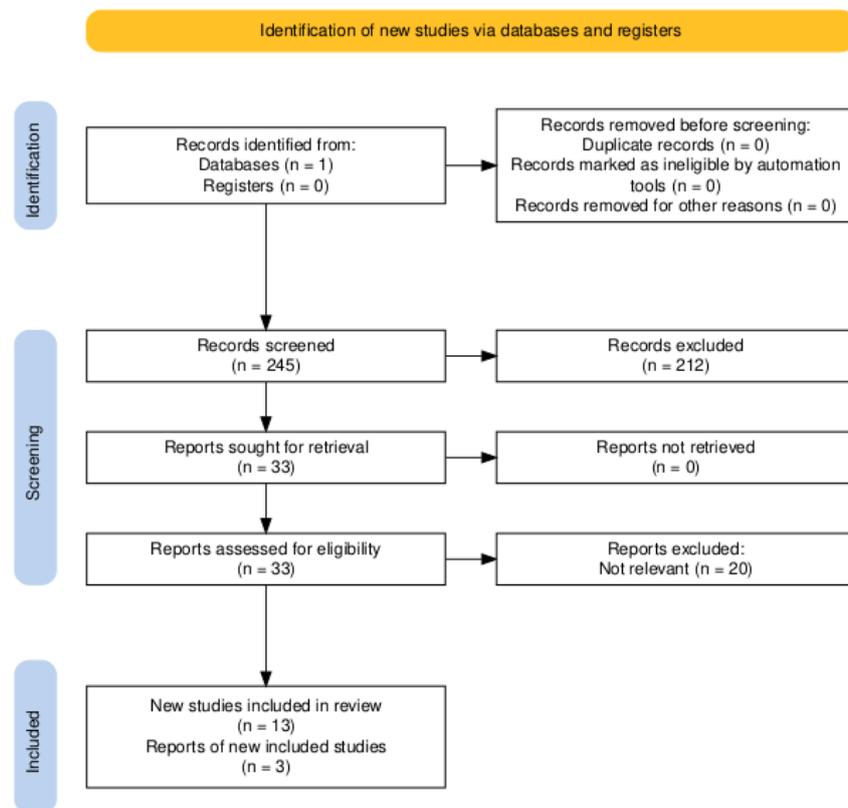


Figure 1. Prisma flow diagram of article selection.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3 Results

A comprehensive review of sixteen studies investigating the traction of impacted maxillary canines reveals ten distinct orthodontic methods employed to facilitate eruption. The commonly used method involves nickel-titanium (NiTi) closed-coil springs, which deliver continuous, light forces, and were prominently analysed by Sezici et al. (2020) and Schubert (2008) using both FEM and clinical approaches. Another widely used approach is the Kilroy spring, a loop-activated device designed for vertical extrusion with controlled moment delivery, featured in studies by Sezici et al. (2020) and Tepedino et al. (2018). Similarly, the Ballista spring, known for its palatal mechanics and rotational properties, was evaluated by Başer et al. (2023) using 3D FEM analysis.

Several studies, including those by Kocsis and Seres (2012) and Migliorati et al. (2021), utilised temporary anchorage devices (TADs) or miniscrews to achieve absolute anchorage and reduce side effects such as anchorage loss or reciprocal tooth movement. The segmented-arch technique, which allows isolated force application to the impacted canine, was studied through nonlinear FEM modelling by Malhab et al. (2023). A related approach is the cantilever system, typically made of titanium-molybdenum alloy (TMA), which was investigated in depth by Tepedino et al. (2018).

Double-wire mechanics, utilising a superelastic CuNiTi wire over a stabilising base arch-wire, were shown by Fekonja (2024) to significantly reduce traction duration and appointment frequency while maintaining effective and consistent force application. In contrast, clear aligners, favoured for their aesthetic appeal, were evaluated in a finite element analysis (FEM) by Yadav et al. (2020), which revealed biomechanical limitations in force vector control and stress distribution compared with traditional fixed appliances. Complementing these mechanical approaches, biologically driven acceleration methods such as corticotomy-assisted traction have gained attention. A randomised controlled trial by Mousa et al. (2023) reported that minimally invasive corticotomy substantially increased the rate of impacted canine movement without exacerbating periodontal compromise. Meanwhile, conventional stainless-steel ligatures and power chains, though lacking precision in force modulation, remain common in adolescent treatment protocols, as demonstrated by Becker and Chaushu (2003) and Yang et al. (2020), owing to their clinical familiarity and simplicity.

3.1 Biomechanics, stress distribution and anchorage control

Orthodontic traction methods for impacted canines differ significantly in their biomechanical behaviour, particularly in stress distribution, anchorage control and moment generation. As summarised in **Table 1**, each appliance offers unique strengths and limitations. Kilroy springs, for instance, generate high stress at the cervical third of the impacted canine root, increasing the risk of root resorption when moment control is inadequate. Finite element modelling (FEM) has shown that stress values in the cervical region with Kilroy springs are nearly twice as high as those observed with NiTi closed-coil springs. In contrast, NiTi springs deliver forces more apically along the root surface and demonstrate a safer biomechanical profile, with reduced stress on adjacent structures (Sezici et al., 2020).

Ballista springs exhibit oblique force vectors and concentrate stress at the buccal apex, potentially compromising mechanical stability and increasing localised periodontal risk, as reported by Baser et al. (2023). TMA cantilever springs, particularly when combined with a transpalatal arch (TPA), offer greater control over moment generation and force direction. Tepedino et al. (2018) noted that this configuration can generate both extrusive

and rotational forces, facilitating physiologic canine eruption.

The segmented-arch technique, while useful for isolating force to a specific tooth, may inadvertently redirect excessive stress to adjacent premolars if anchorage is not adequately managed. Malhab et al. (2023) observed such stress concentrations in FEM analyses. Similarly, clear aligners, though advantageous in terms of aesthetics and patient comfort, have been shown to exert eight to 11 times more stress on adjacent teeth compared with fixed appliances, reflecting inferior vector control and potential unintended side effects (Yadav et al., 2011).

Among the available options, TAD-supported NiTi spring systems exhibit highly favourable biomechanical characteristics. Migliorati et al. (2021) demonstrated that these systems enable direct and localised force application with absolute anchorage control, minimising unwanted side effects such as molar tipping or anchorage loss.

Additionally, the Double Wire technique, which incorporates a superelastic CuNiTi wire over a stainless steel base arch, has shown clinical benefits, including improved arch-form control and more consistent force delivery compared with active ligation systems. According to Fekonja et al. (2024), this method also reduced the need for frequent reactivation, although it was not evaluated through FEM modelling.

In summary, while appliances such as Kilroy or Ballista springs may be effective in generating traction, they carry increased biomechanical risks due to stress concentration and uncontrolled moments. In contrast, TAD-supported systems, TMA cantilevers and Double Wire mechanics appear to offer superior biomechanical efficiency and clinical control, making them preferable for safe and effective management of impacted canines.

Table 1. Comparison of traction methods on stress distribution and anchorage control.

Traction Method	Stress Distribution	Anchorage Control	Evidence Type
<i>Kilroy Spring</i>	<i>High cervical stress; risk of resorption</i>	<i>Requires precise moment control</i>	<i>FEM</i>
<i>NiTi Closed-Coil Spring</i>	<i>Apically directed; lower stress on adjacent teeth</i>	<i>Moderate; depends on appliance positioning</i>	<i>FEM</i>
<i>Ballista Spring</i>	<i>Concentrated at buccal root apex; oblique vectors</i>	<i>Less stable; higher risk without additional anchorage</i>	<i>FEM</i>
<i>TMA Cantilever (with TPA)</i>	<i>Controlled force with rotational moment via TPA</i>	<i>High when combined with TPA</i>	<i>FEM</i>
<i>Segmented Arch Technique</i>	<i>May overload adjacent premolars if unbalanced</i>	<i>Anchorage sensitive; prone to stress redirection</i>	<i>FEM</i>
<i>Clear Aligners</i>	<i>High stress on adjacent teeth (8–11 × fixed)</i>	<i>Poor control; deformation limits force precision</i>	<i>FEM</i>
<i>TAD-Supported NiTi Spring</i>	<i>Localized, optimal distribution; minimal side effects</i>	<i>Absolute control with miniscrew anchorage</i>	<i>Clinical (CBCT)</i>
<i>Double Wire (CuNiTi + Base Archwire)</i>	<i>Not FEM-modeled; clinically more physiologic and stable</i>	<i>Enhanced via dual-arch stabilization</i>	<i>Clinical</i>

3.2 Success rate in canine retrieval

A synthesis of success rates across multiple studies reveals a consistent trend favouring techniques that integrate skeletal anchorage or biologically facilitated mechanics. **Table 2**

presents a consolidated summary of outcomes.

TAD-supported techniques yielded high success rates. Kocsis and Seres (2012) reported 88.4% in their retrospective study, and Migliorati et al. (2021) reported an implied 100% alignment in a CBCT-based evaluation. Similarly, Potrubacz et al. (2018) reported 100% success using physiologic-force cantilevers, and Mousa et al. (2023) achieved 100% success in an RCT evaluating corticotomy-assisted mechanics. Fekonja (2024) also achieved complete success (28/28 canines) using a double-wire system, with added clinical advantages such as reduced reactivation and fewer appointments. Schubert (2008) showed a slightly lower success rate of 95.6% using Easy-Way-Coil springs, with two ankylosis-related failures.

In contrast, Becker and Chaushu (2003) demonstrated a marked decline in success among adult patients treated with conventional mechanics: only 69.5% compared with 100% in adolescent controls, highlighting age as a critical factor.

Overall, skeletal anchorage, biologically aided movement (e.g., corticotomy), and controlled force systems (cantilevers, double wires) result in superior alignment outcomes. Patient-specific factors such as age, impaction depth, and root morphology remain pivotal in case selection.

Table 2. Comparison of traction methods on success rate of canine retrieval.

Method	Success Rate	Notes
<i>TAD with NiTi spring</i>	88.4% (61/69)	<i>Adult patients included</i>
<i>TAD + NiTi spring with CBCT</i>	<i>Implied 100%</i>	<i>CBCT-confirmed root/crown displacement</i>
<i>TMA Cantilever</i>	100%	<i>Low-force system (0.6 N)</i>
<i>Corticotomy-assisted</i>	100%	<i>Fastest mean movement rate (RCT)</i>
<i>Easy-Way-Coil (EWC)</i>	95.6% (43/45)	<i>2 failures due to ankylosis</i>
<i>Double-wire system</i>	100% (28/28)	<i>Fewer reactivations & shorter duration</i>
<i>Conventional (Adults vs Adolescents)</i>	<i>Adults: 69.5%, Adolescents: 100%</i>	<i>Age-dependent outcomes</i>

3.3 Velocity of impacted canine movement

Velocity of canine movement varies substantially by method (**Table 3**), force type and patient profile. Corticotomy-assisted techniques provided the fastest movement rates; Mousa et al. (2023) reported an average of 1.15 mm/month, which was 39% faster than traditional traction. TAD-based systems also showed strong performance: Kocsis and Seres (2012) reported 0.9–1.2 mm/month using NiTi springs, and Migliorati et al. (2021) observed CBCT-confirmed rates of 1.08–1.96 mm/month at the crown and 0.44–0.84 mm/month at the apex.

Fekonja (2024) did not provide exact monthly velocities but reported treatment durations that were approximately six weeks shorter with the double-wire system than with active ligatures, indicating increased efficiency. Potrubacz et al. (2018) noted accelerated movement using cantilevers in younger patients, though without quantified velocities.

Conversely, Becker and Chaushu (2003) revealed that adult patients treated conventionally required an average of 12.1 months for alignment, more than double the 5.5 months observed in adolescents, emphasising the impact of age on velocity. FEM-based models by

Tepedino et al. (2018) and Yadav et al. (2020) confirmed qualitative differences in force systems, with aligners demonstrating slower, less efficient force delivery compared with fixed appliances or spring systems.

In summary, the highest movement velocities are achieved with corticotomy and TAD-based techniques. Age, anchorage type and force application method all significantly influence treatment time. CBCT offers the most precise velocity tracking and should be used to standardise future comparisons.

Table 3. Comparison of traction methods on canine movement velocity.

Method	Velocity (mm/month)	Method	Notes
<i>Corticotomy-assisted</i>	<i>1.15 mm/month</i>	<i>Clinical observation (RCT)</i>	<i>+39% faster with corticotomy, statistically significant (P=0.027)</i>
<i>TAD + NiTi spring</i>	<i>0.9–1.2 mm/month</i>	<i>Clinical records</i>	<i>Traction averaged 3.5 months; velocity estimated</i>
<i>TAD + NiTi spring with CBCT</i>	<i>Crown: 1.08–1.96, Apex: 0.44–0.84 mm/month</i>	<i>CBCT superimposition</i>	
<i>Double-wire vs active ligature</i>	<i>~6 weeks shorter</i>	<i>Treatment duration comparison</i>	<i>Double-wire required fewer visits; implied faster movement</i>
<i>Cantilever (0.6 N)</i>	<i>Faster in young patients (not quantified)</i>	<i>Retrospective observation</i>	
<i>Clear aligner vs Kilroy spring (FEM)</i>	<i>Aligners slower (qualitative)</i>	<i>Clinical duration from exposure to debond</i>	<i>Aligner produced lower stress and less movement</i>
<i>Conventional (Adults vs Adolescents)</i>	<i>Adults: 12.1 mo, Adolescents: 5.5 mo</i>	<i>Clinical record-based timing</i>	

3.4 Effect on impacted canine and complications

Based on finite element modelling by Sezici et al. (2020), Kilroy springs produce high cervical stress on the impacted canine root, requiring careful moment control to avoid root resorption. In contrast, NiTi closed-coil springs apply a gentler, apically directed force with minimal associated risk, representing a biomechanically safer alternative (**Table 4**).

Baser et al. (2022) investigated the Ballista spring, which demonstrated stress concentration at the buccal apex. Although effective, the spring's oblique vector may pose a moderate risk of apical damage if not properly directed.

According to Tepedino et al. (2018), the TMA cantilever, especially when supported by a transpalatal arch, provides a controlled extrusive moment and maintains physiologic movement with a lower risk of root resorption, provided anchorage is adequately maintained.

Xia et al. (2021) analysed clear aligners, reporting that they produce less controlled force systems and generate eight to 11 times more stress on adjacent teeth compared with fixed appliances. This biomechanical inefficiency increases the risk of uncontrolled tipping and lateral incisor trauma. Additionally, Malhab et al. (2023) examined the segmented arch technique, which delivers focused force to the impacted canine but can redirect excessive stress to premolars if anchorage is insufficient.

Schubert (2008) evaluated the Easy-Way-Coil® system, showing high clinical success;

however, two cases of ankylosis were reported, suggesting a rare but notable complication.

Clinical CBCT-based studies by Migliorati et al. (2021) supported the use of TAD-based NiTi springs, which provide stable and localised force with excellent anchorage control and no observed damage to root structure or pulpal vitality. Kocsis and Seres (2012) reported an 88.4% success rate using a TAD + NiTi spring system, with no resorption observed. Minor complications included occasional mini-screw failure, but overall treatment outcomes remained favourable.

Grenga et al. (2020) explored piezo-assisted closed traction, which yielded safe periodontal outcomes and effective canine repositioning within approximately six months without any reported complications.

Finally, Fekonja et al. (2024) assessed the double-wire (piggyback) archwire system, which provided sustained and stable force delivery, greater efficiency, and fewer reactivations compared with active ligation methods. Meanwhile, Malhab et al. (2022) noted that adding a TPA with auxiliary springs can enhance vector control, although excessive force may lead to molar tipping if not properly managed.

Table 5 provides a comparison of how retraction methods affect the impacted canine and associated complications.

Table 4. Effect of traction methods to impacted canine and complications.

Traction Method	Effect on Impacted Canine	Notable Complications
<i>Ballista Spring</i>	<i>Stress concentrated at buccal apex; moderate risk</i>	<i>Possible apex damage if direction uncontrolled</i>
<i>Piggyback Archwire (Double-wire)</i>	<i>Sustained force with good efficiency; fewer visits</i>	<i>Minimal risk; better force stability</i>
<i>Piezo-assisted Closed Traction</i>	<i>Safe periodontal outcome; reposition in ~6 months</i>	<i>None reported; periodontal health maintained</i>
<i>TAD + NiTi Spring (Kocsis)</i>	<i>88.4% success rate; no resorption or vitality loss</i>	<i>Mini-screw failure in some cases</i>
<i>Segmented Arch Technique</i>	<i>Focused force on canine; but stress shifted to premolars</i>	<i>May overload premolars if not balanced</i>
<i>TPA + Auxiliary Spring</i>	<i>Stabilizes arch and improves vector control</i>	<i>TPA may cause molar tipping if overloaded</i>
<i>TAD-based Traction</i>	<i>Stable movement with good control; minimal damage</i>	<i>No root resorption or vitality loss reported</i>
<i>Easy-Way-Coil (EWC)</i>	<i>High success; risk of ankylosis in rare cases</i>	<i>2 cases of ankylosis reported</i>
<i>Kilroy Spring</i>	<i>High cervical stress in FEM models; force requires careful moment control</i>	<i>Risk of root resorption due to cervical stress if unbalanced</i>
<i>NiTi Closed-Coil Spring</i>	<i>Gentle and controlled movement; minimal resorption</i>	<i>Very low complication rate</i>
<i>Cantilever (TMA)</i>	<i>Controlled moment; lower risk of resorption</i>	<i>Generally safe with proper design</i>
<i>Clear Aligner</i>	<i>Forces less controllable; higher stress on adjacent teeth</i>	<i>High stress on adjacent teeth (8–11×); uncontrolled tipping</i>

3.5 Other variables that effect success rate of canine retrieval

Successful orthodontic traction of impacted canines depends on an interplay of clinical, anatomical and biomechanical variables. **Table 5** shows that patient age is among the most consistent predictors of success: adolescents typically achieve near-complete alignment rates, whereas patients over 30 years of age exhibit significantly reduced success because of increased bone density and decreased cellular responsiveness (Becker & Chaushu, 2003). The depth and angulation of impaction also significantly affect outcomes; greater vertical height or mesial angulation correlates with prolonged treatment duration and a higher risk of failure (Fekonja, 2024). Additionally, root morphology, particularly the presence of dilacerations, can hinder mechanical efficiency and increase the likelihood of surgical or orthodontic complications (Stabryla et al., 2022).

From a biomechanical perspective, light, continuous forces in the range of 0.3–0.6 N are considered optimal for safe and effective tooth movement. Forces exceeding 1 N have been associated with periodontal ligament compromise and an increased risk of root resorption (Yadav et al., 2011; Sezici et al., 2020; Tepedino et al., 2018). The mode of force delivery is also critical: cantilevers and NiTi coil springs allow for superior control and directional precision compared with elastic chains or aligners, which tend to generate diffuse or uncontrolled vectors and impose stress on adjacent teeth (Sezici et al., 2020).

Anchorage control is another essential component of successful traction. The use of temporary anchorage devices (TADs) enables absolute anchorage, preventing molar mesialisation and maintaining consistent force directionality (Heravi et al., 2016). Additionally, the moment-to-force ratio (M/F ratio) is a fundamental biomechanical parameter: systems capable of generating appropriate counter-moments enable precise crown and root movement (Tepedino et al., 2018).

The surgical exposure technique further modulates treatment outcomes. Closed-eruption and piezo-assisted surgeries are associated with superior periodontal preservation, minimal gingival scarring and better aesthetic results compared with open-eruption techniques (Grenga et al., 2021). Root proximity to adjacent teeth, particularly lateral incisors, has also been linked to an elevated risk of root resorption because of localized pressure zones during traction (Heravi et al., 2016; Yang et al., 2020).

Emerging adjunctive procedures, such as corticotomy, have demonstrated efficacy in accelerating movement, reducing treatment time by up to 39% without compromising safety or outcomes (Mousa et al., 2023). The presence of ankylosis, though rare, is another critical factor. In cases described using the Easy-Way-Coil® system, early detection via CBCT or absent movement after activation may signal the need to revise or discontinue traction (Kocsis & Seres, 2012).

Finally, patient compliance with hygiene, elastic wear and scheduled appointments is a critical modifier of treatment success. Even the most biomechanically optimised systems, such as cantilevers or TAD-based appliances, cannot overcome the negative impact of irregular attendance or poor cooperation. Studies show a significant increase in both treatment duration and the number of required visits in more challenging cases, underscoring the importance of consistent patient engagement (Becker & Chaushu, 2003). In sum, successful traction of impacted canines requires careful attention to both mechanical precision and biological context. Optimal outcomes are best achieved through individualised planning that addresses anatomical risk factors, force-system selection and collaborative surgical–orthodontic integration.

Table 5. Variables influencing impacted canine traction success.

Category	Variable	Effect on Success
<i>Patient Factor</i>	<i>Age</i>	<i>Older age reduces bone responsiveness and lowers success rate</i>
<i>Anatomical Factor</i>	<i>Depth and Angulation of Impaction</i>	<i>Deeper or mesially angulated impactions increase difficulty and risk</i>
<i>Anatomical Factor</i>	<i>Root Morphology (e.g., dilaceration)</i>	<i>Dilacerated or complex root shapes impede movement</i>
<i>Anatomical Factor</i>	<i>Proximity to Adjacent Teeth</i>	<i>Increased risk of resorption and reduced vector control near lateral roots</i>
<i>Biomechanical Factor</i>	<i>Force Magnitude</i>	<i>Optimal range ~0.6 N; >1.5 N increases root and PDL damage risk</i>
<i>Biomechanical Factor</i>	<i>Force Continuity and Type</i>	<i>Continuous light forces are more biologically favorable</i>
<i>Biomechanical Factor</i>	<i>Moment-to-Force Ratio (M/F)</i>	<i>Balanced M/F ratios enhance control over tooth movement</i>
<i>Anchorage Strategy</i>	<i>Use of Temporary Anchorage Devices (TADs)</i>	<i>Prevents molar anchorage loss and improves force delivery</i>
<i>Force System Design</i>	<i>Appliance Type (e.g., NiTi vs aligner)</i>	<i>Cantilevers/NiTi more effective than aligners or chains</i>
<i>Surgical Technique</i>	<i>Closed or Piezo-assisted Surgical Exposure</i>	<i>Enhances periodontal healing and improves aesthetics</i>
<i>Anatomical Risk</i>	<i>Root proximity to lateral incisor</i>	<i>Crowding near incisors elevates resorption risk during traction</i>
<i>Adjunctive Technique</i>	<i>Corticotomy</i>	<i>Accelerates movement (~39% faster); safe adjunct</i>
<i>Pathology Detection</i>	<i>Ankylosis</i>	<i>Early detection essential to revise or abandon traction if fused</i>
<i>Patient Behavior</i>	<i>Compliance with appointments and elastics</i>	<i>Noncompliance significantly reduces predictability and outcomes</i>

4 Discussion

The selection of orthodontic materials plays a critical role in the biomechanical control and biological safety of impacted canine traction. As the objective in such cases is to apply continuous, physiologic forces with minimal tissue damage, the mechanical behaviour and degradation profile of each material must be carefully considered.

Among current materials, nickel–titanium (NiTi) has been repeatedly validated as the most effective for long-range activation. Its superelasticity and shape memory allow it to deliver consistent forces in the biologically optimal range of approximately 50–80 grams, aligning with the periodontal ligament’s adaptive threshold (Fekonja, 2024; Higa et al., 2016). This force consistency is particularly advantageous in complex canine impactions, where force needs to be maintained over longer intervals and through angular deviations (Sezici et al., 2020).

In contrast, titanium–molybdenum alloy (TMA) provides a clinically useful balance between flexibility and form stability. Owing to its lower modulus of elasticity compared to stainless steel, TMA is preferred in cantilever mechanics, where controlled moment-to-force ratios (M/F) are critical (Tepedino et al., 2018). Studies have shown TMA’s ability to

sustain extrusion and tipping forces in impacted canine treatment while reducing the risk of anchorage loss (Migliorati et al., 2021). Its capacity for directional control makes it especially relevant in segmented-arch or TAD-supported systems.

While stainless steel remains popular for its affordability and strength, its rigid mechanical profile limits its use in applications requiring subtle, biologically compatible forces. Its low deflection and springback properties make it more suited for passive stabilisation than active traction unless precisely modulated (Fekonja, 2024; Higa et al., 2016).

Significant limitations are associated with elastomeric power chains, particularly regarding force degradation and lack of directional control. Empirical studies consistently demonstrate rapid force decay up to 50% within the first 24 hours and over 70% within a week as a result of viscoelastic relaxation, intraoral moisture, pH variations and exposure to acidic beverages (Nattrass, 1998; Torres-Rosas et al., 2023). Additionally, elastomers lack the structural stiffness to deliver meaningful moments or maintain force vectors over time, rendering them suboptimal for 3D control in palatal impactions (Yadav et al., 2020; Torres-Rosas et al., 2023).

From a biological standpoint, material selection also impacts corrosion resistance, plaque accumulation and patient hygiene. NiTi and TMA demonstrate superior performance in these domains, maintaining stability over extended durations. In contrast, elastomers are prone to discolouration, biofilm formation and surface degradation, particularly in long-term use (Torres-Rosas et al., 2023).

These findings reinforce the view that NiTi springs and TMA cantilevers remain the materials of choice in the retraction of impacted canines, offering both mechanical consistency and biological compatibility. Elastomeric chains, while useful in short-term or auxiliary scenarios, should be applied with caution, particularly in adult patients or cases requiring extended anchorage.

Future research may benefit from the integration of digital force monitoring or smart-wire systems that can be adjusted by clinicians, are easy to handle and enable real-time tracking of force delivery and degradation. Such innovations could allow clinicians to adjust mechanics dynamically in response to each patient's biological tolerance and tissue response, ultimately improving treatment efficiency and safety.

4.1 Corticotomy in adults

Impacted canine treatment in adult patients presents unique challenges, particularly due to diminished biological responsiveness. Age-related changes such as reduced bone turnover, increased cortical bone density and lower periodontal plasticity often lead to prolonged treatment durations and lower alignment success compared to younger individuals. As demonstrated by Becker and Chaushu (2003), adults achieved only a 69.5% success rate in impacted canine retrieval, compared to 100% in adolescents, underscoring the limitations of conventional force mechanics in biologically mature patients (Becker and Chaushu, 2003).

To overcome these constraints, corticotomy-facilitated orthodontics has emerged as a biologically targeted adjunct that enhances treatment efficiency. This approach leverages the Regional Acceleratory Phenomenon (RAP), a localized, transient increase in bone remodelling and vascularity following surgical injury first described by Frost (1983) in the orthopaedic literature. The RAP facilitates reduced bone resistance, allowing for more rapid tooth movement. The concept was adapted to orthodontics by Wilcko et al. (2001), who introduced Accelerated Osteogenic Orthodontics (AOO), combining alveolar decortication

with fixed-appliance therapy. Their protocol produced treatment durations of 6–9 months, significantly shorter than conventional non-extraction protocols.

The benefits of corticotomy have since been confirmed through clinical trials and systematic reviews. In a randomised controlled trial, Mousa et al. (2023) found that corticotomy-assisted eruption of palatally impacted canines reduced traction time from 9.7 to 6.1 months, and total treatment time from 20 to 14 months, without increasing the risk of root resorption or periodontal compromise. Similarly, Baeshen et al. (2020) concluded in a systematic review that corticotomy reduced treatment duration by 2.2–3 times compared to conventional approaches, while maintaining periodontal safety.

From a clinical standpoint, corticotomy enables the use of light, continuous forces aligning with biological force thresholds while maintaining velocity. This is especially beneficial in adult patients with dense cortical bone, complex impaction trajectories or high aesthetic expectations. Furthermore, advances in technique such as flapless or piezoelectric corticotomy have improved patient acceptance and reduced postoperative morbidity, with most discomfort resolving within one week (Baeshen et al., 2020).

However, corticotomy is not without limitations. As noted by Khlef et al. (2023), patients may still experience mild to moderate pain and swelling, and concerns remain about its invasiveness, cost and the need for surgical expertise (Baeshen et al., 2020). Moreover, long-term data regarding root stability, periodontal health and relapse rates are limited, and patient-reported outcomes are underrepresented in the current literature.

In summary, corticotomy presents a biologically sound, clinically effective adjunct in the orthodontic management of impacted canines, particularly in adult patients with limited biological responsiveness. When applied with proper case selection and surgical technique, corticotomy enhances treatment predictability, reduces overall duration and minimises reliance on high-force mechanics. Nevertheless, further research is warranted to clarify long-term safety, define evidence-based protocols for optimal implementation and to determine whether this will become the gold standard for impacted canine treatment in all patients.

4.2 Temporary Anchorage Devices

The implementation of Temporary Anchorage Devices (TADs) has markedly advanced the biomechanical control of impacted canine traction. Historically, conventional approaches relied on molar anchorage following full-arch bonding, which inherently introduced biomechanical compromises, including increased friction, reciprocal tooth movement and inadvertent stress on adjacent structures—particularly lateral incisors—an effect known to contribute to root resorption (Heravi et al., 2016). TADs, in contrast, offer absolute skeletal anchorage, allowing force to be applied directly and precisely to the impacted canine without disturbing the broader arch system (Migliorati et al., 2021).

Clinical studies strongly support this biomechanical advantage. Kocsis and Seres (2012) demonstrated that TAD-supported traction resulted in high alignment success with minimal molar movement and anchorage loss. Migliorati et al. (2021), using CBCT-based superimposition, provided detailed validation of three-dimensional root and crown movement trajectories during TAD-based traction, confirming predictable directional control. Importantly, Heravi et al. (2016) showed that initiating canine disimpaction with TADs prior to full-arch mechanics significantly reduced root resorption of adjacent lateral incisors compared to traditional transpalatal arch anchorage, underscoring the periodontal benefit of isolating force systems.

These clinical outcomes are reinforced by finite element method (FEM) analyses. Xia et al. (2022) reported that molar-based and aligner-based anchorage systems produced higher stress concentrations on adjacent teeth, elevating the risk of root resorption. Complementing these findings, Kocsis and Seres (2012) showed that TAD-supported vertical and distal traction vectors significantly minimised stress propagation to the lateral incisor root.

Beyond anchorage benefits, Papadopoulos (2006) noted that TADs can be safely loaded immediately under light orthodontic forces (≤ 2 N), expediting workflow and enhancing treatment efficiency. However, Papadopoulos also highlighted technical limitations: insertion in non-keratinised mucosa is associated with increased inflammation risk, and implant failure rates are higher when the diameter is < 1.2 mm or when placed in areas with insufficient cortical bone.

These observations point to important clinical considerations and limitations. While TADs offer clear biomechanical superiority, their success is technique-sensitive and dependent on precise surgical placement, adequate hygiene and anatomical factors such as bone density and soft tissue thickness. Patient compliance and comfort may also influence stability, particularly in younger individuals. Furthermore, despite promising short-term results, long-term data on periodontal health and root integrity following TAD-first protocols remain scarce.

From a research standpoint, further prospective trials comparing TAD-first to traditional full-arch strategies are needed. Standardisation in force measurement, timing of loading and outcome metrics, including patient-reported experiences, would help define best practices. Additionally, innovations such as bioactive surface coatings, digital planning integration and minimally invasive delivery systems may further refine the clinical utility of TADs.

4.3 Aligners

Clear aligners are increasingly selected by patients due to their aesthetic appeal, comfort and ease of hygiene (Rossini et al., 2014). However, their use in impacted canine traction is limited by biomechanical inefficiencies. Compared to fixed appliances, aligners lack the rigidity and archwire anchorage necessary to deliver precise force systems and moment-to-force ratios required for controlled extrusion or complex directional movement.

Finite element modelling by Xia et al. (2022) revealed that aligners, when used without auxiliaries, produced significantly higher periodontal ligament stress on adjacent anchorage teeth—eight to 11 times greater than for fixed appliances. This stress concentration was especially prominent around lateral incisors, raising concerns about unintended movement and root resorption during impacted canine traction.

Rossini et al. (2014), in their systematic review, concluded that aligners were effective in alignment and minor tipping but performed poorly in controlling extrusion, rotation and torque, particularly in canines and premolars. The average accuracy for canine rotation was only 32%, and extrusion predictability was as low as 30%, compared to much higher rates for intrusion or bodily movements in posterior teeth.

Further, Weir (2017) emphasised that many of these limitations can only be mitigated through significant appliance customisation. Advanced features such as attachments, power ridges, pressure points and the integration of auxiliaries like TADs, interarch elastics or sectional wires are increasingly necessary to enable aligners to handle three-dimensional control of impacted teeth. Without these modifications, aligners are biologically inefficient for initiating movement in deeply impacted canines.

Despite these limitations, aligners may still serve a role in mild labial impactions or as a finishing tool once the canine has been partially aligned by fixed systems or skeletal anchorage. Their removability, comfort and aesthetics make them appealing in later treatment phases, particularly for patients with high cosmetic demands.

In conclusion, clear aligners should not be considered a standalone tool for impacted canine traction, especially in complex or palatal impactions. Their role should be limited to selective, favourable cases or used as part of a hybrid strategy that leverages skeletal anchorage and auxiliary mechanics to overcome biomechanical shortcomings.

4.4 Biomechanical trade-offs in impacted canine eruption

The biomechanical goal of impacted canine traction is to achieve efficient movement while preserving periodontal health and root integrity. However, faster eruption rates often come at a biological cost, particularly when high-force systems are employed. Devices such as Kilroy springs, elastic chains and certain power-assisted mechanics are capable of producing rapid canine movement exceeding 1.1 mm/month, as reported by Sezici et al. (2022). Despite these results, FEM and clinical data consistently associate these higher forces with increased stress concentrations in the cervical third of the root and the periodontal ligament (PDL), creating conditions favourable for hyalinisation and external root resorption (Sezici et al., 2022).

In contrast, light, continuous force systems such as NiTi closed-coil springs, TMA cantilevers and TAD-supported setups demonstrate more favourable biological behaviour. These methods typically maintain movement velocities around 0.6–0.8 mm/month and deliver forces within the PDL's physiological pressure threshold (approx. 10–15 kPa) (Potrubacz et al., 2018). Tepedino et al. (2018) specifically demonstrated that TMA cantilevers anchored with a transpalatal arch could deliver both extrusive and rotational moments while preserving periodontal integrity, emphasising the utility of moment-to-force control in physiological movement.

This trade-off underscores the need for case-specific treatment planning. In adult patients with dense cortical bone, increasing force alone may not yield efficient results and could increase biological risk. Instead, corticotomy-facilitated orthodontics offers an alternative: by enhancing local bone turnover through the regional acceleratory phenomenon (RAP), Mousa et al. (2023) demonstrated that treatment time could be reduced by nearly 40% without increased risk of root resorption. Such biologically based strategies allow for improved efficiency without compromising periodontal safety.

Conversely, in high-risk patients, including those with thin roots, reduced bone support or close proximity to adjacent roots, biomechanically conservative systems should be prioritised even if treatment duration is extended. Zeno et al. (2018) used finite element modelling to show that buccal and oblique force vectors applied through flexible archwire systems transmitted high stress concentrations to adjacent lateral incisors and premolars with relatively smaller root surface areas and limited tolerance to orthodontic stress.

These findings collectively argue for a risk-adaptive approach to canine traction. Rather than adopting a one-size-fits-all strategy based solely on velocity, clinicians should weigh anatomical constraints, tissue tolerance and long-term periodontal goals. Ultimately, achieving controlled, biologically compatible movement, even at the cost of slower progress, remains the hallmark of successful impacted canine management.

4.5 Retrieval vs. Extraction in Impacted Canines

Managing borderline impacted canines requires nuanced clinical judgement, integrating anatomical, biomechanical and radiographic indicators to determine whether retrieval is feasible or whether extraction is the more biologically sound choice. In favourable cases, retrieval success is significantly higher when the impacted canine demonstrates mesial angulation less than 45°, a vertical distance from the occlusal plane of less than 14–15 mm, and no radiographic evidence of adjacent root resorption. These parameters, as defined by Ericson and Kurol (1988), provide a reliable guideline for early intervention and are especially predictive when combined with skeletal anchorage or segmental mechanics to optimise force direction and control.

When anatomical markers suggest increased difficulty—such as angulation exceeding 75–90°, vertical impaction depths greater than 18 mm, or the presence of root resorption—the likelihood of successful orthodontic alignment diminishes significantly. Further complicating factors include ankylosis, dilacerated or malformed roots, transposition and ectopic eruption outside the alveolar envelope (Becker & Chaushu, 2003). In these situations, the benefits of retrieval must be weighed carefully against the risk of prolonged treatment, periodontal damage or irreversible harm to adjacent teeth.

Ericson and Kurol's sector classification system offers a practical framework for prognostic evaluation. When the canine cusp tip lies mesial to the lateral incisor root apex or the tooth axis crosses the midline, retrieval becomes increasingly complex and unpredictable, even with modern anchorage systems (Ericson & Kurol, 1988). These features help define “borderline” cases—those for which traditional orthodontic correction may be possible but not predictably safe or efficient.

In such scenarios, alternative management strategies may provide better long-term outcomes. Autotransplantation can be considered in growing patients with immature roots, while decoronation may be appropriate for ankylosed teeth to preserve alveolar bone. In adult patients or those with poor eruption potential, canine substitution with premolars or prosthetic replacement (e.g., implants) may offer a more stable and aesthetic solution (Ericson & Kurol, 1988).

Ultimately, the decision to retrieve or extract should extend beyond anatomical feasibility alone and include considerations of long-term periodontal health, patient preferences, treatment duration and aesthetics. Advances in 3D imaging and biomechanical planning now allow clinicians to better define risk thresholds and set realistic expectations. In borderline cases, a risk-adaptive, interdisciplinary approach may help guide treatment towards outcomes that prioritise function, stability and patient satisfaction. Further classification for borderline cases also needs to be re-evaluated because modern techniques, such as digital technologies implemented in dentistry, could improve surgical precision to facilitate eruption.

Conclusions

The management of impacted maxillary canines remains a multifactorial clinical challenge that requires careful integration of biomechanical precision, anatomical evaluation and patient-specific considerations. This review indicates that techniques incorporating temporary anchorage devices (TADs), titanium-molybdenum alloy (TMA) cantilevers, corticotomy methods and the double-wire technique consistently outperform conventional mechanics in

both success rates and biomechanical control.

TAD-supported NiTi springs and TMA cantilevers provide precise force direction, minimal stress on adjacent structures and enhanced anchorage stability. The double-wire technique, using a CuNiTi over a stabilising base archwire, offers additional clinical advantages, including more consistent force delivery, reduced need for reactivation and shorter overall treatment duration. Meanwhile, corticotomy significantly accelerates movement in adult patients without compromising periodontal safety, making it a valuable adjunct in biologically less responsive cases.

Conversely, methods such as Kilroy springs and clear aligners, though applicable in select situations, demonstrate biomechanical limitations, including stress concentration, reduced control over moment vectors and increased risk of root resorption when not precisely managed.

Overall success in canine retrieval is influenced by factors such as age, impaction characteristics, applied force magnitude and compliance. A risk-adapted treatment strategy based on CBCT imaging and sound biomechanical design can optimise outcomes. Further research, such as randomised controlled trials directly comparing different traction methods with standardised force systems, outcome metrics and long-term follow-up, is essential to establish definitive clinical guidelines and enhance evidence-based decision-making in the management of impacted canines.

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Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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Correspondence should be addressed to:

Chotwit Khunpradit, 63/698 Wirat Hongyok Rd., Vichit, Mueang Phuket, Phuket 83000, Thailand

E-Mail: chotwit.k@gmail.com

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