Surgical Orthodontic Management of Impacted Maxillary Teeth in the Esthetic Zone

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Abstract

AIM: This study aimed to investigate differences in aesthetic aspects of gingival conditions, periodontal pocket depths, root lengths, and crown lengths of impacted maxillary central incisors and canines treated with the closed-eruption management technique.

METHODS: This review focused on the closed-eruption approach (CEA) for impacted maxillary central incisors and canines located on the vestibular or palatal sides. A comprehensive literature search was conducted using Electronic PubMed, employing keywords such as "closed-eruption approach", "impacted maxillary incisor", "impacted maxillary canine", and "surgical orthodontic retraction". Additional journals were consulted to gather further information. Out of 45 identified articles, 10 publications from 2007 to 2015 met the inclusion criteria.

RESULTS: After analyzing the 10 eligible articles, results showed detailed descriptions of gingival conditions (e.g., OGH, KT, GC, GM), periodontal pocket depths (PPD), root lengths (RL), and crown lengths (CL) of impacted central incisors and canines following CEA treatment. Notably, distinct outcomes emerged between impacted maxillary incisors (IMIs) and impacted maxillary canines (IMCs).

CONCLUSION: Treating impacted teeth in the aesthetic zone of the maxillary region requires thorough comprehension of surgical procedures. Our findings suggest that the closed-eruption approach (CEA) is a reliable technique yielding favorable outcomes for gingival tissues, PPD, RL, and CL upon completion of treatment.

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1 Introduction

Tooth impaction is one of the common issues encountered routinely in clinical dentistry. Following wisdom tooth impaction, the impaction of maxillary canines and central incisors is among the most frequently impacted teeth (Vilarinho & Lira, 2010; Avinash & Aieshya, 2011). There are many causes of tooth impaction. For example, a lack of space in the alveolar process, trauma, ankylosis, and mechanical barriers—including prominent frena, supernumerary teeth, tumours, odontomes, and local cysts—are included (Sant'Anna et al., 2012). However, local etiological factors may also be involved, including discrepancies between dental arch length and tooth size, prolonged retention or early loss of primary canines, abnormal positions of the tooth germ, ankylosis, cystic or neoplastic formations, root dilaceration, the presence of an alveolar fissure, odontomes, supernumerary teeth, crowding, and traumatic factors (Mesotten et al., 2005; Bishara, 1992; Joshi & Shetye, 1994).

Additionally, the aetiology of tooth impaction has been described as multifactorial, involving genetic and environmental factors associated with insufficient space in the alveolar process, abnormal frena, prolonged retention of deciduous teeth, trauma, ankylosis, supernumerary teeth, tumours, odontomes, and local cysts (Fardi et al., 2011).

When the impacted tooth is presented, potential complications may arise, such as root displacement and resorption, periodontal problems in adjacent teeth, referred pain, and the formation of cysts and odontogenic tumours (Babacan et al., 2010).

Due to the anterior region of the maxilla being regarded as an aesthetic zone, many surgical interventions have been introduced and challenged in order to disimpact the tooth, such as closed-eruption management, open-eruption management, or apical repositioning management. With regard to these types of management, it is quite difficult to make a decision regarding which method could yield a better aesthetic outcome for soft tissue, less bone resorption, good periodontal support, and a lower amount of root resorption of the impacted tooth when it is moved into the occlusion plane.

The aim of this review was to explore any differences in the aesthetics of gingival condition, periodontal pocket depth, root length, and crown length of impacted maxillary central incisors and canines when they are surgically managed and guided into occlusion with closed-eruption management.

2 Methods

For this literature review, articles were accessed through PubMed by using keywords such as "closed-eruption technique," "impacted maxillary incisors," "impacted maxillary canine," and "surgical orthodontic retraction." Moreover, the American Journal of Orthodontics and Dentofacial Orthopedics, the Chinese Journal of Stomatology, and Angle Orthodontist were chosen for this study. Impacted maxillary canines and central incisors with unilateral and bilateral impaction constitute the inclusion criteria for this thesis. Additionally, impacted teeth with incomplete root development are also included in this study.

A total of approximately 45 articles were identified, out of which 10 papers were selected based on their relevance to this study. The research methodologies of these 10 selected papers primarily included multicenter randomized clinical control trials, with 2 papers being case reports. The documents reported related to surgical orthodontic management of impacted maxillary canines and incisors using the closed-eruption approach were extracted and are detailed in this study (Table 1). Furthermore, tooth impaction occurring at ei-

ther the vestibular or palatal aspects within the aesthetic zone of the maxilla serves as an inclusion criterion. The exclusion criteria consisted of impacted teeth associated with ankylosis, infection, abnormal crown shape, or those not located within the aesthetic zone of the maxilla.

Table 1. Summary of studies on impacted teeth, with abbreviations as follows: CnP for Canine (Palatal side), MCIi for Maxillary Central Incisor (Immature), LII for Labial Inverted Impacted Incisor in Mixed Dentition, CnL for Canine (Labial side), CnB for Canine (Buccal side), and MCI for Maxillary Central Incisors.

AUTHOR (YEAR)	SAMPLE SIZE	TOOTH TYPE
Smailiene, 2013	21	CnP
Nicola, 2015	33	CnP
Shi, 2015	30	MCIi
Crescini, 2007 (a)	125	CnP=78, CnL=47
Nicola, 2013	62	CnP
Sun, 2012	14	LII
Shi, 2015	50	MCIi
Pinho, 2012	1	MCI & Cn
Crescini, 2007 (b)	168	CnP=118, CnB=50
Elpis, 2008	1	MCI

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

An impacted tooth is regarded as a tooth that is retained in the jaw without emerging into the oral cavity by its expected eruption time (Favre de Thierrens et al., 2003). An impacted tooth should be monitored or require intervention when the contralateral side has erupted for more than six months, or both central incisors remain unerupted while the lower incisors have erupted for over one year, or there is abnormal tooth eruption that disrupts the correct order (e.g., lateral incisors erupting before central incisors) (Favre de Thierrens et al., 2003).

The closed-eruption approach is a surgical procedure performed for an impacted tooth by raising a flap toward the impacted tooth. Subsequently, the impacted tooth is surgically exposed, and an orthodontic attachment is bonded to the impacted tooth surface. Ligature wire, an elastomeric power chain, or a gold chain is used to pull the impacted tooth into occlusion, after which the flap is sutured back to its original position. In this method, the impacted tooth is drawn with very light force into the occlusal plane (Shi et al., 2015; Parkin et al., 2013; Pinho, 2012; Elpis G et al., 2008; Hunt, 1977).

3.1 Esthetic of gingival condition

There were seven studies conducted concerning the gingival condition after the closed-eruption approach. The gingival condition for this study focused on keratinized tissue (KT), gingival margin (GM), gingival contour (GC), and overall gingival health (OGH).

Generally, gingival tissue comprises 75% para-keratinized tissue, 15% keratinized tissue, and 10% non-keratinized tissue. Keratinized tissue in the aesthetic zone consists of gingival tissue surrounding the cervical area of the teeth; moreover, it is readily visible on the facial aspect of the teeth, measured from the gingival margin to the mucogingival junction (Bouri et al., 2008). The presence of KT plays an important role in maintaining gingival health (Wenstrom et al., 1981). The gingival margin (GM) of the maxilla typically exhibits the same level between the central incisor and canine but resides more apically compared to the margins of the lateral incisors (Seixas et al., 2012). Gingival contour (GC) refers to the gingiva surrounding the neck of the teeth towards the attached gingiva. The underlying bone structure, tooth position, periodontium, tooth form, and design of the cementoenamel junction (CEJ) collectively influence the shape of the GC (Borghetti, 2002; Joly et al., 2010; Lindhe, 2010). Overall gingival health (OGH) is assessed based on the appearance of the gingiva, as depicted in photographs taken after treatment with the closed-eruption approach and orthodontic treatment (Parkin et al., 2015).

3.2 Measurement methods

In order to assess keratinized tissue (KT), gingival margin (GM), gingival contour (GC), and overall gingival health (OGH), various methods were employed across these seven studies, which are described in detail below.

Method 1 The assessment of overall gingival health (OGH) was conducted by two panels (11 orthodontists, 6 men and 5 women; and laypeople, 5 men and 6 women). The authors used photographs taken 3 months post-debonding, which were displayed in a PowerPoint presentation (Microsoft, Redmond, WA) to the two panels (Parkin et al., 2015). To compare which gingival condition was superior, both panels were asked the following question: "Which canine looks best in terms of gum health and canine length?"

Parkin et al. (2015) reported that, using the open eruption technique, the judges, who were orthodontists, scored 50.5%–55.4%, with a mean of 52.9%; laypeople scored 35.5%–37.5%, with a mean of 36.5%. In contrast, for the operated canine using the closed-eruption technique, the orthodontist group rated 51.1%–56.2%, with a mean of 53.7%. However, the laypeople rated 35.7%–37.6%, with a mean of 36.7%.

Method 2 for (KT) There were two studies by Crescini et al. that investigated keratinized tissue (KT) after the closed-eruption approach (Crescini et al., 2007a; Crescini et al., 2007b). Keratinized tissue (KT) was measured after the completion of orthodontic treatment. The method of measurement commenced from the gingival margin to the mucogingival junction, and subsequently, the median position was measured on the buccal aspect of the crown. Lugol's liquid stain was employed to identify the keratinized tissue.

A total of 125 patients were treated with a closed eruption approach (Crescini et al., 2007a). Among these, 78 patients had palatal impaction and 47 had vestibular impaction. The keratinized tissue width at the end of treatment was a mean of 4.5 $\pm$ 1.2 mm, while the control group had 4.2 $\pm$ 0.9 mm. This indicated that the KT of impacted canines was

0.28 mm greater than that of the control group, with statistical significance (p = 0.0028). Moreover, another study involving 168 patients (Crescini et al., 2007b) reported that all impacted canines were successfully moved into occlusion. However, there were two cases where the wire chain broke and necessitated raising the flap for re-bonding the attachment. At the end of treatment, the mean keratinized tissue width was 4.42 ± 1.19 mm. For the outcomes of both studies, KT was 4.5 ± 1.2 mm versus 4.42 ± 1.19 mm; thus, the difference was not statistically significant.

Method 3 for (KT) and (GC) Two studies were noted regarding KT and GC. One study presented a case report involving the impaction of both central maxillary incisors due to supernumerary teeth (Elpis et al., 2008). Another case report discussed the impaction of maxillary central incisors and a canine (Pinho, 2012). Keratinized tissue (KT) and gingival contour (GC) were evaluated using photographs, dental casts, panoramic X-rays, and cephalometric radiographs following the closed-eruption approach.

The results from Elpis et al. (2008) on a boy aged 10 years indicated successful treatment with the closed eruption approach. Gingival contour presented with acceptable results, and keratinized tissue width showed a mild discrepancy between both central incisors. Additionally, Pinho (2012), with cases of both maxillary central incisor impaction and left maxillary impaction, reported an excellent outcome with normal gingival contour, as well as adequate width of keratinized attached gingiva.

Method 4 for (GM) Two studies by Shi et al. focused on the gingival margin of impacted teeth after the closed-eruption approach. Both studies were conducted on unilaterally osseous-impacted maxillary central incisors with immature roots, although they differed in the number of samples. Both studies also assessed the position of the gingival margin after the closed-eruption approach and subsequent orthodontic treatment through radiography, study models, and intraoral photographs (Shi et al., 2015).

3.3 Indicators of gingival health

As described above, overall gingival health (OGH), keratinized tissue (KT), gingival contour (GC), and gingival margin (GM) were assessed as indicators of gingival health (**Supplementary Table S1**).

The position of the gingival margin (GM) was evaluated following the closed-eruption approach and after orthodontic treatment, utilising radiography, study models, and intraoral photographs. Fifty impacted immature maxillary incisors were reported at the conclusion of the treatment period spanning 14–17 months. The position of the gingival margin was compared with the contralateral incisor. In 34 cases (68%), the positions were confirmed as similar to the contralateral incisor; however, 16 cases (32%) were more apical than their contralateral incisors. Specifically, five cases (10%) were 0.5 mm more apical, four cases (8%) were 1.0 mm more apical, four cases (8%) were 1.5 mm more apical, and three cases (6%) were 2.0 mm more apical than the control group (Shi et al., 2015). Furthermore, another study of 30 samples of unilateral osseous impacted immature maxillary central incisors revealed that the gingival margin of the impacted incisors was 0.5 mm higher than that of the contralateral incisors (Xiang Ru Shi et al., 2015).

Periodontal pocket depth (PPD) is recognised as the depth of the gingival sulcus increasing progressively. A diagnosis of periodontitis is made if the periodontal pocket depth

(PPD) is ≥ 4 mm at two or more interproximal sites, or at one site with a PPD ≥ 5 mm (Levin et al., 2012). Four studies have reported on the status of PPD in impacted central incisors and canines in the maxillary arch, employing two methods to analyse PPD.

The primary measurement of periodontal pocket depth (PPD) commenced from the base of the pocket to the gingival margin using a Williams probe. Six points on each root surface were measured: mesio-buccal (MBP), buccal (BP), disto-buccal (DBP), palatal (PP), disto-palatal (DPP), and mesio-palatal (MPP). Among the four studies, three were conducted by Smailiene et al. (2013) with 43 samples, Crescini et al. (2007a) with 125 samples, and Crescini et al. (2007b) with 168 samples.

Photographs, dental casts, panoramic X-rays, and cephalometric radiographs were employed for analysis. This method was applied in a study by Pinho (2012) involving a 14-year-old boy presenting with impaction of both maxillary central incisors and a canine.

Three studies determined the periodontal pocket depth (PPD) according to method 1 (**Table S2**). In summary of method 1, the periodontal pocket depth (PPD) of the impacted tooth after the closed-eruption approach was reported with varying results. The PPD of 21 samples (closed-eruption group) was 2.28 mm (SD, 0.69), while the contralateral side measured 2.20 mm (SD, 0.42) (Smailiene et al., 2013). The PPD of 125 samples was 1.9 ± 0.6 mm, and the contralateral side was 1.7 ± 0.6 mm (Crescini et al., 2007a), while the PPD of 168 samples was 2.54 ± 0.45 mm (range 1.5 to 4.5 mm) (Crescini et al., 2007b).

Smailiene et al. (2013) reported on 43 samples—35 females and 8 males—with unilaterally palatally impacted maxillary canines. Group 1 consisted of 22 samples selected for the open technique, while another Group 2 comprised 21 patients chosen for the closed-eruption approach by the same oral surgeon. Periodontal examinations were conducted for both groups and compared to the contralateral side. For the 22 cases treated with the open eruption approach, the periodontal pocket depth was 2.14 mm (SD, 0.38), and the contralateral side was 1.95 mm (SD, 0.38). In contrast, for the 21 cases treated with the closed-eruption approach, the periodontal pocket depth was 2.28 mm (SD, 0.69), and the contralateral side was 2.20 mm (SD, 0.42). Therefore, the post-treatment outcomes of surgical orthodontic management did not differ significantly between these two groups, the open eruption and closed eruption approaches.

In the study involving 125 impacted canines on both palatal and vestibular sites, all cases were treated successfully (Crescini et al., 2007a). The mean from descriptive statistics reported that the periodontal pocket depth (PD) was 1.9 ± 0.6 mm, while in the control group, it was 1.7 ± 0.6 mm at the end of orthodontic treatment, which had an overall duration of 20.6 ± 4.2 months. None of the patients reported significant pain or loss of the attaching device during treatment.

The study population increased to 168 patients, with 125 cases presenting unilateral impacted canines and 43 cases with bilateral impacted canines. Among these patients, 128 were females and 40 were males, with ages ranging from 12.8 to 52.0 years (mean age 17.2 ± 6.0 years). Descriptive statistics revealed that the mean PD was 2.54 ± 0.45 mm (range 1.5 to 4.5 mm). Seven canines had a PD greater than 3 mm (three canines had PD = 3.5 mm, three canines had PD = 4.0 mm, and one canine had PD = 4.5 mm) (Crescini et al., 2007b).

Only the study conducted by Pinho (2012) utilised method 2; the impaction of permanent central incisors and the left canine was treated very successfully with the closed-eruption approach. Periodontal support was deemed good at the end of the treatment; however, no exact report was provided regarding the depths of periodontal support from this study.

There were two methods for measuring root length after the closed-eruption approach. Two studies employed cone beam computed tomography (CBCT) as determined by method 1. Measuring root length was based on a three-dimensional image of the median sagittal section of the crown and the apical point. The key anatomical landmarks are the labial and lingual cementoenamel junctions (CEJ) and the alveolar crest (toward the nearest level of the alveolar bone) as noted by Shi et al. (2015), who analysed 30 samples (age: 6.5–11.2, mean 8.44 ± 1.20 years). Root development was examined with periapical X-ray every three months, followed by a minimum of 12 months of post-treatment CBCT images of the contralateral maxillary central incisor (control) (Shi et al., 2015).

The root length of the maxillary labial inverted impacted incisor in mixed dentition was obtained from 14 cases (Sun et al., 2012). The closed eruption approach, combined with the Nance arch and a conventional appliance, was introduced for treating the impacted tooth. At the end of orthodontic treatment, CBCT, Simplant 13.0 3D reconstruction, and multiplanar reconstruction (MPR) methods were utilised for measuring the impacted root length and comparing it with the surrounding roots.

One study employed panoramic X-ray, cephalometric X-ray, or periapical X-ray as determined by method 2. Shi et al. (2015) used periapical X-ray to evaluate root development of impacted immature maxillary incisors after orthodontic treatment on 50 samples (age: 6.4–10.4 years). The impacted dilacerated root had formed less than two-thirds of the entire root length (test group), whereas the contralateral maxillary central incisor had already erupted (control group). Additionally, two other studies reported case reports: one from Elpis et al. (2008), regarding both central maxillary incisors impacted due to supernumerary teeth, and another from Pinho (2012), describing a 14-year-old boy who presented with the impaction of both maxillary central incisors and a canine.

There were five studies that demonstrated the results of root length after the closed-eruption approach (**Table 2**). According to Shi et al. (2015), the root length of the impacted central incisor in the developing stage of the test group was 10.66 ± 2.10 mm, while that of the control group was 11.04 ± 1.76 mm. Conversely, Sun et al. (2012) reported that the root length for the test group was 9.82 ± 2.82 mm and for the control group was 10.28 ± 1.38 mm. Furthermore, other studies demonstrated no signs of root resorption with the closed-eruption approach at the end of treatment (Elpis et al., 2008; Shi et al., 2015; Pinho, 2012).

Table 2. Root length of impacted maxillary canines and central incisors treated with closed-eruption approach.

AUTHOR (YEAR)	SAMPLES	TOOTH IMPACTION	ROOT LENGTH / RESORPTION
Shi (2015)	30	Imp. imm. Mx central incisors	Test: 10.7 ± 2.1 mm; Ctrl: 11.0 ± 1.8 mm
Elpis (2008)	1	2 Imp. Mx central incisors	No root resorption
Fan (2012)	14	Labial inv. imp. incisor	Test: 9.8 ± 2.8 mm; Ctrl: 10.3 ± 1.4 mm
Shi (2015)	50	Imm. Mx central incisor	No root resorption
Pinho (2012)	1	3 Imp. teeth: 2 Mx centrals, 1 canine	No root resorption

Imp. = impacted; imm. = immature; Mx = maxillary; Ctrl = control; inv. = inverted; centrals = central incisors.

Concerning the aesthetic zone two studies determined the root length using Cone Beam Computed Tomography (CBCT) according to method 1; there was no statistically significant difference regarding gender in the study. In the study by Shi et al. (2015), 30 impacted immature maxillary central incisors were treated with the closed-eruption approach. Prior to

the initiation of treatment, the root lengths of the impacted incisors were shorter than those of the contralateral incisors, indicating delayed development of the impacted teeth. Upon completion of treatment, the root apices of 28 patients had reached complete development, while the other two were at the same stage as the contralateral incisors. No signs of root resorption or periapical radiolucency were noted. The root length of the impacted incisors after treatment measured 10.66 ± 2.10 mm, whereas the contralateral incisors measured 11.04 ± 1.76 mm. This indicated that the root length of the impacted teeth was 0.46 mm shorter than that of the contralateral incisors. However, there was no statistically significant difference between the two groups ($P = 0.59$). The results from Sun et al. (2012) using the closed-eruption approach combined with a Nance arch and conventional appliance to bring the impacted tooth into ideal occlusion indicated that at the end of orthodontic treatment, the root lengths of the impacted incisors were 9.82 ± 2.82 mm and the homonymous incisor roots were 10.28 ± 1.38 mm.

Three studies assessed the root length using panoramic X-ray, cephalometric X-ray, or periapical X-ray according to method 2. Following the closed-eruption approach, root development of 50 impacted immature maxillary incisors was reported without signs of internal or external resorption, canal calcification, atresia, or stenosis. Moreover, the studies indicated that both groups continued to develop normally based on periapical X-ray views (Shi et al., 2015). This study yielded similar results to those reported by Elpis et al. (2008), who studied the impaction of both permanent maxillary central incisors, and Pinho (2012), who reported successful treatment of the impaction of permanent central incisors and the left canine with the closed-eruption approach.

Crown length (CL) of the impacted tooth is an important and interesting point following the closed-eruption technique. Generally, crown length (CL) can be measured from the midpoint of the incisal edge to the straight gingival margin (Shi et al., 2015). In total, five studies have evaluated crown length (CL) after treatment using different methods.

Three studies utilised study models/dental cases as determined by Method 1. A multicentre, randomised controlled trial conducted by Parkin et al. (2013) recruited 62 patients with unilateral palatally displaced canines (PDC) for the closed and open technique. Twenty-nine patients were treated with the closed-eruption technique and thirty-three with the open eruption technique. Crown heights were measured three months after debonding on the study model. Crown heights were evaluated by comparing the operated and unoperated canines in both the open and closed groups. The height of the operated canines was subtracted from the height of the unoperated canines for all patients. An independent samples t-test was used to compare the differences.

Two studies by Elpis G et al. (2008), involving a boy with both central maxillary incisors impacted due to supernumerary teeth, and Pinho (2012), who presented a 14-year-old boy with impaction of both maxillary central incisors and a canine, were addressed using photographs, dental casts, panoramic X-rays, and cephalometric radiographs following the closed-eruption approach. However, the closed-eruption approach was combined with a removable expansion appliance in Pinho's study.

One study employed intraoral photographs as determined by Method 2. Another multicentre randomised controlled clinical trial from Parkin et al. (2015) presented intraoral photographs of 67 cases (Closed, 33; Open, 34) to two panels of judges (11 orthodontists, 6 men and 5 women; and laypeople, 5 men and 6 women). The three-month debond photographs were presented in a PowerPoint presentation (Microsoft, Redmond, WA) to the panels, and the assessment of crown length was based on the question, "Which canine

length looks best?"

Another study measured clinical crown length as determined by Method 3. Shi et al. (2015) measured and compared the clinical crown height of 30 impacted maxillary immature incisors with the contralateral sides from the midpoint of the incisal edge to the gingival margin along a line parallel to the long axis of the incisors during follow-up with CBCT.

Five studies evaluated the crown length (CL) after treatment combined with the closed-eruption approach (**Table S3**). Three studies determined crown length (CL) using study models/dental casts according to Method 1. The crown lengths of 62 cases—29 patients treated with the closed-eruption technique and 33 with the open-eruption technique—showed different results. The closed-eruption technique resulted in shorter crowns, ranging from 0.0 to 1.0 mm (mean, 0.5 mm) when compared to contralateral canines, while the open approach revealed longer crown lengths, equal crown lengths, and shorter crown lengths ranging from -0.5 to 0.5 mm (mean = 0 mm) when compared with the contralateral side based on the study model 3 months post-debonding (Parkin et al., 2013).

A case report by Elpis G et al. (2008) described the treatment of a 10-year-old boy. The emergence profile of both permanent central incisors exhibited a mild discrepancy at the end of orthodontic treatment. Another case report by Pinho (2012) on a 14-year-old boy with impaction of two maxillary central incisors and a canine reported adequate crown length in relation to the smile line following treatment.

One study determined crown length (CL) using intraoral photographs according to Method 2. In this study, 67 cases were evaluated: 33 cases for closed-eruption and 34 cases for open-eruption. Intraoral photographs were taken for a PowerPoint presentation (Microsoft, Redmond, WA), and participants were asked, 'Which canine length looks best?' The two panels included 11 orthodontists (6 men and 5 women) and laypeople (5 men and 6 women). The results for the closed-eruption group indicated that orthodontists rated it positively at 59.5% (56.8%–62.2%) and laypeople at 43.1% (41.6%–44.6%). For the open-eruption group, orthodontists rated it at 58.8% (56.2%–61.4%) and laypeople at 44.2% (42.7%–45.6%). These results suggest that higher percentages correlate with better clinical crown length (Parkin et al., 2015).

Another study determined crown length (CL) using clinical crown length according to Method 3. Shi et al. (2015) reported results from 30 impacted maxillary immature incisors, with ages ranging from 6.5 to 11.2 years (mean age of 8.44 ± 1.20 years). The impacted incisors exhibited longer crowns than contralateral incisors, with a total clinical crown height of 9.87 mm for impacted incisors compared to 9.37 mm for contralateral incisors. This difference was statistically significant, although it was not clinically significant (P = 0.045).

According to the studies above, the length of impacted canines is equal to or shorter than that of the contralateral side, ranging from 0.0 to 1.0 mm (mean = 0.5 mm) as observed with the closed-eruption approach (Parkin et al., 2013). Additionally, the closed-eruption approach exhibited better CL compared to the open-eruption approach (Parkin et al., 2015). However, the results were not significantly different.

In summary, the results for the maxillary impacted central incisors indicated that they were 0.5 mm longer than the contralateral side (Shi et al., 2015), exhibited mild discrepancies (Elpis G et al., 2008), and were favourable in relation to the smile line (Pinho, 2012).

4 Discussion

This study focused on tooth impaction in the aesthetic zone of the maxillary arch. The maxillary canine and maxillary central incisor are commonly observed as the impacted teeth following wisdom teeth, which was the rationale for their inclusion in our study. Furthermore, the selection of surgical methods for impacted maxillary teeth is crucial for achieving aesthetic results. According to a study by Vilarinho and Lira (2010), the closed-eruption technique plays an important role in the aesthetic zone. Conversely, Robert et al. (2010) reported that the closed-eruption approach (CEA) could mitigate scarring in the aesthetic zone, particularly in cases of buccal impaction. Therefore, the closed-eruption approach was primarily addressed in this study.

Four vital factors were investigated, namely: gingival condition, periodontal pocket depth (PPD), root length (RL), and crown length (CL). The gingival condition after surgical interventions was assessed based on overall gingival health (OGH), keratinized tissue (KT), gingival contour (GC), and gingival margin (GM).

The overall gingival health (OGH) was estimated with the question 'Which canine appears best with regard to gum health and canine length?' The evaluation of the closed-eruption approach by orthodontists showed a preference of 53.7%, compared to 52.9% for the open-eruption approach. Laypeople, on the other hand, rated the closed-eruption approach at 36.7%, compared to 36.5% for the open-eruption approach (Nicola et al., 2015). These results indicated that there were no significant differences between the two approaches within the groups, but a notable difference was observed in the estimates provided by orthodontists and laypeople. The findings from both groups revealed the aesthetic outcomes of OGH for CEA. This discrepancy could arise from the operational technique, as CEA preserved the overall gingival flap, whereas the open-eruption approach (OEA) partially removed gingival tissue.

Regarding keratinized tissue (KT): two studies with different samples evaluated the keratinized tissue of impacted teeth following the closed-eruption approach. In a sample of 125 unilateral impactions (78 palatal and 47 labial), the result for KT was 4.5 $\pm$ 1.2 mm, while the contralateral side measured 4.2 $\pm$ 0.9 mm (Crescini et al., 2007a). In another study involving 168 samples (125 with unilateral impaction and 43 with bilateral impaction), the results indicated that of the total samples, 118 were palatal impactions and 50 were labial impactions. Eventually, the keratinized tissue was measured at 4.42 $\pm$ 1.19 mm (Crescini et al., 2007b). The outcomes of both studies were not significantly different. In light of these results, the KT from both studies is comparable to the KT of normal canine eruption, which was reported as 4.32 $\pm$ 1.33 mm (Egreja et al., 2012). Additionally, adequate KT was obtained from the study by Elpis et al. (2008) involving CEA. In conclusion, this indicates that CEA provided good KT for the impacted tooth at the end of treatment. However, further studies are recommended to differentiate KT between labial and palatal impaction, given that the different locations of tooth impaction may yield varying KT outcomes.

GC: A study on a patient with both an impacted maxillary central incisor (IMCI) and a canine was conducted. The outcome of GC following Closed-Eruption Approach (CEA) was deemed acceptable in the study (Pinho, 2012). The results were not described in detail; however, it was similarly noted that Elpis et al. (2008) observed normal GC at the conclusion of treatment, albeit without systematic data. Both studies did not provide a specific report, necessitating further investigations. Nonetheless, it was stated that GC was acceptable and normal following CEA. Therefore, within the context of CEA, it did not adversely affect the

GC of the impacted tooth post-treatment.

GM: Two studies with differing sample sizes reported varying GM outcomes. One study involved 50 samples, in which 34 cases were confirmed with the contralateral side. Among these, 5 cases exhibited an apical margin 0.5 mm more apical, 4 cases had a margin 1.0 mm more apical, 4 cases presented a margin 1.5 mm more apical, and 3 cases had a margin 2.0 mm more apical than the contralateral side following CEA (Shi et al., 2015). This data indicated a higher percentage of improved gingival margins. Additionally, another publication encompassing 30 samples treated under CEA indicated an apical margin 0.5 mm more apical than the contralateral side (Shi et al., 2015). In summary, both studies suggest that GM after CEA can yield better outcomes. Compared to the normal eruption of the contralateral side, there were minimal percentages causing greater apical gingival margins, ranging from 0.5 mm to 2.0 mm with CEA. These variations in GM could be attributable to the thickness of the cortical labial bone and the biotype of each patient.

Periodontal Pocket Depth (PPD) was analysed using a William probe at six distinct points following the closed-eruption approach (CEA). The result for PPD was 2.28 mm (SD = 0.69) for the palatally impacted canine only (Smailiene et al., 2013). This was not significantly different from the study with 168 canine impactions on the labial and palatal sides, which reported a PPD of 2.54 ± 0.45 mm (Crescini et al., 2007b). Moreover, Smailiene et al. (2013) found that the result was not significantly different from the study of 125 samples, which reported a PPD of 1.9 ± 0.6 mm (Crescini et al., 2007a). All of these research studies revealed improved PPD following CEA, which is consistent with the findings of Quirynen et al. (2000). Although CEA resulted in a favourable PPD, further studies should investigate and differentiate the results of PPD between canine impaction on the palatal and labial sides. Specifically, we seek to understand the depth of periodontal pocket in canines following labial and palatal retraction after closed eruption separately.

There were five studies concerning root length (RL) after the closed-eruption approach (CEA). The results from three studies were particularly interesting, indicating no influence on root resorption of the impacted tooth (Shi et al., 2015; Pinho, 2012; Elpis G et al., 2008). In one study involving 30 impacted immature maxillary central incisors treated with the closed-eruption approach, it was noted that the post-treatment root length in the surgical group was 10.66 ± 2.10 mm, which was comparable to that of the contralateral incisors with normal eruption at 11.04 ± 1.76 mm (Shi et al., 2015). Regarding this matter, another study involving 280 immature incisors found no significant difference between treated patients and untreated patients with orthodontic traction (Mavragani et al., 2002). Furthermore, a study by Sun et al. (2012) treated 14 maxillary labial inverted impacted incisors in mixed dentition, reporting an outcome after the closed-eruption approach of 9.82 ± 2.82 mm for the impacted group compared to 10.28 ± 1.38 mm for the contralateral side, indicating that the impacted group was 0.46 mm shorter than the contralateral control group ($p = 0.59$). This outcome is consistent with the findings of Shi (Shi et al., 2015). Based on these outcomes, it is believed that immature teeth with or without impaction can undergo surgical orthodontic treatment or orthodontic treatment alone while maintaining normal root development. Although the root lengths of impacted teeth remain immature, they can be successfully treated with CEA without negative influences.

Overall, crown length (CL) was estimated by measuring from the midpoint of the incisal edge straight to the gingival margin after CEA (Shi et al., 2015). Five different studies reported varying outcomes regarding crown length. Nicola (2013) claimed that the crown length of impacted canines in the closed-eruption group was shorter than that of the con-

tralateral group (mean difference of 0.5 mm) and was even greater than that of the open eruption group. In contrast, Shi reported that the CL of impacted maxillary immature incisors was 0.5 mm longer than that of the contralateral group ($p = 0.045$) (Shi et al., 2015). Other studies revealed that the CL achieved in these cases resulted in an aesthetically pleasing smile line (Pinho, 2012) and a more attractive CL compared to the open eruption group (Nicola et al., 2013). However, Elpis G et al. (2008) observed a mild discrepancy in CL at the conclusion of their study. In summary, impacted maxillary canines (IMC) on the palatal side appear to exhibit slightly shorter CL than the contralateral side, whereas impacted maxillary central incisors (IMCI) tend to exhibit a slightly longer CL or mild discrepancy compared to contralateral sides among these five studies. The differing results might be attributed to variations in tooth impaction (maxillary central incisor versus maxillary canine) and location (labial impaction versus palatal impaction). Nevertheless, the closed-eruption technique demonstrated a higher positive outcome for CL among these five studies.

Conclusions

Delayed eruption of impacted teeth is a commonly encountered problem during orthodontic treatment. A well-planned multidisciplinary approach should be followed to achieve a successful treatment outcome in such cases. Proper localization of the impacted tooth, the correct choice of surgical technique, and optimal orthodontic forces are key to a good treatment outcome.

According to this study, the technique not only provides aesthetic results but also reveals good periodontal support at the end of treatment, with substantial evidence supporting the closed eruption technique. The closed-eruption technique is a viable method that every surgeon, periodontist, and orthodontist should embrace. All impacted teeth can be brought into the occlusal table with very successful results using this technique. It not only provides aesthetic benefits for the gingival tissue, probing depth, radiolucency but also demonstrates a more positive outcome in clinical length at the end of treatment.

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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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