Corticotomy-Assisted Orthodontics for Canine Distalization: A Systematic Review and Meta-Analysis of Clinical Controlled Trials

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Abstract

Numerous treatment modalities have been developed to expedite orthodontic treatment time, which improves patient compliance and reduces the likelihood of complications. Corticotomy-assisted orthodontia (CAO) is one procedure that was reported to be highly promising. An electronic search of PubMed and Embase in addition to a search of peer-reviewed journals up to December 1st, 2016 was performed. A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Quantitative assessment was performed on the articles that fell within the inclusion criteria. Eight randomized controlled trials (RCTs) were included. Weighted mean differences (WMD) of the amount of canine movement (mm) were calculated between the CAO group (test) and the conventional orthodontic group (control) at different follow-up periods. The WMD of canine movement after 2 weeks was 0.58 mm, and after 1 month was 0.83 mm. In longer follow-ups, the WMD after 2 months was 1.17 mm, and after 3 months was 1.61 mm. Results comparing the test and control groups in all time periods favored the CAO groups for complete canine retraction. No significant adverse effects on the periodontium were reported at any of the treatment phases. CAO facilitates complete maxillary canine distalization up to 3 months, and can reduce the overall treatment time by 50%.

Key words: Orthodontics, acceleration, periodontics, tooth movement technique, canine distalization

Introduction

Over the years, several treatment modalities have been developed to improve the outcomes of orthodontic treatment, particularly the time needed to complete treatment. This does not only improve patient compliance, but also helps to reduce known iatrogenic risks associated with orthodontic tooth movement. Common complications noted in orthodontic cases involving extractions are root resorption and enamel decalcification (Duker, 1975; Hajji *et al.*, 2001). This is particularly true when cases requiring higher levels of load are treated, such as canine retraction (Casa *et al.*, 2001). These cases have a higher tendency for external apical root resorption (Chan and Darendeliler, 2006), in addition to loss of anchorage (Zhou *et al.,* 2015).

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Corticotomy-assisted orthodontia (CAO) is a novel periodontal surgery involving decortication of bone around retracted teeth during orthodontic treatment (Zimmo *et al.*, 2017). This surgery has proven to be effective in reducing loss of anchorage, periodontal complications and total treatment time needed for complex orthodontic cases such as canine distalization (Long *et al.*, 2013).

A corticotomy is a surgical procedure where cuts are made through dentoalveolar cortical bone with some degree of penetration into the medullary spaces (Wilcko *et al.*, 2008). This intentional injury is made adjacent to and around the roots of teeth being planned for accelerated orthodontic movement. In 1959, Kole suggested the "bone block" theory where cuts are made to form a block of bone that can be entirely moved with the contained teeth. He claimed that those cuts would reduce the resistance in the teeth and facilitate tooth movement (Kole, 1959). Thirty years later, Harold Frost investigated the physiologic bone healing response and found its magnitude to be in direct correlation with the severity of the corticotomy, coining the term "regional acceleratory phenomenon (RAP)" (Frost, 1983). Wilcko and co-workers explained the facilitated tooth movement to be attributed to the demineralization-remineralization phenomena secondary to the corticotomy injury. An increase in bone turnover and a decreased bone density occurred (Wilcko *et al.*, 2008). The bone's re-mineralization was from the remaining soft collagenous bone matrix around the teeth after the corticotomy, and they described the facilitated tooth movement as a "bone matrix transportation" theory (Wilcko *et al.*, 2008).

Conventional orthodontic modalities can achieve complete canine distalization in 7 months on average (Pilon *et al.*, 1996). Corticotomy-assisted orthodontia has been found to accelerate the treatment time up to 2 - 3 times compared to conventional orthodontia during the first month (Aboul-Ela *et al.*, 2011; Al-Naoum *et al.*, 2014). Lately, many clinical trials have investigated the use of corticotomy-assisted canine retraction and compared it to conventional treatment. However, there is a lack of systematic analysis of the CAO influence on the canine retraction rate to date. Therefore, this study aimed to investigate the focused questions of whether there is a difference between the rate of canine movement and time needed for treatment completion in conventional treatment versus when CAO is utilized. The study also aims to investigate any negative influence on the periodontium as a result of CAO surgery.

Material and methods

Focused population, intervention, comparison, outcome (PICO) question

"Is there a difference in the rate of canine movement and time needed for treatment completion when corticotomy-accelerated orthodontics is utilized in premolar extraction cases compared to cases treated with conventional orthodontia?"

PICO

- Population: patients undergoing orthodontic treatment for canine distalization.
- Intervention: corticotomy-accelerated orthodontics.
- Comparison: retraction of canine by conventional orthodontia.
- Outcomes:
  - Primary outcomes: the amount of canine movement per month.
  - Secondary outcomes: the effect of CAO on probing depth (PD) and gingival inflammation.

Eligibility criteria

The inclusion criteria of the study were: 1) randomized controlled trials (RCT); 2) 10 or more patients; 3) studies that utilized CAO as the intervention for canine retraction; 4) English publications. In contrast, animal studies, studies other than RCTs, RCTs with sample sizes of less than 10 patients or even systematic reviews were all excluded. Other exclusion criteria included medically compromised patients, smokers, interventions used for canine retraction other than CAO, and non-English publications.

Search strategy

This review was written and conducted according to the PRISMA guidelines (Preferred Reporting Items for Systematic Review and Meta-Analyses). The search for literature in peer-reviewed journals was performed through two different databases (PubMed and Embase) as well as a manual search up to December 1st, 2016. Articles were selected based on the eligibility criteria and the data were independently extracted by two reviewers. Articles not meeting the inclusion criteria were excluded. In an incidence of disagreement, a consensus was reached through discussion.

Screening process

In order to perform the literature search, several key words in combination with the controlled terms (MeSH and EMTREE) were used through two different databases (PubMed and Embase). The key words used in the search process included a combination of the following: wilckodontics, corticotomy, corticotomy-assisted orthodontics, alveolar decortication, corticotomy-facilitated orthodontics, periodontally accelerated osteogenic orthodontics, regional acceleratory phenomena, rapid orthodontics, rapid tooth movement, decortication, tooth movement, piezocision, accelerated tooth movement,

accelerated orthodontic tooth movement, piezosurgery, osteotomy, accelerated osteogenic orthodontics, cortication, canine, cuspid, upper canine, maxillary canine, canine exposure, canine retraction, cuspid retraction, tooth exposure, rapid canine retraction, canine movement, impacted cuspid, impacted canine, palatally impacted canine.

A manual search of peer-reviewed journals was also performed. The search and selection of the articles were done by two independent reviewers. Each reviewer examined the articles' title and abstract, and for those meeting the eligibility criteria, a careful full-text screening was performed. Discussion was conducted to resolve any disagreement.

Data extraction

Data extraction was performed for those articles that met the eligibility criteria (*Figure 1*).

Statistical analyses

The primary outcomes were the rate and amount of canine movement per month. The secondary outcome was the influence of the corticotomy procedure on PD and inflammation of the gingiva. A software program (Review Manager (RevMan), Version 5.0. Copenhagen; The Nordic Cochrane Centre, The Cochrane Collaboration, 2008) was utilized to estimate the weighted mean difference (WMD) of the amount of canine movement (mm) between the corticotomy and control groups. Each article contribution was weighed. Random effects meta-analyses of the selected studies were applied to avoid any bias being caused by methodological differences between studies. Graphical representation utilizing forest plots were produced to show the outcome difference between the CAO and the control group at different time points using the millimeter as the analysis unit. A p value ≤ 0.05 was used as the level of significance. Heterogeneity was assessed with chi-square test and I2 test, which ranges between 0% and 100% and in which lower values represent less heterogeneity. Because of limited data regarding the secondary outcomes, we were unable to perform a meta-analysis for those studies reporting them. The reporting of these meta-analyses adhered to the PRISMA statement (Liberati *et al.*, 2009).

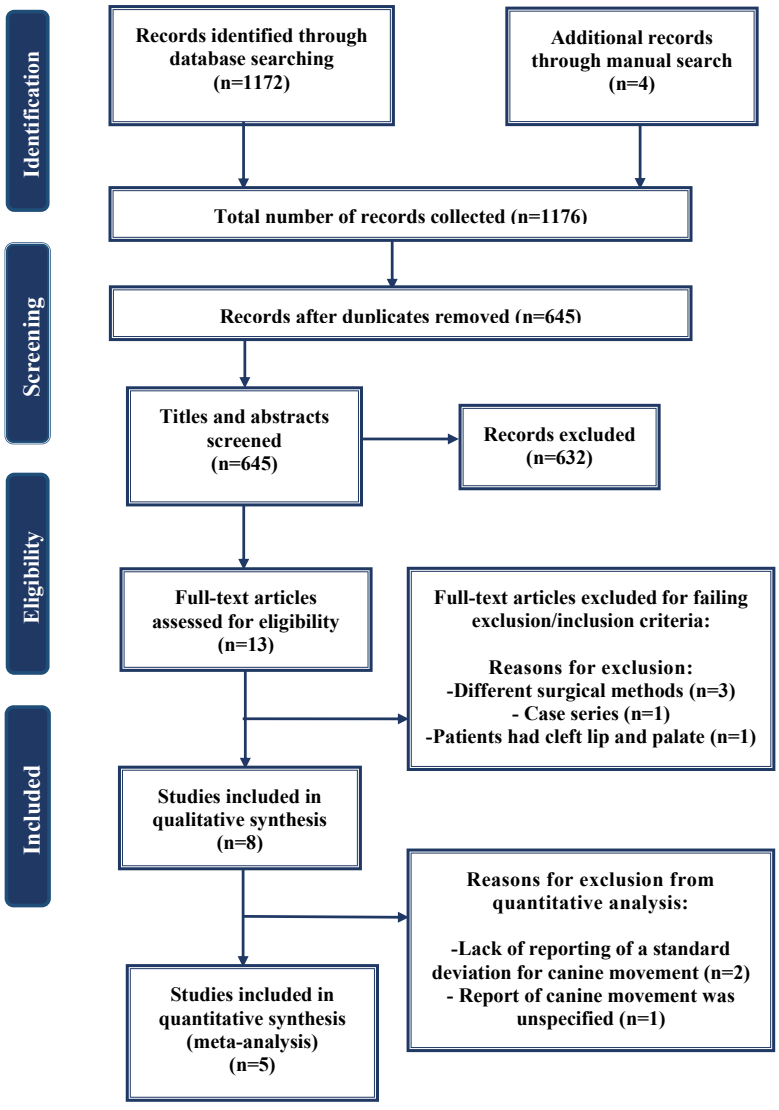


Figure 1. Flow diagram of literature search and screening process

Quality assessment

Based upon the published literature, the criteria used to assess the quality of the selected RCTs were modified from the RCT checklist of the *Cochrane Handbook for Systematic Reviews of Interventions* (version 5.1.0., http://www.cochrane.org/resources/handbook); Higgins *et al.*, 2011). This provided guidelines for the following parameters: sequence generation, allocation concealment method, masking of the examiner, address of incomplete outcome data, and free of selective outcome reporting. The degree of bias was categorized as: low risk if all the criteria were met, moderate risk when only one criterion was missing, and high risk if two or more criteria were missing (*Table 1*). Two reviewers (MS and KS) assessed all the included articles independently.

Results

The search yielded 579 references through PubMed and 593 references through Embase and four other articles through manual search methods. After removal of duplicate records, 645 articles underwent title and abstract screening based on the selection criteria. Full-text review was done on 13 articles. The reviewers agreed on including 8 studies (Aboul-Ela *et al.*, 2011; Al-Naoum *et al.*, 2014; Abbas *et al.*, 2016; Aksakalli *et al.*, 2016; Abed and Al-Bustani, 2013; Alikhani *et al.*, 2013; Salman and Ali, 2014; Jahanbakhshi *et al.*, 2016). The sample size ranged between 12 - 30 participants with the same range of individuals included in each group, as most of the included studies conducted a split-mouth design. The age of participants ranged between 15 - 26 years old. From the eight included studies, three studies were excluded from the meta-analysis for the following reasons: Two studies showed a lack of standard deviation report in the canine movement (Salman and Ali, 2014; Aboul-Ela *et al.*, 2011), while another study (Alikhani *et al.*, 2013) did not report the canine movement in mm. This information could not be obtained to complete the meta-analysis, even after attempting to contact the authors. One study (Al-Naoum *et al.*, 2014) had not provided an accumulative canine movement in mm; however, the numbers were provided after contacting the author.

The studies demonstrated different study periods as follows: two studies with a 1-month period (Abed and Al-Bustani, 2013; Alikhani *et al.*, 2013), one study with a six-week period (Salman and Ali, 2014), one study with 2 months (Aksakalli *et al.*, 2016), two studies with 3 months (Abbas *et al.*, 2016; Al-Naoum *et al.*, 2014) and one study with 4 months (Aboul-Ela *et al.*, 2011).

Characteristics of selected studies

A great heterogeneity was found between the selected articles (*Table 2*). Six of the included studies used a split-mouth design, considering one site as the test and the other as the control (Al-Naoum *et al.*, 2014; Salman and Ali, 2014; Aboul-Ela *et al.*, 2011 ; Abed and Al-Bustani, 2013; Aksakalli *et al.*, 2016; Jahanbakhshi *et al.*, 2016). One included study had one CAO test group and a separate control group where no intervention was done (Alikhani *et al.*, 2013). Another study had two groups of individuals comprising two split-mouth designs in each group, comparing CAO with full-flap reflection to the control sites in one group, and flapless piezocision to the control sites in the second group, performing further analysis between both test sites (Abbas *et al.*, 2016). Four studies had performed a full-thickness flap accompanied with round bur corticotomies (Aboul-Ela *et al.*, 2011; Al-Naoum *et al.*, 2014; Abed and Al-Bustani, 2013; Jahanbakhshi *et al.*, 2016). One study performed a flapless corticotomy through utilizing lasers (Salman and Ali, 2014), while another had utilized the piezosurgery knife to perform a flapless corticotomy accompanied by piezocision (Aksakalli *et al.*, 2016). The final study performed the flapless procedure with PROPEL™ orthodontics by placing micro-osteoperforations (MOPs; Alikhani *et al.*, 2013).

Table 1. Quality assessment of the included articles (risk of bias).

Study	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Total risk of bias
Salman and Ali (2014)	Unclear	High	High	High	Unclear	Low	High
Aboul-Ela *et al*. (2011)	Low	Low	High	Unclear	Low	Low	High
Abbas *et al.* (2015)	Low	Unclear	Unclear	High	Low	Low	High
Abed and Al-Bustani (2013)	Unclear	High	High	High	Unclear	Low	High
Al-Naoum *et al*. (2014)	Low	Unclear	Unclear	High	Low	Low	High
Alsakalli *et al.* (2016)	Low	Low	Low	Low	Low	Low	Low
Alikhani *et al.* (2013)	Low	Low	Unclear	Low	Low	Low	Moderate
Jahanbakshi *et al.* (2016)	Low	High	High	High	Unclear	Low	High

Table 2. Summary of selected studies included in the meta-analysis.

	Reference	Subject number and age	Study type	Groups	Key results
1	Salman and Ali (2014)	Number: 15 Mean age: 21.7	Type: Split mouth Follow-up time: 1.5 month	Test: CAO with Er-YAG Laser Control: No surgery	SS higher net canine movement in test vs. control. NSSD Pre- and post-surgery. No gingival inflammation
2	Aboul-Ela *et al*. (2011)	Number: 13 Mean age: 19	Type: Split mouth Follow-up time: 4 months	Test: CAO with #2 round bur Control: No surgery	SS higher canine movement in test vs control especially first 2 months, NSD in PD and GI scores
3	Abbas *et al*. (2015)	Number: 20 Mean age: 15-25	Type: 2 test groups (both split mouth design) Follow-up time: 3 months	Test: CAO Control: CAO with Piezosurgery	SS higher canine movement rate in both test groups vs controls. SS higher canine movement rate in corticotomy vs piezocision, NSSD in PD and less root resorption in both test groups vs control group.
4	Abed and Al-Bustani (2013)	Number: 12 Mean age: 21.7	Type: Split mouth Follow-up time: 1 month	Test: CAO with #1.5 round bur Control: No surgery	SS higher canine movement rate in test vs control, NSD in PD and GI
5	Al-Naoum *et al*. (2014)	Number: 30 Mean age: 20.04	Type: Split mouth Follow-up time: 3 months	Test: CAO with #2 round bur Control: No surgery	SS higher canine movement rate in test vs control at different time points
6	Alsakalli *et al*. (2016)	Number: 10 Mean age: 16.3	Type: Split mouth Follow-up time: 2 months	Test: CAO with Piezosurgery Control: No surgery	SS higher canine movement rate in test vs conrtol, NSSD in GI score
7	Alikhani *et al*. (2013)	Number:20 Mean age: 26.8	Type: Test/control groups Follow-up time: 1 month	Test: CAO with Propel™ Control: No surgery	SS higher canine movement rate at the side of the perforations compared with control and contralateral side
8	Jahanbakshi *et al*. (2016)	Number: 15 Mean age: 25	Type: Split mouth Follow-up time: 4 months	Test: CAO with #2 round bur Control: No surgery	SS higher canine movement rate in test vs. control. Difference speeds at different time points

SS, statistically significance; NSSD, no statistically significant difference; NSD, no significant difference; PD, probing depth; GI, gingival inflammation

Meta-analysis for canine movement after two weeks of intervention and orthodontics activation

Only two of the selected articles reported movement of the canine after two weeks of treatment (Al-Naoum *et al*., 2014; Abbas *et al*., 2016). The effect sizes were established from each study and then combined in the meta-analysis. The WMD of canine movement was 0.58 mm (95% CI = -0.17 to 1.33, $p < 0.00001$) favoring the CAO group (*Figure 2*).

Meta-analysis for canine movement after one month of intervention and orthodontics activation

Five studies reported the movement of the canine after one month of treatment (Abed and Al-Bustani, 2013; Abbas *et al*., 2016; Aksakalli *et al*., 2016; Jahanbakhshi *et al*., 2016; Al-Naoum *et al*., 2014). The effect sizes were established from each study and then combined in the meta-analysis. The WMD of canine movement was 0.83 mm (95% CI = 0.25 to 1.40, $p < 0.00001$) favoring the CAO group *(Figure 3*).

Figure 2. Meta-analysis for canine movement (mm) after two weeks of intervention and orthodontics activation.

Study or subgroup	Corticotomy Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Al-Naoum *et al.*, 2014	1.31	0.46	30	0.34	0.19	30	49.4%	0.97 (0.79, 1.15)
Abbas *et al.*, 2015	0.45	0.09	20	0.25	0.06	20	50.6%	0.20 (0.15, 0.25)
Total (95% CI)			**50**			**50**	**100.0%**	**0.58 (-0.17, 1.33)**

Heterogeneity: Tau^2 = 0.29; Chi^2 = 67.06, df = 1 (p < 0.00001); I^2 = 99%
Test for overall effect: Z = 1.51 (p = 0.13)

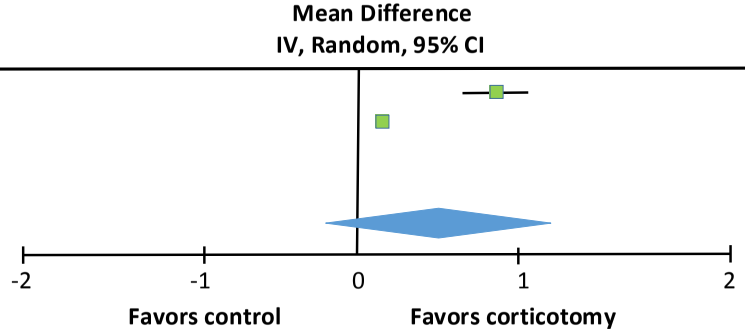
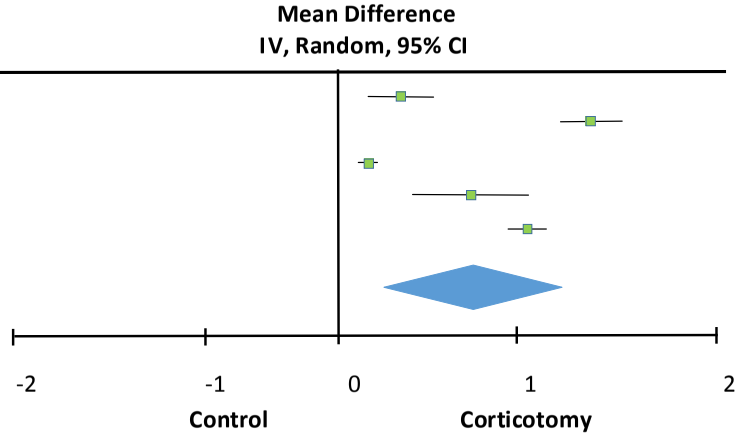


Figure 3. Meta-analysis for canine movement (mm) after one month of intervention and orthodontics activation.

Study or subgroup	Corticotomy Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Abed and Al-Bustani, 2013	1.74	0.47	12	1.22	0.4	12	19.6%	0.52 (0.17, 0.87)
Al-Naoum *et al.*, 2014	2.09	0.75	30	0.65	0.4	30	19.9%	1.44 (1.14, 1.74)
Abbas *et al.*, 2015	0.55	0.09	20	0.32	0.08	20	21.1%	0.23 (0.18, 0.28)
Aksakalli *et al.*, 2016	1.53	0.67	0	0.78	0.24	10	18.8%	0.75 (0.31, 1.19)
Jahanbakhsh *et al.*, 2016	2.2	0.32	15	1	0.13	15	20.7%	1.20 (1.03, 1.37)
Total (95% CI)			**87**			**87**	**100.0%**	**0.83 (0.25, 1.40)**

Heterogeneity: Tau^2 = 0.41; Chi^2 = 164.11, df = 4 (p < 0.00001); I^2 = 98%
Test for overall effect: Z = 2.83 (p = 0.005)



Meta-analysis for canine movement after two months of intervention and orthodontics activation

Three studies reported the movement of the canine after two months of treatment (Al-Naoum *et al*., 2014; Abbas *et al*., 2016; Aksakalli *et al*., 2016). The effect sizes were established from each study and then combined in the meta-analysis. The WMD of canine movement was 1.17 mm (95% CI = -0.16 to 2.51, $p < 0.00001$) favoring the CAO group (*Figure 4*).

Meta-analysis for canine movement after three months of intervention and orthodontics activation

Only two studies reported the movement of the canine after 3 months of treatment (Al-Naoum *et al*., 2014; Abbas *et al*., 2016). The effect sizes were established from each study and then combined in the meta-analysis. The WMD of canine movement was 1.61 mm (95% CI = -0.54 to 3.77, $p < 0.00001$) favoring the CAO group (*Figure 5*).

Risk of bias assessment

The results of risk of bias assessment for the included RCTs are summarized in *Table 1*. Six studies were considered to have a high risk of bias while the other two studies were regarded as having low to moderate risk of bias.

Discussion

Corticotomy-assisted orthodontia has primarily been used to accelerate orthodontic treatment. Other indications include: management of borderline orthognathic surgical cases (Handelman, 2011), treating severe anterior open bites in conjunction with skeletal anchorage (Moon *et al*., 2007), and improving the incidence of orthodontic relapse (Wilcko *et al*., 2008). All of the studies included in this review reported on the use of CAO for canine distalization in premolar extraction cases. Further analysis of CAO performance in other treatments is encouraged. Contraindications of CAO may include: adverse pharmaceutical management (prolonged corticosteroids use, medications that slow bone metabolism such as bisphosphonate, NSAIDs, etc.) and dental reasons (inadequately endodontically treated teeth and/or periodontally diseased teeth; Wilcko *et al*., 2009). All studies included here took these factors into consideration and used reported contraindications as part of the exclusion criteria, in addition to factors such as poor oral hygiene, smoking, and systemic diseases, to avoid any possible interference with the treatment progress and results.

The main objective in analyzing the included studies was to measure the distance of canine movement over the treatment period and compare the movement distance between conventional orthodontia and CAO. All the studies showed different rates on average because of the variation in the methods used and the treatment time frame. One study showed the average rate of movement produced through CAO to be 3.34 times faster than conventional methods over a three-month period (Al-Naoum *et al*., 2014). Other studies showed the average rates to be 2.3 times faster over a one-month period (Alikhani *et al*., 2013), 2 times faster over a six-week period (Salman and Ali, 2014), 1.9 times faster over a three-month period (Abbas *et al*., 2016), 1.7 times faster over a four-month period (Aboul-Ela *et al*., 2011) and another study over a two-month period (Aksakalli *et al*., 2016), 1.64 times faster over a four-month period (Jahanbakhshi *et al*., 2016), and 1.4 times the rate over a one-month period (Abed and Al-Bustani, 2013).

Concerns regarding complications from CAO were also addressed. These complications could be seen on the teeth involved, such as loss of vitality, root resorption, and negative changes in the periodontium, or those that involved altered patient comfort by increased pain and swelling of the treated area (Zimmo *et al*., 2017). None of the included studies reported any dental or periodontal complications during the treatment period. One study reported root resorption in the control side to be more than twice the resorption found in the test side (Abbas *et al*., 2016). This could all be due to the short follow-up periods these studies had. As for patient discomfort, five of the included studies reported no significant complications in any of their patients (Aboul-Ela *et al*., 2011; Abbas *et al*., 2016; Aksakalli *et al*., 2016; Alikhani *et al*., 2013; Jahanbakhshi *et al*., 2016). One study reported swelling in one patient for 2 days (Salman and Ali, 2014) and another reported swelling in four patients for 2 days as well (Abed and Al-Bustani, 2013). One study, however, showed 80% of the patients having moderate to severe swelling at 3 days that completely subsided at 1 week, and 50% of the patients experiencing severe pain while eating on day 1 (Al-Naoum *et al*., 2014). This can be explained by the nature of the surgical procedure that they enlisted: 20 corticotomy perforations where made on the buccal and palatal side of the canine. While more aggressive, these enhanced surgical measures resulted in a higher canine retraction rate average (3.34 times faster) and produced the quickest canine distalization rate compared to all other studies. These findings support the claim that RAP effect, and consequently the magnitude of tooth movement, is strongly influenced by the amount and intensity of the injury (Frost, 1989) (Wilcko *et al*., 2009; McBride *et al*., 2014).

Figure 4. Meta-analysis for canine movement (mm) after two months of intervention and orthodontics activation.

Study or subgroup	Corticotomy Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Al-Naoum *et al.*, 2014	3.23	0.91	30	1.14	0.44	30	33.8%	2.09 (1.73, 2.45)
Abbas *et al.*, 2015	0.74	0.12	40	0.46	0.09	40	34.6%	0.28 (0.23, 0.33)
Aksakalli *et al.*, 2016	2.9	0.86	10	1.73	0.72	10	31.6%	1.17 (0.47, 1.87)
Total (95% CI)			**80**			**80**	**100.0%**	**1.17 (-0.16, 2.51)**

Heterogeneity: $Tau^2 = 1.34$; $Chi^2 = 100.49$, df = 2 ($p < 0.00001$); $I^2 = 98\%$

Test for overall effect: Z = 1.72 ($p = 0.09$)

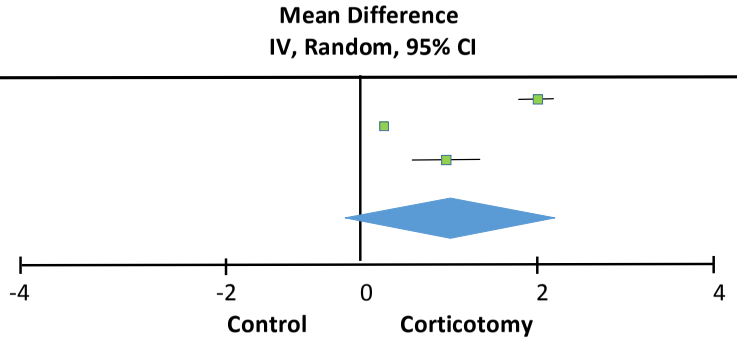
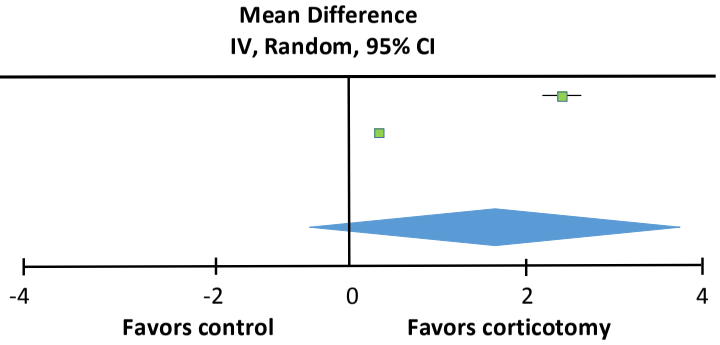


Figure 5. Meta-analysis for canine movement (mm) after three months of intervention and orthodontics activation.

Study or subgroup	Corticotomy Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Al-Naoum *et al.*, 2014	4.26	0.96	30	1.54	0.53	30	49.6%	2.72 (2.33, 3.11)
Abbas *et al.*, 2015	1.11	0.15	20	0.59	0.04	40	50.4%	0.52 (0.45, 0.59)
Total (95% CI)			**50**			**50**	**100.0%**	**1.61 (-0.54, 3.77)**

Heterogeneity: $Tau^2 = 2.40$; $Chi^2 = 117.22$, df = 1 ($p < 0.00001$); $I^2 = 99\%$

Test for overall effect: Z = 1.46 ($p = 0.14$)



In addition, it was reported that when a full thickness flap elevation was performed and compared to a flapless (peizocision) approach, a greater amount of canine movement had occurred, which is possibly attributable to the amount of trauma and thus more RAP effect (Abbas *et al*., 2016). Although a flapless approach was found to result in a slower rate of tooth movement when compared to flap elevation, there are situations where a more conservative approach could be beneficial, such as reduced cost and time, improved patient comfort and acceptance, and simplified wound healing. In addition, most studies included the placement of an incision 2-3 mm from the free gingival margin when elevating a flap. This resulted in preservation of the patient's esthetics. Nonetheless, based on our analysis, the evidence shows that CAO is a relatively safe procedure for canine distalization.

One of the aims of our study was to verify if CAO causes any potential damage to the surrounding periodontium. It was believed that CAO might cause buccal bone resorption that eventually leads to gingival recession (Yaffe *et al*., 1994) and therefore, bone grafting was introduced in combination with corticotomy to prevent such sequelae (Wilcko *et al*., 2009). Previous studies found no influence of CAO on the periodontium (Fischer, 2007) and in the case of the included studies in this review, none of them showed any effect on the periodontium throughout the treatment period, varying between 1 - 4 months. This suggests that CAO is a safe clinical procedure with no potential harm to the periodontium of the involved teeth with or without bone grafting and so long as the orthodontic boundary conditions are not violated.

Various methods were used in performing CAO in the included studies and were found to influence the amount of tooth movement. Three studies used a #2 round bur (Aboul-Ela *et al*., 2011; Al-Naoum *et al*., 2014; Jahanbakhshi *et al*., 2016) while another study used a #1.5 bur (Abed and Al-Bustani, 2013). One study used a piezotome to make the cuts and holes in the corticotomy and piezocision groups (Abbas *et al*., 2016), one used a piezosurgery knife (Aksakalli *et al.,* 2016), another used Er:YAG laser (Salman and Ali, 2014), and one relied on a handheld device designed by PROPEL orthodontics to place the perforations in the bone (Alikhani *et al*., 2013). Although there is a large heterogeneity between the included studies in terms of amount of trauma produced by differences in flap elevation, instrument use, and number and depth of perforations, there was no significant difference between the CAO effects on the rate of tooth movement in this study.

There was a large variance between the studies for the time of premolar extraction. One study extracted the premolars on the day of the surgery (Jahanbakhshi *et al*., 2016) while two studies extracted one of the premolars 1 day before the surgery and the other premolar on the day of the surgery (Aboul-Ela *et al*., 2011; Abbas *et al*., 2016). They justified this sequence to reduce patient discomfort and surgery time on the day of the CAO procedure and found no difference in the results between both extractions. Other studies chose to extract the premolars 4 weeks (Al-Naoum *et al*., 2014) and 6 months (Alikhani *et al*., 2013) prior to the surgery while the remaining studies did not mention the time of premolar extraction (Salman and Ali, 2014; Abed and Al-Bustani, 2013; Aksakalli *et al*., 2016). Nonetheless, we did not find any difference in the results attributable to this variance, possibly due to the small number of studies.

A limitation to this study is the heterogeneity among the selected studies. This can include the differences in whether a flap was elevated or not, the methods used in corticotomy perforation, the reported treatment time, the orthodontic device used, the assessment methods and the time of premolar extraction. However, the results of all included studies, regardless of these differences, were similar and fell in the same range of outcomes. It was also difficult to perform a meta-analysis on many parameters because not all of the studies reported or measured them.

It is important that more clinical studies be performed that have long follow-up periods to assess the stability of the results, the rate of orthodontic relapse and the risks of the root resorption, and the long-term effect on the periodontium and teeth vitality. We also believe that more studies should be conducted to examine the various uses of CAO in other treatment approaches, such as improving the dentoalveolar bone phenotype in vulnerable patients and the associated long-term changes in the periodontium and orthodontic outcome stability.

Conclusion

Based on the results in this review, the CAO procedure has been shown to accelerate maxillary canine distalization, reducing the treatment time by 50% when compared to conventional orthodontic tooth movement. In addition, CAO is safe for the periodontium and dental structures.

Acknowledgments and conflict of interest

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