Self-Ligating Brackets and "The Frankel like Effect": A Systematic Review

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Abstract: ***Objectives**: The aim of this Systematic review was to compare the effect of Self-Ligating Brackets (SLB) and conventional brackets (CB) on buccal bone (height& thickness), transverse dental dimensions, and incisal inclinationin adult orthodontic patients with mild to moderate crowding. **Methods**: A systematic search was conducted on May 2016 and updated on May 2017, in PubMed, CENTRAL, Lilacs, and Embase. Date or language restrictions were not applied. Hand search was performed too. Search was performed on orthodontic patients receiving treatment using SLB compared to (CB).The Primary outcomes of interest were the changes in alveolar bone thickness and height and changes in the arch width and incisor inclination. Studies which fulfilled the selection criteria were assessed for methodological quality using validated checklists. Studies of moderate and high quality were included. **Results**: Out of 930 initially retrieved articles, 8 articles were included in this review for qualitative and quantitative analysis. There was noevidence for the difference in alveolar bone changes foreitherintervention. Both interventions demonstrated no difference in arch width expansion except for maxillary inter-canine width and mandibular inter-molar width. There was no difference in maxillary incisor inclination between both interventions. However, CB showed more mandibular incisor inclination. **Conclusion**: There is no conclusiveevidence to confirm or refute the claims that SLB produce superior physiologic tooth movement with more bone deposition. Both SLB and CB produce statistically and clinically significant dental expansion. SLB produce less proclination. Rigorous randomized clinical trials are needed to investigate alveolar bone changes between SLB and CB.*

Keywords: self-ligating; brackets; alveolar bone; dento-alveloar expansion

1. Introduction

Dental crowding is one of the most prevalent forms of malocclusion all over the world [1-5]. Various treatment modalities are available today to alleviate dental crowding and re-align teeth.

Methods of gaining space to relieve crowding range from conservative fixed orthodontics, without any further intervention, to more invasive approaches for space gaining such as extraction of teeth. Other available methods that don't involve extraction are inter-proximal stripping, distalization and expansion.

These modalities involve certain limitations. Stripping is an invasive procedure that provides a limited gain of space[6,7], while distalization is a slow procedure that might require extraction of the 2nd or 3rd permanent molars and may further open the bite in a skeletal open bite patient. Expansion using conventional brackets, could compromise retention if the arch dimensions are changed drastically, the peridontium may also suffer leading to bone dehiscence, fenestration, gingival recession and tooth mobility[8].

There are claims in the orthodontic literature that treatment using self-ligating brackets (SLBs) can overcome the previously mentioned adverse effects experienced with conventional brackets during transverse dental expansion. This is explained as being due to the low forces produced by the Cu-NiTi wires and the low friction levels produced by the bracket design; these two components allow for new force equilibrium that allows the arch to reshape itself. This claim or phenomenon is referred to as a "Frankel like effect"[9-11]. Statements and case reports have been made regarding the SLB System's ability to achieve biologically induced tooth movements and treatment that in most cases does not require the extraction of permanent teeth, rapid palatal expansion, or distalization of molars. This technique appears to move teeth to physiologically determined positions, stimulating the alveolar bone to follow[9].

However, some of the literature does not support these claims [12,13].Observing the expansive dento-alveolar effect of different ligation methods appropriately requires exclusively non-extraction treatment subjects. Systematic reviews have been published regarding the influence of SLB treatment on the arch width compared to treatment with CB. However, all these reviews pooled extraction and non-extraction protocols. Furthermore, the fundamental anatomic as well as histological differences between maxillary and mandibular arches suggest that pooling them together might be inappropriate. Hence, there is still no robust evidence to support the claims that treatment-using SLB promotes alveolar bone remodeling.

The aim of this systematic review is to assess the available evidence regarding the claims that self-ligating systems offer a biologic, stable, and conservative approach to relive dental crowding.

Objectives

The aim of this review is to compare the effect of SLB and conventional brackets (CB) on buccal bone (height and thickness), transverse dental dimension, and incisal inclinationin adult orthodontic patients with mild to moderate crowding.

2. Materials and methods

A systematic search was conducted on May 2016 and updated on May 2017 in PubMed, CENTRAL, Lilacs, and Embase. Language and date restrictions were not applied. Grey literature was electronically searched using open grey (opengrey.eu), Clinicaltrials.gov, and thesis and dissertations on ProQuest. A hand search was performed in the following journals: Angle Orthodontist, American Journal of Orthodontics and Dentofacial Orthopedics, European Journal of Orthodontics. Reference lists of the included articles were checked for relevant studies.

The search strategy was developed by two authors: (MB and KA). Broad terms were used for a sensitive search. Specific search strategies per database are outlined in table1.

An email alert was set for the PubMed and Embase search that allowed update of results during the process of developing the review. Alerts were checked regularly until December 2017.

Two authors (MB and KA) independently screened all the retrieved studies. The articles were subject to the following inclusion criteria: 1) Study type: prospective clinical trials [randomized controlled trials (RCTs), and controlled clinical trials (CCTs)]. 2) Patients: adults with class I or mild class II and III malocclusion, moderate to severe crowding. 3) Intervention: fixed appliance orthodontic therapy with SLB. 4) Control: fixed appliance orthodontic treatment with CB. 5) Outcomes: Primary outcomes: changes in alveolar bone thickness and height measured by CBCT. Secondary outcomes: changes in transverse dental linear measurements (maxillary and mandibular inter-canine, inter-first premolar, inter-second premolar and inter-first molar widths) and Changes in incisal inclination (torque).

The following exclusion criteria were also considered: 1) Patients in any groups receiving any of the following additional intervention in addition to the intervention of interest: a) Interproximal reduction. b) Dental extractions other than third molars. c) Therapeutic interventions exclusive of orthodontic arch wires (eg: headgears, lip bumpers, class II elastics, etc.) 2) Patients that had pervious orthodontic treatment or orthognathic surgery.

These criteria were applied to the title and abstract then the full texts of the eligible studies were evaluated. Disagreement regarding study selection was resolved by discussion until a consensus was reached.

For quality assessment of the included studies, three reviewers used two tools to assess the risk of bias of the included studies. For RCTs, we used the Cochrane risk of bias assessment tool. This tool consists of five items for which there is empirical evidence for their biasing influence on the estimates of an intervention's effectiveness in randomized trials (sequence generation, allocation concealment, blinding, incomplete outcome data, and selective outcome reporting) and a catch-all item called "other sources of bias[14]. For non-randomized clinical trials we used the JBI checklist for non-randomized experimental studies[15]. This process was carried out independently by three review authors (MB, HS, and MS) and whenever there was a disagreement we resolved it by discussion.

We developed a data extraction sheet based on the *Cochrane handbook for systematic reviews of interventions*[16], pilot-tested it on two randomly-selected included studies, and refined it accordingly. One review author extracted the following data from included studies and the second author checked the extracted data. Disagreements were resolved by discussion between the two review authors (MB and KA).

A meta-analysis was performed when two or more studies reported homogenous subject criteria, methodology and outcomes. One study compared more than two intervention groups[17-19]. In Felming's study, they compared three intervention groups, two SLB groups and a CB group, to avoid duplicating the subjects in the control group; both SLB intervention groups were combined.

Assessment of the risk of bias that may affect the cumulative evidence such as publication bias was investigated using a funnel plot whenever possible.

Sensitivity analysis was performed to test the cause of heterogeneity across studies whenever possible assessing treatment protocol, timing of data collection, measurement technique, study design, and quality of included studies.

3. Results

The PRISMA[20] flow chart (Fig.1) presents the study selection process. The total number of retrieved articles from electronic databases, grey literature search and hand search was 930 articles. 733 articles were screened by title and abstract after duplicates were removed using endnote[21]. Three eligible RCTs were reported on clinicaltrials.gov but were not included after contacting the authors, since they are ongoing. These studies are expected to contribute to the future update of this review. Twenty-onefull text articles were assessed.

The reasons for study exclusion of a trial from the review are presented in table 2. Fourteen studies were excluded for being observational studies or ongoing-trials, or for having no control groups or irrelevant outcomes.

Seven articles were included in the qualitative and quantitative synthesis; three randomized clinical trials[19,22,23] and four controlled clinical trials[12,24-26]. After one year from the initial search an email alert by Embase revealed a new RCT[27]which was then excluded from the review due to its high risk of bias. The characteristics of the included studies are presented in tables3, 4 and 5.

A meta-analysis was not possible for alveolar bone changes since one RCT was found comparing between changes in buccal bone thickness in groups treated with SLB versus CB using CBCT. Linear measurements were taken from the root surface to the buccal bone at 3mm and 6 mm away from the cemento-enamel junction (CEJ). There was a slight decrease in buccal bone thickness in both groups at 3mm from the CEJ, which was not clinically significant. However, for the thickness at 6mm from the CEJ, the slight decrease in buccal bone thickness was only evident in the canine region for both groups.However, this study was excluded due to its high risk of bias.

Meta-analyses of random effects models were performed for maxillary and mandibular inter-canine width (fig. 3 and 4), inter-first premolar width (fig 5 and 6), inter second-premolar width (fig. 7 and 8), and inter-molar width (fig. 9 and 10) and for maxillary and mandibular incisor inclination (fig 11 and 12).

Three randomized controlled trials, and four non-randomized controlled trials where used in the meta-analyses. For the dento-alveolar transverse width measurements there was no statistical difference between both SLB and CB except for inter-canine and mandibular inter-molar widths. The pooled effect for maxillary inter-canine width showed SLB group to be 0.91 mm greater expansion with a 95% CI of (0.09-1.84). For mandibular inter-canine width , the pooled estimate was 0.52 mm greater expansion with CB group compared to SLB with a 95% CI (-0.94- 0.11). The mandibular inter-molar width analysis showed that both groups caused expansion with the SLB group showing a 0.68 mm more expansion with the CB group with a 95% CI (0.27-1.09).

A forest plot was constructed to pool the results of the upper incisor (Ui/SN)and lower incisor inclination measurements (Li/MP: IMPA). For the maxillary incisors there was moderate heterogeneity (I^2=49%). The pooled effect showed1.94° less proclination with SLB than CB with a 95% confidence interval (-3.45, 0.44).

For the mandibular incisor inclination measurements; there was no difference found in the torque control between SLB and CB.

The maximum number of studies included in any meta-analysis was less than ten. Therefore publication bias was not assessed.

4. Discussion

Self-Ligating Brackets were introduced to orthodonticsin the 1930s[28] . However, they did not receive much attention until their re-introduction by Damon[29]in the late 1990s. Their claims of clinical advantages evolved over the years from being mainly easier to use with less chair time to being more comfortable and hygienic to the patient. Moreover, it is claimed that SLB's less friction and lighter forces produce an optimal environment for tooth movement and physiologic "arch development" with periodontal adaptation rather than alveolar bone dehiscence or fenestration.

Self-ligation is clearly a controversial topic in contemporary orthodontics. There are 9 published systematic reviews and meta-analyses published between 2009 and 2017 investigating most of the previously mentioned outcomes/ claims. Do Nascimento[30], Arnold[31], and Yang[32] investigated the periodontal status and oral hygiene. Celar[33] investigated initial pain, number of visits and treatment time. Fleming[34], Chen[35] and Papageorgiou[36] investigated alignment efficiency, space closure, bond failure rate, dental arch dimensions and root resorption. Al-Thomali[37] and Ehsani[38] looked at in-vitro studies investigating torque expression and frictional resistance respectively. In comparison to these previous studies, the present review only includes studies with non-extraction protocols to test the expansion potential and side effects of SLB as an alternative to extraction protocols in moderate to severe crowding. We have used critical appraisal tools specific to each study design rather than using one for all the included studies. Pooling of experimental studies (RCTs and CCTs) and non-experimental studies (observational) was avoided. Outcomes for the maxilla and mandible were pooled separately due to the bone histologic and physiologic differences and the fact that the mandibular arch width is constrained by maxillary arch width.

Buccal bone changes

A meta-analysis was not possible since we found only one clinical trial[27] investigating change in buccal bone thickness. It was unclear how randomization was done by coin tossing. No sample size calculation was reported and the sample size (16 patients) was relatively small. Moreover, reporting of allocation concealment and missing data was not clear. The SLB used was EasyClip but the slot size was not mentioned. Outcome measures were taken at the beginning of treatment and 6 months later, irrespective of the arch wire utilized at that stage. Insufficient information was reported regarding the standardization of the techniques across all the patients. Therefore, it was judged to have a high risk of bias, and was excluded from the review. Moreover, we found an ongoing trial on clinicaltrials.gov by Nader et al 2016[39]. This trial is still in the recruitment phase. Hence, the results might change in an update of this review with inclusion of this trial's results.

Transverse Arch Width

For the maxillary dental arch width both intervention groups showed transverse dental expansion. There was no statistical or clinical difference between both groups except for the inter-canine width, where SLB showed more expansion. This difference is statistically and clinically significant. Both studies [23,26]included in this analysis were conducted in a public healthcare setting and therefore the results are generalizable. Also the initial amount of crowding and age were similar across studies. Consequently the studies were homogenous which was evident by the test for heterogeneity (I^2=0).

Four studies were included in the mandibular meta-analysis. Only two studies investigated the inter-premolar widths[19,24]. The pooled estimate showed expansion in both intervention groups. SLB was associated with less inter-canine expansion, which was statistically significant but clinically insignificant. On the contrary, the inter-molar width showed more expansion with SLB compared to CB. These results are in agreement with Papageorgiou et al[36] and in disagreement with Chen etal [35]where they found no difference between groups. The differences in the results between the maxillary and mandibular dental arch widths could be explained by a variety of reasons. In the maxillary arch crowding could be relieved through flaring of upper incisors, as opposed to the mandibular arch, where the lower incisors are limited by their overlapping antagonist; the upper incisors. This arrangement could possibly drive the lower molars to move into the disto-buccal wider part of the arch to create space and relieve crowding. Another contributing factor is the smaller dimensions of the SLB brackets compared to CB, which provides a larger inter-bracket distance in the SLB group. This could cause more mesio-buccal rotation of the lower molars leading to a larger inter-molar width, since it is measured from cusp tip to cusp tip.

Incisor Inclination

A meta-analysis of the lower incisor inclination was conducted, pooling the estimates of one RCT [19] and two CCT [12,24]. The forest plot showed no difference between both groups. This result is in an agreement with Papageorgiou et al[36] and in disagreement with Chen et al[35]. However, clinical application of these results should be handled with caution.

There are different contributing factors that affect torque expression in orthodontics. Some of these factors are related to the arch wire material, shape and size. Other factors are related to the bracket design, such as bracket prescription, namely torque values, and slot dimensions. The time of placement of the arch wire also comes into play when it comes to torque expression i.e.: the more time the rectangular wire is in place the more torque is expressed. Bracket position also plays a role in torque expression. Finally, the mode of ligation, weather friction or friction-less, plays a great role in torque expression. Since the mode of ligation is the factor being tested for its effect on torque expression, it is only reasonable to unify all the other previously mentioned confounders in the treatment protocol of the trials investigating SLB and CB. However, these confounders were neither adequately nor consistently addressed across all the studies. For example, the CCT included in this analysis [40] showed performance risks of bias by taking the T1 measurements after the six mandibular teeth were aligned irrespective to the possible irregularities in the posterior segment. Moreover, in this clinical trial the last archwire used before final measurement was a round archwire (0.020-in medium Stenalloy archiwre) in the CB group and a rectangular wire (0.014x0.025-in CuNiTi archwire) in the SLB group. Such differences in the treatment protocol could preclude full torque expression in the CB group and therefore skew the results.

5. Limitations

This review has some limitations. It was not possible to retrieve some of the studies[24,41,24,42] which could have been a useful addition to this review. The study by Pandis et al[43] was excluded as the results were similar to a previous study (reference).

While evidence regarding the clinical application of SLBs is starting to accumulate, their influence on bone deposition compared to CB is still under-investigated. There is no strong direct prospective comparison of different types of SLBs and CB in the maxillary and mandibular arches with non-extraction orthodontics.

6. Conclusion

1) There was no conclusive evidence to show the difference in buccal bone thickness after treatment with SLB and CB.
2) Both SLB and CB produce statistically and clinically significant dental expansion.
3) SLB produce more expansion in the maxillary inter-canine and mandibular inter-molar width, while CB produces more expansion in the mandibular inter-canine width.
4) There was no significant difference between the change in maxillary and mandibular inter-premolar width and the maxillary inter-molar width.
5) No statistical difference was found for the buccolingual inclination of the mandibular incisors between SLB and CB. These results must be interpreted with caution.
6) SLB provide slightly less proclination in maxillary incisors than CB.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

'**Declarations of interest**: none'.

List of abbreviations

SLB: Self ligating brackerts
CB: Conventional brackets
RCT: Randomized controlled trial
CCT: Controlled clinical trial.

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Figure Captions

Table 1: The search strategy and number of hits per database

	Database	**Keywords**	# of hits
Electronic databases	Pubmed	((self ligatable[All Fields] OR self ligate[All Fields] OR self ligated[All Fields] OR self ligates[All Fields] OR self ligating[All Fields] OR self ligation[All Fields] OR self ligature[All Fields]) OR (self ligatable[All Fields] OR self ligate[All Fields] OR self ligated[All Fields] OR self ligates[All Fields] OR self ligating[All Fields] OR self ligation[All Fields] OR self ligature[All Fields]) OR SLB[All Fields]) AND (orthodontic appliance design[MeSH Terms] OR (((orthodontics, corrective/instrumentation[MeSH Terms] OR orthodontic brackets[MeSH Terms]) OR "adolescent"[MeSH Terms]) OR orthodontics, corrective/instrumentation[All Fields] AND methods[MeSH Terms])) AND (Clinical Trial[ptyp] OR Comparative Study[ptyp] OR Controlled Clinical Trial[ptyp] OR Evaluation Studies[ptyp] OR Multicenter Study[ptyp]	138
	Central	((Orthodontic Appliance design [MeSH Terms]) OR (Orthodontic Brackets [MeSH Terms) OR ("Adolescent" [MeSH Terms])) AND Self ligat*	51
	Lilacs	braquetes autoligantes OR self ligat*	40
	Embase	(self-ligat* or self ligat*) and (orthodontic* or orthodontic* appliance design or bracket*) limit to humans	257
Grey Literature	ProQuest	(orthodontic* AND (self ligat* OR self-ligat*) AND (TRANSVERSE OR WIDTH OR ARCH) with(additional limits:Source type Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals, Working Papers)	307
	Opengrey	(orthodontic ligating)	2
	Clinicaltrials.gov	(self ligating orthodontic)	11
Hand search	Angle Orthodontist	(self ligat* OR self-ligat*) AND (transverse OR width)	69
	AJODO	(self ligat* OR self-ligat*) AND (transverse OR width)	35
	EJO	((self ligat* OR self-ligat*) AND (transverse OR width))	20
Total			930

Table 2: Excluded studies and causes of exclusion.

Study ID	*Reason for exclusion*
1. Abdullah, 2016	Ongoing trial
2. Al Sanea, 2008	Retrospective cohort
3. Burton, 2006	Retrospective cohort
4. Ehsani, 2010	Retrospective cohort
5. Fleming, 2014	Duplicate report of another included study
6. Forero 2017	On-going trial
7. Garlock, 2012	Retrospective cohort
8. Gilbert, 2005	Retrospective cohort
9. Li, 2015	Prospective cohort
10. Pandis, 2007	Duplicate report of the same study as Pandis 2009
11. Pandis, 2010	Irrelevant outcomes
12. Nader, 2016	On-going trial
13. Robert, 2012	Ongoing trial
14. Vajaria, 2011	Retrospective cohort
15. Ibiapina, 2016	High risk of bias

Table 3: Study characteristics

Study ID	*Study Design*		*Arch of interest*		*Sample Size*	*Pretreatment mean age (years)*
	RCT	*CCT*	*Maxilla*	*Mandible*		
Fleming, 2009	√			√	60	16
Fleming, 2013	√		√		81	19.7
Ibiapina, 2016	√		√		16	22.3
Jiang, 2008		√		√	26	14.9
Pandis, 2006		√	√		54	16
Pandis, 2009		√		√	56	13.7
Pandis, 2011	√			√	50	13.3
Tecco, 2009		√	√		40	15.8

Table 4: Summary of methodological data

Trial	*Bracket Design*	*Archwires*	*End Time-point definition*	*Outcomes*	*Outcome Measures*
Fleming, 2009	SLB: SmartClip brackets, 0.022" slot, MBT prescription CB: Victory brackets, 0.022" slot, MBT prescription.	0.019x0.025" SS for both groups.	Passive engagement of last wire.	1. Mandibular 3-3 2. Mandibular 4-4 3. Mandibular 5-5 4. Mandibular 6-6 5. Lower incisor inclination.	1. Cusp tip to cusp tip for arch width measurements. 2. Lower incisor with mandibular plane (Me-Go)
Fleming, 2013	Active SLB: In-Ovation Passive SLB: Damon Q CB: Ovation 0.022' slot, Roth prescription.	0.019x0.025" SS for all 3 groups.	Passive engagement of last wire.	1. Maxillary 3-3 2. Maxillary 4-4 3. Maxillary 5-5 4. Maxillary 6-6 5. Maxillary incisor inclination 6. Maxillary first molar inclination	1. Cusp tip to cusp tip for arch width measurements. 2. Upper incisor with maxillary plane
Ibiapina, 2016	Passive SLB: Easy Clip CB: 3M Unitek	Not mentioned	6 months after beginning of the treatment	1. Buccal bone thickness (at 3, 4, 5, and 6) 2. Maxillary 3-3 3. Maxillary 4-4 4. Maxillary 5-5 5. Maxillary 6-6	1.From the most buccal point on the root to the buccal bone at 3mm and 6 mm from the CEJ. 2.From cusp tip to cusp tip for all dental arch width measurements
Jiang, 2008	SLB: Damon3 CB: New sub	0.017x0.025"Cu NiTi for both groups	After treatment	1. Skeletal relationships 2. Mandibular 3-3 3. Mandibular 4-4 4. Mandibular 6-6 5. Mandibular incisor inclination	1. SNA, SNB, ANB, MP/PP, MP/SN. 2. Cusp tip to cusp tip for arch width measurements 3. Li/MP, Li/A-Pog
Pandis, 2006	SLB: Damon2 CB: 0.022" lot, Roth prescription, Microarch, GAC	0.019x0.025" SS for both groups.	After treatment (de-bonding)	Maxillary incisor inclination	1. Ui/SN, Ui/PP
Pandis, 2009	SLB: Damon 2 CB: Michroarch,	SLB: 0.014x0.025"	After alignment stage.	1. Mandibular 3-3 2. Mandibular 6-6	1. Cusp tip to cusp tip for 3-3 2. Central grove to central

	0.022" slot, Roth prescription	CuNiTi CB: 0.020" medium Sentalloy.		3. Inclination of lower incisor	groove for 6-6 3. Li/NB, Li/A-Pog, Li/MP for incisor inclination
Pandis, 2011	SLB: Damon MX 0.022 slot CB: Microarch brackets, 0.022" slot, Roth prescription	0.016x0.025 SS for both groups.	Passive placement of last wire.	1. Mandibular 3-3 2. Mandibular 6-6	1. Cusp tip to cusp tip for 3-3 2. Groove to groove for 6-6
Tecco, 2009	SLB: Damon 3MX CB: Victory, 0.022" slot, MBT prescription.	SLB: 0.016x0.025" CuNiTi CB: 0.019x 0.025" Nitinol.	1 year after treatment.	1. Maxillary 3-3 2. Maxillary 4-4 3. Maxillary 5-5 4. Maxillary 6-6	1. Tip to tip for 3-3 2. Fossae to fossae for all the other outcomes.

Table 5: Summary of results

Study ID	Maxillary outcomes										Mandibular outcomes										Sample (n)	
	Inter-canine Mean(SD)		Inter-first premolar Mean (SD)		Inter-second premolar Mean (SD)		Inter-molar Mean (SD)		Incisal inclination Mean (SD)		Inter-canine Mean (SD)		Inter-first premolar Mean (SD)		Inter-second premolar Mean(SD)		Inter-molar Mean (SD)		Incisal inclination Mean (SD)			
	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB	SLB	CB
Fleming 2009											0.85 (1.52)	1.17 (1.77)	0.73 (2.06)	1.46 (1.55)	1.43 (2.23)	1.72 (1.8)	1.41 (2.14)	0.5 (1.44)	1.46 (0.93)	1.36 (1.35)	29	31
Fleming 2013	1.8702 (2.0265)	0.88 (2.18)	4.1107 (2.5)	3.7 (3.19)	3.8654 (2.1973)	3.59 (2.8)	1.5353 (1.9434)	1.41 (2.08)	2.2392 (5.6942)	2.84 (5.68)											28	28
Ibiapina 2016	0.36 (2.02)	0.82 (2.08)	1.77 (2.15)	1.57 (2.55)	1.88 (1.86)	1.08 (2.62)	0.04 (1.30)	0.76 (2.35)													8	8
Jiang 2008											0.57 (1.61)	1.08 (2.43)	2.1 (2.41)	2.48 (1.54)	1.87 (2.07)	2.54 (0.96)	1.42 (0.8)	0.65 (1.28)	9.2 (9.03)	9.9 (5.35)	13	13
Pandis 2006									4.3 (0.9)	6.7 (0.9)											27	27
Pandis 2009											1.6 (2.23)	1.8 (1.92)					2.4 (3.11)	1 (3.08)			27	27
Pandis 2011											1.40 (0.8)	2.1 (1.4)					1.9 (1.3)	1.5 (0.9)			25	25
Tecco 2009	3.3 (2.6)	2.6 (2.4)	4.4 (2.5)	4.3 (2.1)	4.2 (1.8)	4.1 (2.1)	2.3 (1.5)	2.4 (2.0)													20	20

Table 6: Quality assessment of non-randomizedexperimental studiesusing JBI critical appraisal checklist for comparable cohort/case control[15]

Study ID	Is it clear what the 'cause' is& what is the 'effect'?	Were participants similar?	Were the participants in any comparison group receiving similar treatment other than the intervention of interest?	Was there a control group?	Were there multiple measurements of the outcome?	Was follow-up complete and/or reported?	Were outcomes measures measured the same way across comparison groups?	Were outcomes measured in a reliable way?	Was appropriate statistical analysis used?
Jiang 2008	Yes	Unclear	Unclear	Yes	No	Unclear	Yes	Yes	Unclear
Pandis 2006	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes
Pandis 2007	Yes	Yes	Yes (for width) No (for inclination)	Yes	Yes	No	Yes	Yes	Yes
Pandis 2009	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

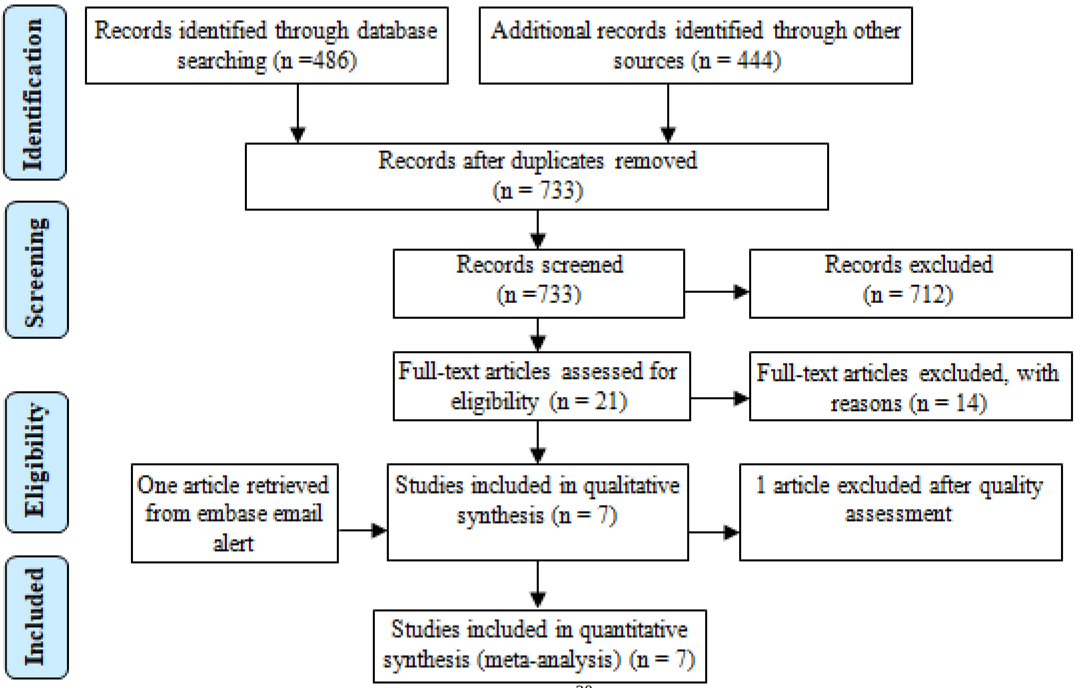
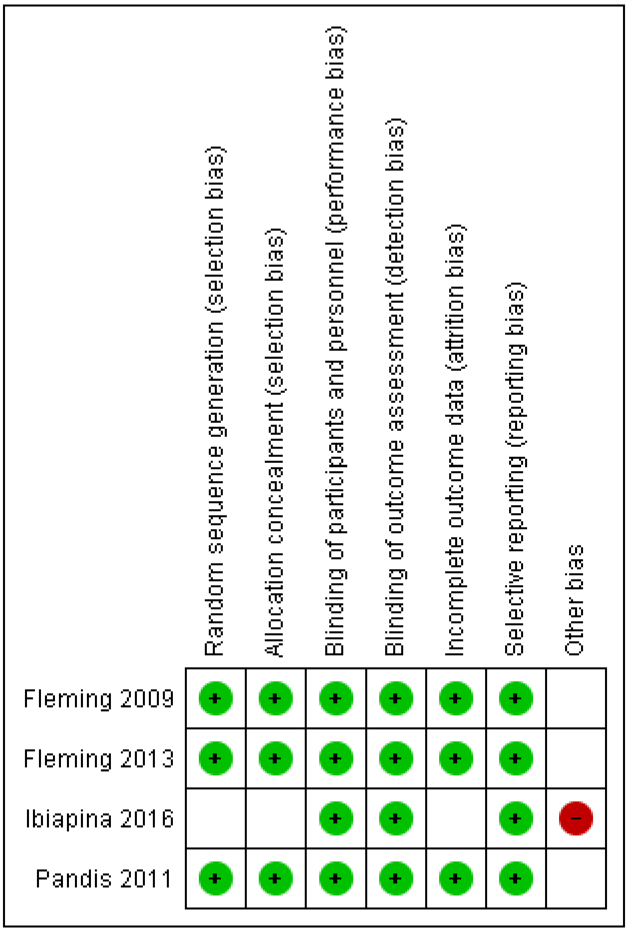


Figure 1: PRISMA[20] flow chart

PRISMA 2009 Flow Diagram



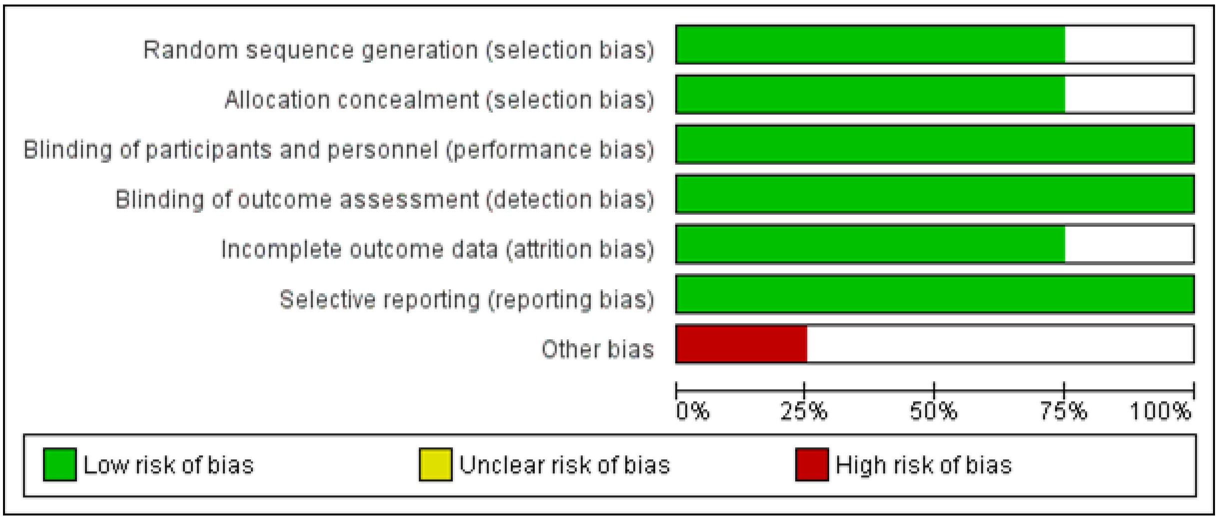


Figure 2: Summary of risk of bias assessment of RCTs

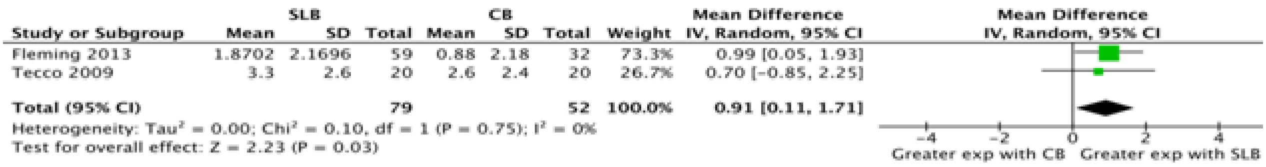


Figure 3: Meta-analysis of maxillary inter-canine width

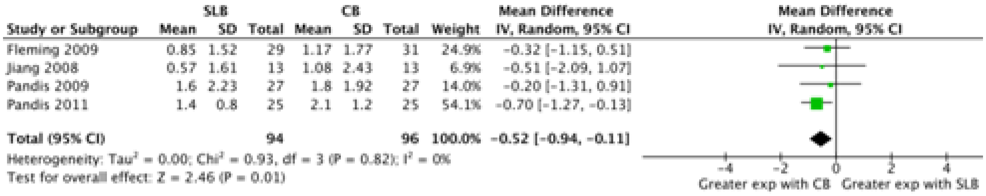


Figure 4: Meta-analysis of mandibular inter-canine width

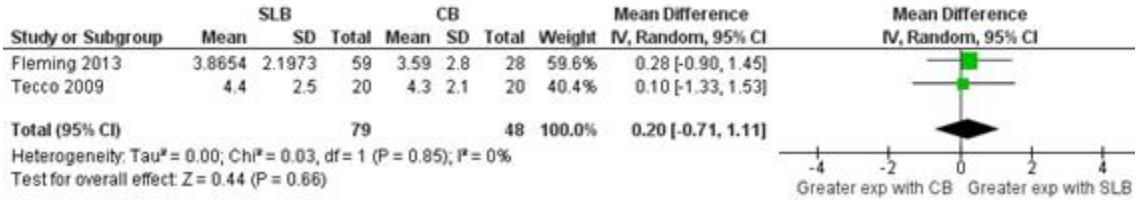


Figure 5: Meta-analysis of maxillary inter-first premolar width

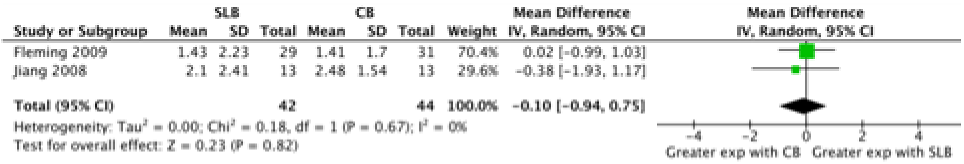


Figure 6: Meta-analysis of mandibular inter-first premolar width

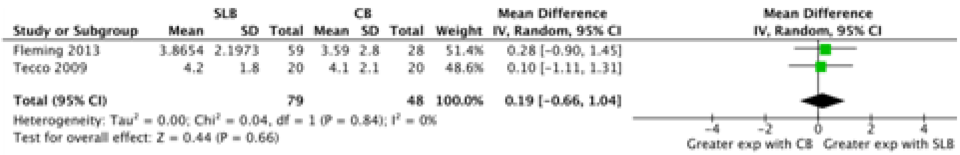


Figure 7: Meta-analysis of maxillary inter-second premolar width

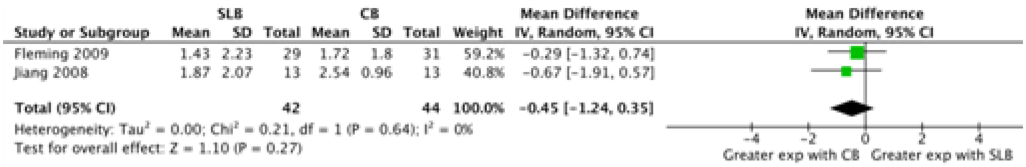


Figure 8: Meta-analysis of mandibular inter-second premolar width

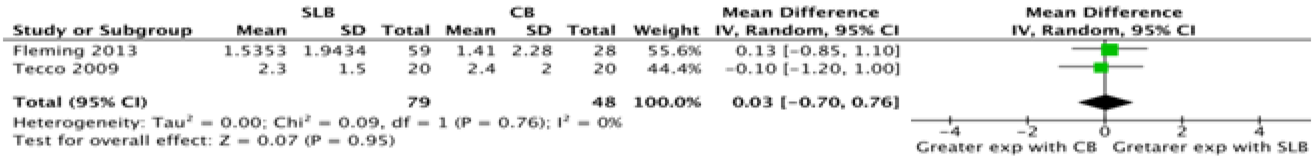


Figure 9: Meta-analysis of maxillary inter-molar width

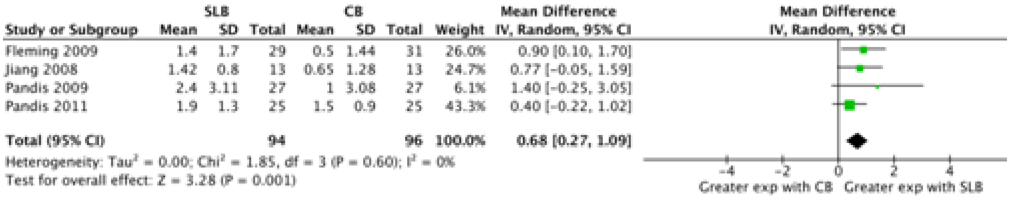


Figure 10: Meta-analysis of mandibular inter-molar width

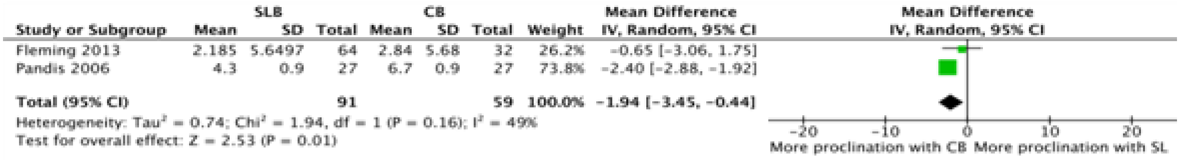


Figure 11: Meta-analysis of maxillary incisor inclination

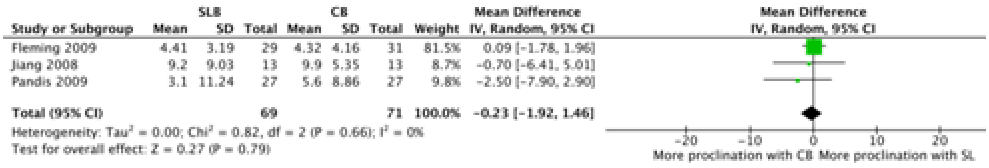


Figure 12: Meta-analysis of mandibular incisor inclination