Effectiveness of micro-implant in vertical control during orthodontic treatment of Class II malocclusion: A systematic review and meta-analysis

Jing Peng
Stomatological Hospital of Guangzhou Medical University
Yahui Lei
First Affiliated Hospital of Jinan University, Jinan University
Yucheng Liu
Stomatological Hospital of Guangzhou Medical University
Jianming Chen (orangeforest393@163.com)
Stomatological Hospital of Guangzhou Medical University
Bin Zhang
Stomatological Hospital of Guangzhou Medical University

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Abstract

Objective

To compare the effectiveness of micro-implant (MI) and conventional anchorage (CA) in vertical control during orthodontic treatment of Class II malocclusion.

Materials and Methods

Literature search was conducted through Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, EMBASE, Web of Science, China National Knowledge Infrastructure (CNKI), Wanfang Database, VIP, and China Biology Medicine (CBM) from inception to December 2021. Randomized clinical trials (RCTs) and Compared clinical trials (CCTs) were included. Mean differences (MDs) with 95% confidence intervals (CIs) were conducted. A meta-analysis concerning change of mandibular plane, vertical change of upper and lower molar, change of occlusal plane, SNB, chin position and profile was carried out.

Results

A total of 10662 records were identified in the database search, A total of 19 studies (10 RCTs and 9 CCTs) were included in the final analysis. MI significantly decreased mandibular plane angle and intruded upper molars compared to CA. No significant difference was found in vertical change of lower molars, occlusal plane, SNB, chin position and profile.

Conclusion

MI seems to be more effective than CA in vertical control during orthodontic treatment of Class II malocclusion. **Clinical Relevance** MI should be given priority when considering the vertical control of Class II patients, which is beneficial to the counterclockwise rotation of mandible or at least prevention of deterioration of the profile.

Introduction

Class II malocclusion is one of the most common problems in orthodontics, which always accompanied with maxillary protrusion and mandibular retrognathia. As for nongrowing teenagers and adults, camouflage treatment involves displacement of teeth to compensate for jaw discrepancy is the substitute for orthognathic surgery. The key point of treatment is maximizing the tooth movement that is desired, while minimizing undesirable side effects [1]. As a kind of maximum anchorage, micro-implant (MI) is widely used for it has many advantages such as minimal anatomic limitations, simpler placement and removal procedure, low patients' compliance and relatively low cost. Most previous studies showed it's more effective in sagittal control compared with conventional anchorage (CA) [2–4]. Nevertheless, a large part of Class II patients featured with increased mandibular plane angle, increased lower facial height and reduced overbite, poor vertical control would result in clockwise rotation of mandibular and further deterioration of the profile. However, evidence on the efficiency of micro-implant in vertical control is controversial, some researchers reported favorable outcome as it could help the counterclockwise rotation of mandibular [5–7], others found more molar extrusion or it's inferior to traditional anchorage [3, 8, 9]. The aim of this systematic review and meta-analysis is to compare the effectiveness of MI and CA in vertical control during orthodontic treatment in Class II malocclusion.

Methods

Protocol and registration

This systematic literature review was conducted and reported in accordance with Cochrane Handbook and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). This review was registered in PROSPERO with the number CRD42022306228 (www.crd.york.ac.uk/prospero).

Eligibility criteria

The criteria for this review was based upon the PICOS approach as follows:

Participants

Adults or nongrowing adolescents of Class II malocclusion seeking orthodontic camouflage treatment to improve occlusion and profile, requiring extraction of premolars.

Intervention

Use of MI as the anchorage reinforcement.

Comparison

Other CA such as transpalatal arch (TPA), headgear, Nance button, J hook and other types of anchorage except for MI.

Outcome: The primary outcomes: change of mandibular plane which includes MP-SN and MP-FH, vertical change of upper and lower molar. The secondary outcomes: change of occlusal plane, SNB, chin position and profile.

Study design

randomized controlled trial (RCT) and controlled clinical trial (CCT).

Exclusion criteria.

Studies were excluded for the following reasons:

- Animal and lab studies, case reports, case-series reports, literature reviews.
- Fewer than 10 subjects in study group or control group.
- Patients still have growing potential.
- Individuals with craniofacial clefts or other syndromic conditions.

Search strategy

We performed electronic search through the following databases (up to 19 December 2021): Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, EMBASE, Web of Science, China National Knowledge Infrastructure (CNKI), Wanfang Database, VIP, and China Biology Medicine (CBM), with no restriction to language and publication year. Search algorithm used in PubMed was listed: (("Orthodontic Anchorage Procedures"[Title/Abstract]) OR (implant[Title/Abstract]) OR (micro-implant[Title/Abstract]) OR (microimplant[Title/Abstract]) OR (mini-screw[Title/Abstract]) OR (miniscrew[Title/Abstract]) OR ("screw implant"[Title/Abstract]) OR ("temporary anchorage device"[Title/Abstract]) OR ("palatal implant"[Title/Abstract]) OR ("midpalatal implant"[Title/Abstract]) OR (mini-plate[Title/Abstract]) OR (miniplate[Title/Abstract])) AND ("Orthodontics"[Mesh]). Search terms and strategies of other databases were similar to the PubMed.

Data extraction

J.P and Y.H.L designed the research, another researcher (Y.C.L) searched the databases and was in charge of duplicate checking. Two independent researchers (J.P and Y.H.L) searched the articles, assessed their suitability by titles and the abstract, any discrepancy was consulted with two experienced researchers (J.M.C and B.Z). Studies meeting the criteria for inclusion will be downloaded by Y.C.L as full texts, and the two researchers (J.P and Y.H.L) continued the further reviewing.

The following data were extracted from the included studies: year of publication, sample size, age of the patients at the beginning of the treatment, types of appliances used for anchorage reinforcement, types and dimensions of MI, loading method of each group, change of mandibular plane, vertical change of upper and lower molar, change of occlusion plane, SNB, chin position and profile.

Risk of bias in individual studies

As for RCTs, we assessed the risk of bias according to the Cochrane Collaboration tool. Domains of random sequence generation, allocation concealment, blinding of participants and personnel, blinding of assessors, incomplete outcome data, selective reporting of outcomes, and other potential sources of bias were assessed.

The quality of the CCTs were assessed according to the MINORS Scale. Quality items includes a clearly stated aim, inclusion of consecutive patients, prospective collection of data, endpoints appropriate to the aim of the study, unbiased assessment of the study endpoint, follow-up period appropriate to the aim of the study, loss to follow up less than 5%, prospective calculation of the study size, an adequate control group, contemporary groups, baseline equivalence of groups and adequate statistical analyses.

Any disagreement was consulted with the two experienced researchers (J.M.C and B.Z) .

Data analysis

Data analysis was performed using Review Manager 5.4. The investigated outcomes for continuous outcome was expressed as mean difference (MD) with 95% confidence interval (CI). Heterogeneity was measured using the chi-square test and I^2 test. If the test indicated considerable heterogeneity ($I^2 > 50\%$), a random effects model would be used. Otherwise ($I^2 \leq 50\%$), a fixed effects model would be applied. RCTs and CCTs were statistically evaluated both jointly and separately with subgroup analysis and significance established at $P < 0.05$. Results of the analyses are presented graphically with forest plots. Funnel plots and Egger's test was used to evaluate the publication bias through Stata 16.0.

Results

Data analysis

The extraction of the total 10662 articles were depicted and presented in Fig. 1, including 187 in CENTRA, ,2316 in PubMed, 1707 in EMBASE, 1775 in Web of Science, 1592 in CNKI, 2272 in Wanfang Database, 30 in VIP, and 783 in CBM. After removing for 3134 duplicates, 7528 articles were evaluated by titles and abstracts, 7448 of them were excluded due to the inappropriate type of research or irrelevant research purpose, leaving 80 full-text articles for complete reading. Subsequently, we excluded 61 papers due to lack of important outcomes or insufficient sample capacity. Finally, 19 articles met the eligibility criteria of this review, including 10 RCTs [5, 8, 10–17] and 9 CCTs [6, 7, 9, 18–23]. The main characteristics of the included studies are presented in Table 1 and Table 2.

Table 1
Data extracted from the enrolled RCTs

Study	Patients (M/F);age	Micro-implant				Comparators			Outcome
		Number (M/F)	Site and Type	Diameter /Length(mm)	Loading method	Type	Number (M/F)	Loading method	
Al-Sibaie 2013[8]	56(21/35); 16–29	28(9/19)	U5-U6	1.6/7mm	150g, parallel to the occlusal plane	TPA	28(12/16)	Two steps	D,S
Ding 2019[10]	20(8/12);15–26(nongrowing)	10(NR)	TPA + MI infrazygomatic crest	2.0/10mm	150g, Intrude U6, RCA	Headgear	10(NR)	150g, RCA, high headgear face-bow	D,S
Liang 2014[11]	20(10/10); 18–29	10(5/5)	U5-U6 or U6-U7	1.5/10mm	NR	TPA +Nance button	10(NR)	NR	S
Liao 2012[12]	28(11/17); 18–37	14(NR)	U5-U6	1.4/8mm or 1.6/8mm	245g	Headgear +Nance button	14(NR)	245g	D,S,P
Liu 2009[5]	34(6/28); 20–33	17(3/14)	U5-U6	1.2/8mm	upward and backward direction	TPA	17(3/14)	parallel to the occlusal plane	D,S,P
Ma 2016[13]	30(NR); NR	15(NR)	U5-U6	1.6/11mm	100-150g, one step, U7(*)	TPA +Nance button	15(NR)	100-150g, two steps, II or III ET	S,P
Meng 2017[14]	30(12/18); 18–37	15(5/10)	U5-U6 ,L5-L6	1.6/11mm	one step	TPA +Nance button	15(7/8)	one step	D,S
Peng 2017[15]	103(52/51); 18–31	51(NR)	NR	NR	100g	Headgear	52(NR)	150g	S
Si 2014[16]	32(0/32); 16–30	16(0/16)	U5-U6	1.6/11mm	canine distalizition with MI, 100-150g/30–45°	J hook	16(0/16)	II ET, banding, Two steps	D,S,P
Zhang 2012[17]	26(0/26); 18–30	16(0/16)	U5-U6 ,L5-L6	1.6/11mm	NR	TPA +Nance button	12(0/12)	Two steps	S

M male, *F* female, *U5* upper second premolar, *U6* upper first molar, *U7* upper second molar, *L5* lower second molar, *L6* lower first molar, *RCA* rocking chair arch, *ET* elastic traction, *D* demtal, *S* skeletal, *P* profile, *NR* not reported, * not included

Table 2
Data extracted from the enrolled CCTs

Study	Patients	Micro-implant				Comparators			Outcome
	(M/F); age	Number (M/F)	Site and Type	Diameter /Length(mm)	Loading method	Type	Number (M/F)	Loading method	
Ao 2010[18]	26 (8/18); 18–24	13 (3/10)	TPA + MI U5-U6	1.6/11mm	100g, canine distalizition with MI	TPA	13 (5/8)	NR	D,S,P
Chen 2014[19]	31(13/18); 22–30	15 (6/9)	U5-U6	1.6/9mm	NR	Headgear	16 (7/9)	300-350g, different type of headgear	D,S,P
Deguchi 2009[7]	30(0/30);18–46	15 (0/15)	U5-U6 ,L6-L7	1.3/6-8mm or 1.5/9mm	intrude posterior section	Headgear	15 (0/15)	anterior elastics, accentuated-curve archwires, multiloop edgewise archwire	D,S
Kuroda 2007[9]	22(0/22); 13–29 (nongrowing)	11 (0/11)	U5-U6	1.3/8mm	100g	Headgear + TPA	11 (0/11)	Closing loop mechanics, different type of headgear	D,S,P
Ouyang 2014[20]	20(0/20); 18–35	10 (0/10)	U5-U6	1.6/9mm	NR	Headgear	10 (0/10)	350g	D,S
Tan 2018[21]	40(18/22); 19–26	20 (NR)	U5-U6	1.6/9mm	147g, II ET, RCA	J hook	20 (NR)	294g/30° II ET, RCA	D,S
Wu 2015[6]	31(12/19); 18–39	17 (7/10)	U5-U6 ,L6-L7	1.6/11mm	150g, canine distalizition with MI, intrude LM	J hook	14 (5/9)	200g/30–45° +II ET	D,S
Yin 2012[22]	42(18–24); 18–25	21	U5-U6	1.5/10mm	NR	TPA	NR	NR	D,S
Yu 2012[23]	47(20/17); 22–39	34 (15/19)	U1-U2,U5-U6	1.6/11mm or 1.6/9mm	150g /50g(Intrude UI)	Nance arch +J hook	13 (5/8)	200g/60°+II ET	D,S

M male, *F* female, *U1* upper incisor, *U2* upper lateral incisor, *U5* upper second premolar, *U6* upper first molar, *L5* lower second molar, *L6* lower first molar, *L7* lower second molar, *RCA* rocking chair arch, *ET* elastic traction, *D* demtal, *S* skeletal, *P* profile, *NR* not reported

Figure 1 PRISMA diagram of article retrieval

Table 1 Data extracted from the enrolled RCTs

Table 2 Data extracted from the enrolled CCTs

Risk of bias

Results of the quality assessment of the enrolled RCTs are shown in Fig. 2. Four studies scored low risk in Random sequence generation for using software or table of random number [5, 8, 14, 15], while other studies scored unclear risk in this column for authors just broadly referred to random assignment. Only Al-Sibaie et al. used opaque sealed envelopes and described the blinding of assessor who was not involved in the study and unaware of its purpose, thus the Allocation concealment and Blinding of outcome data of it were both graded low risk [8]. However, other authors skipped those information. As the type of anchorage appeared obvious during orthodontic treatment, blinding of participants and personnel was impossible, all included studies scored high risk in this column. All studies were assessed as having a low risk of bias of incomplete outcome data, selective reporting, while other bias was unknown. The common deficiency in all studies were lack of description of randomization, allocation concealment, and blinding of assessors, more scrutiny is needed in future researches. Thus, we evaluated the quality of RCTs as moderate.

None of the included CCTs reached the maximum score of the MINORS Scale, and results are shown in Table 3. Six studies acquired 2 marks in Unbiased assessment of the study endpoint, for the assessments were conducted by different assessors or repeated more than once [7, 16, 18–

21]. Yu et al. lost 1 mark for the repetition was not mentioned [23]. Kuroda et al. and Yin et al. scored 0 marks due to lack of information [9, 22]. Except for Deguchi et al. [7], other researches didn't mention relevant follow-up, thus their "follow-up period appropriate to the aim of the study" and "loss to follow up less than 5%" all scored 0 marks. All studies scored 0 marks in "Prospective calculation of the study size". 4 studies [6, 20, 21, 23] didn't mention the comparison of baseline and scored 0 marks in " Baseline equivalence of groups", while other studies scored 2 marks. All CCTs obtained 2 marks in sections of "A clearly stated aim", "Inclusion of consecutive patients", "Prospective collection of data", "Endpoints appropriate to the aim of the study", "An adequate control group", "Contemporary groups" and "Adequate statistical analyses". The marks ranged from 15 to 22 and all studies scored more than 12 marks, indicating that all CCTs were of relatively moderate to high quality.

Primary outcome measure:

Change of mandibular plane

All included studies involving 668 participants reported the change of mandibular plane as shown in Fig. 3. In the total analysis, we identified heterogeneity across the included studies ($P < 0.001$; $I^2 = 96\%$), and we used a random-effects model to summarize mean effect size and performed subgroup analysis according to study type. The change of mandibular plane in the subtotal analysis result (MD = -1.15; 95% CI = -1.67 to -0.63, $P < 0.001$) showed MI group performed significantly better in decrease of mandibular plane, which is similar to the outcome of RCTs (MD = -0.81; 95% CI = -1.53 to -0.09, $P < 0.05$) and CCTs (MD = -1.56; 95%CI = -2.33 to -0.79, $P < 0.001$). The funnel plot indicated the existence of publication bias, since the studies are diffusely distributed, confirmed with Egger's test ($p = 0.025$). However, with Trim and Fill Analysis, result remained unchanged and proved to be stable.

Vertical change of upper molar

15 studies involving 489 participants reported the vertical change of upper molar as shown in Fig. 4. In the total analysis, we identified heterogeneity across the included studies ($P < 0.001$; $I^2 = 98\%$), and we used a random-effects model to summarize mean effect size and performed subgroup analysis according to study type. The vertical change of maxillary molar in the subtotal analysis result (MD = -1.45; 95% CI = -2.02 to -0.89, $P < 0.001$) showed MI group performed significantly better in intrusion of upper molar, which is similar to the outcome of RCTs (MD = -1.51; 95% CI = -2.86 to -0.16, $P < 0.05$) and CCTs (MD = -1.3; 95% CI = -1.90 to -0.69, $P < 0.001$). The funnel plot indicated the existence of publication bias, since the studies are diffusely distributed, confirmed with Egger's test ($p = 0.009$). However, with Trim and Fill Analysis, result remained unchanged and proved to be stable.

Vertical change of lower molar

4 studies involving 103 participants reported the vertical change of mandibular molar as shown in Fig. 5. All of these studies were CCTs, so we didn't perform subgroup analysis. We identified heterogeneity across the included studies ($P < 0.001$; $I^2 = 91\%$). A negative MD indicated intrusion of lower molar in the MI group compared with the control group, though there was no significant change between the two group (MD = -0.61; 95% CI = -1.79 to 0.57; $P > 0.05$).

Secondary outcome measures:

Change of occlusal plane

6 studies involving 175 participants reported the change of occlusal plane as shown in Fig. 6. In the total analysis, we identified heterogeneity across the included studies ($P < 0.001$; $I^2 = 91\%$), and we used a random-effects model to summarize mean effect size and performed subgroup analysis according to study type. The change of occlusal plane was not significant in the subtotal analysis (MD = -1.18; 95% CI = -2.83 to 0.47, $P > 0.05$), which is similar to the result of CCTs (MD = -0.42; 95% CI = -2.11 to 1.26, $P > 0.05$). Whereas it had a significant difference in RCTs (MD = -3.13; 95% CI = -3.85 to -2.41, $P < 0.001$). However, a negative MD indicated decrease of occlusal plane in the MI group compared with the control group.

Change of SNB

13 studies involving 422 participants reported the change of SNB as shown in Fig. 7. In the total analysis, we identified heterogeneity across the included studies ($P < 0.001$; $I^2 = 76\%$), and we used a random-effects model to summarize mean effect size and performed subgroup analysis according to study type. The pooled result for SNB was not significant in the subtotal analysis (MD = 0.15; 95% CI = -0.20 to 0.51, $P > 0.05$), which is similar to the outcome of RCTs (MD = -0.23; 95% CI = -0.50 to 0.04, $P > 0.05$) and CCTs (MD = 0.53; 95% CI = -0.10 to 1.15, $P > 0.05$).

Change of chin position

4 studies involving 107 participants reported the change of chin position as shown in Fig. 8. In the total analysis, we identified heterogeneity across the included studies ($P < 0.001$; $I^2 = 93\%$), and we used a random-effects model to summarize mean effect size and performed subgroup analysis according to study type. A positive MD indicated forward moving of chin in the MI group compared with the control group, though the pooled result was not significant in the subtotal analysis (MD = 1.55; 95% CI = -0.32 to 3.42, $P > 0.05$), which is similar to the outcome of RCTs (MD = 3.13; 95% CI = -3.81 to 10.07, $P > 0.05$) and CCTs (MD = 0.66; 95% CI = -1.70 to 3.01, $P > 0.05$).

Change of profile

5 studies involving 140 participants reported the change of profile as shown in Fig. 9. In the total analysis, we identified heterogeneity across the included studies ($P > 0.05$; $I^2 = 0\%$), and we used a fixed-effects model to summarize mean effect size and performed subgroup analysis according to study type. The pooled result for profile was not significant in the subtotal analysis (MD = -0.05; 95% CI = -0.65 to 0.54, $P > 0.05$), which is similar to the outcome of RCTs (MD = 0.04; 95% CI = -0.65 to 0.73, $P > 0.05$) and CCTs (MD = -0.30; 95% CI = -1.46 to 0.86, $P > 0.05$). However, a negative MD indicated improve of profile in the MI group compared with the control group.

Discussion

This review provided an insight into the effectiveness of micro-implant in vertical control during orthodontic treatment. Previously, many meta-analysis simply focused on the superiority of micro-implant during en-masse retraction [2–4]. Hence, the qualitative and quantitative interpretation of the results pertinent to this review would be of great value.

Primary outcome measure

According to our quantitative synthesis, micro-implant is superior to traditional anchorage in reducing mandibular plane angle (MD = -1.15; 95% CI = -1.67 to -0.63, $P < 0.001$) and intruding upper molars (MD = -1.45; 95% CI = -2.02 to -0.89, $P < 0.001$). It seems to be noteworthy not only theoretically but also clinically, since vertical control is important in orthodontic treatment. Poor vertical control always companied with clockwise rotation of the mandibular, resulting in further deterioration of the profile of skeletal class II patients. Many studies have pointed out that mandibular rotation is closely related to alteration of the occlusal plane, especially the functional occlusal plane (FOP), which presents the occlusal relationship of posterior teeth.

In MI group, the occlusogingival position of it determines the line of retraction force was below the center of resistance of the maxillary dentition (halfway from the root apex to the alveolar bone crest between the first and second premolars). The force had a vertical and horizontal component, thus, molars and total dentition would be intruded with the retraction of anterior teeth, which is beneficial to the counterclockwise of mandibular [5, 7, 10, 19]. Also, Deguchi et al. and Ding et al. intruded upper molars by MI from the beginning of the treatment, which is good for the improvement of profile of openbite patients and Class II high-angle patients [7, 10]. Moreover, the force used during retraction was focused on MI rather than molars, it reduced the friction and conformed to the principle which advocates thin wire and light force. As a result, the movement of teeth is close to physiological movement [6].

As for control group, the retraction force acted on molars no matter what kind of the anchorage, extrusion and mesial movement of molars inevitably happened as the reciprocal effects of incisor retraction, with opening rotation of the mandible. To a certain extent, the use of headgear in higher traction gear may lead to counterclockwise rotation of the mandible, but it requires good patient compliance [24]. Furthermore, Class II elastic traction is always supplemented in the daytime, which may neutralized the effect of vertical control and results in the extrusion of lower molars [6, 13, 16, 23].

Nevertheless, two studies found mandibular plane angle decreased in control group, while increased in the MI group. These results may caused by the statistically significant distal movement of the upper molars in MI group, as a result of the retraction force applied to anterior teeth, which was translated to posterior teeth through interdental contacts [8]. In study of Kuroda et al., molar extrusion was found in both groups, while the mesial movements of molars in control group canceled the clockwise rotation of mandibular. Contrarily, minimum anchorage loss in the MI group caused a slight clockwise rotation of the mandible [9]. Meanwhile, Class III elastic traction was applied to balance the anchorage between maxillary and mandibular anchorage in MI group, which could also resulted the extrusion of upper molars [13].

Two researchers applied MI in mandibular posterior area to intrude lower molars, which showed priority in intrusion of lower molars in comparation with control group [6, 7]. However, there was no significant change in the pooled result of lower molar, partly because the difference in the anatomic structures between the jaws, as well as discrepancy of methodology and insufficient studies.

Secondary outcome measures

Our meta-analysis showed that with the use of MIs, the occlusal plane decreased, the position of mandibular and chin moved forward, as well as the profile was improved, though the results were not statistically significant. We conjecture reasons may be: 1) Some researchers didn't illustrated the definition of occlusal plane they used, since the line of retraction force was below the center of resistance of the maxillary dentition, clockwise rotation could also happen in the upper arch, with extrusion of incisors [18], bisected occlusal plane (BOP) may increased though functional occlusal plane (FOP) decreased. 2) With the counterclockwise rotation of mandible, it would move forward and SNB angle would increased in the meanwhile. However, retraction of lower incisors may neutralized a part of such effect and resulted the decrease of SNB [14, 17]. 3) Many studies found both groups showed improvement of profile to some extent, as we can't completely deny the function of traditional anchorage. For example, the tongue myofunctional exercise in patients with TPA could have some intrusion to molars. 4) Limited data existed and further well-designed trials will be expected in formulating robust conclusion.

Well vertical control can result in a decreased anteroposterior jaw discrepancy and is important for successful orthodontic treatment [20, 25]. On the contrary, approximately 3mm of increase in the mandibular plane angle was observed with every 1mm extrusion of the molars. Therefore, molar intrusion, or prevention of molar extrusion is crucial for successful treatment of Class II patients, yet Class III patients might not be suitable for treatment with MI from such esthetic point of view.

In clinical use of MI, we should choose the placement individually, infrazygomatic crest may be a better choice which can provide more vertical component can be applied to intrude molars [10]. Also, we should judge the bone density and adjacent anatomical structures before the placement to assess the success rate of MI or the option of anchorage design. However, in order to enhance the control of anterior tooth torque and avoid the pendulum effect, additional devices such as rocking chair archwire, different height of hook in anterior arch, or additional MI in anterior area should be taken into consideration, especially for patients with incompetent lips or gingival smile [10, 21, 23].

Limitation

This systematic review must be evaluated in the context of a number of limitations.

1) While the random sequence generation, allocation concealment and blinding of outcome date of some RCTs remained unclear, future designs should strictly adhere to methodologic guidelines are necessary to improve the quality of study.

2) Methodological issues (such as the wide spectrum of malocclusions, appliances, and kinds of anchorage) existed for all included studies, future studies should strive for more homogeneous designs and report on trials in more detail.

3) Insufficient research into secondary outcomes, which may lead to controversial results.

Conclusions

On the basis of this systematic review and meta-analysis, we concluded the use of MIs enables better vertical control compared with conventional reinforcement methods, which is beneficial to the counterclockwise rotation of mandible or at least prevention of deterioration of the profile.

Due to the moderate quality of evidence, the results should be interpreted with some caution. More high qualitied studies strictly adhering to methodologic guidelines are necessary to provide available evidence for future analysis.

Declarations

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Author contributions

Jing Peng and Yahui Lei created the concept and designed the research, The first draft of the manuscript was written by Jing Peng. All authors made substantial contributions to the research, critically reviewed the manuscript and approved the final version as submitted.

& Jing Peng and Yahui Lei contributed equally to this work and should be considered co-first authors.

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Conflict of interest

The authors declare no conflicts of interest related to the study.

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Table 3

Table 3 is available in the supplementary files section.

Figures

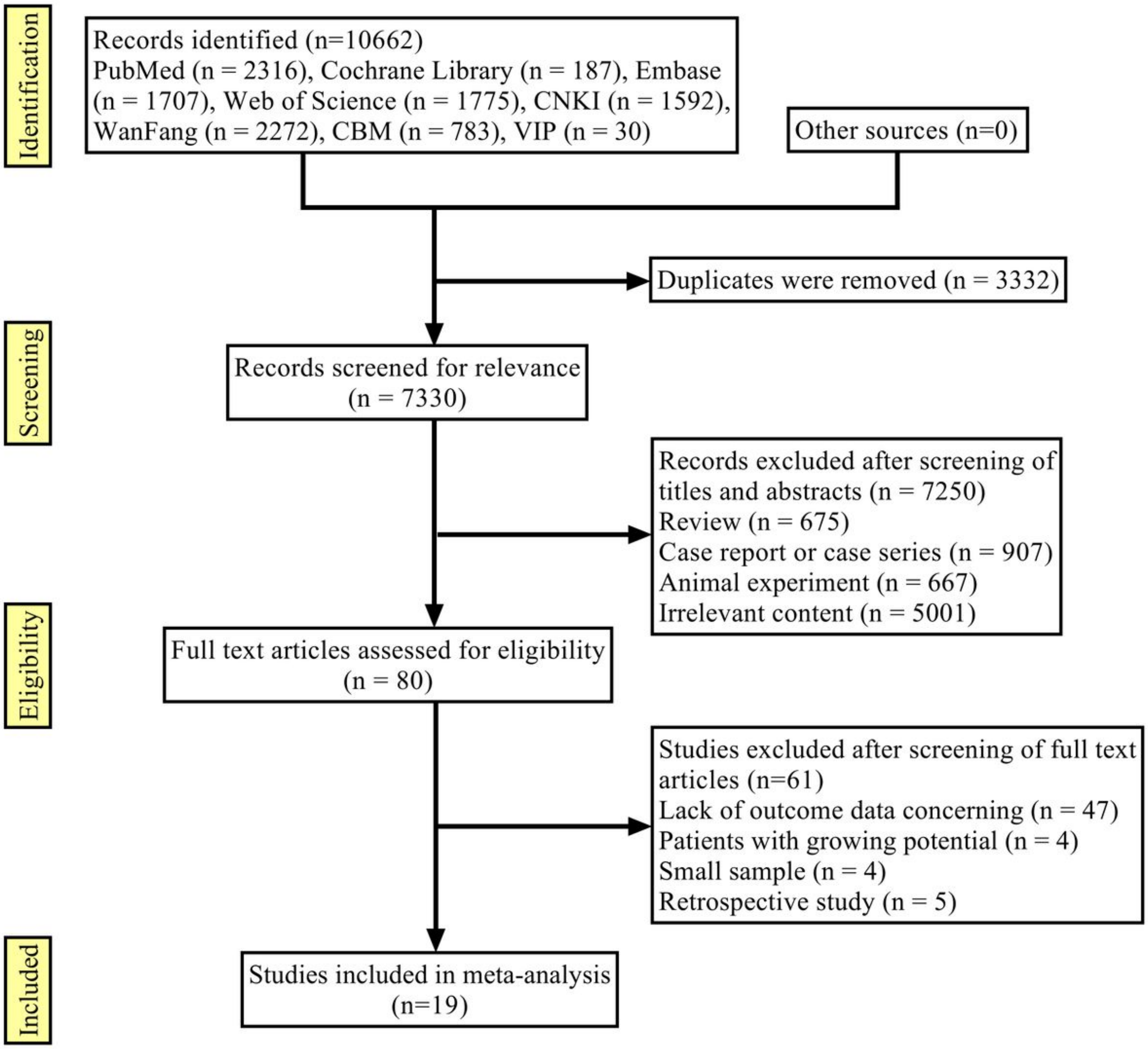

Figure 1

PRISMA diagram of article retrieval

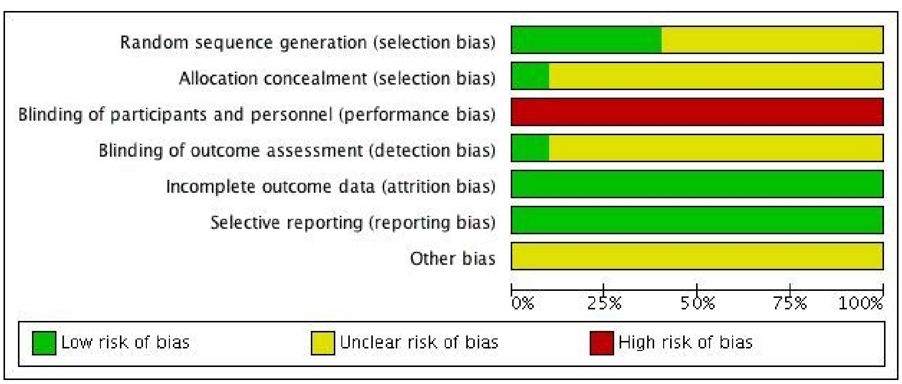

Figure 2

Risk of bias of RCTs

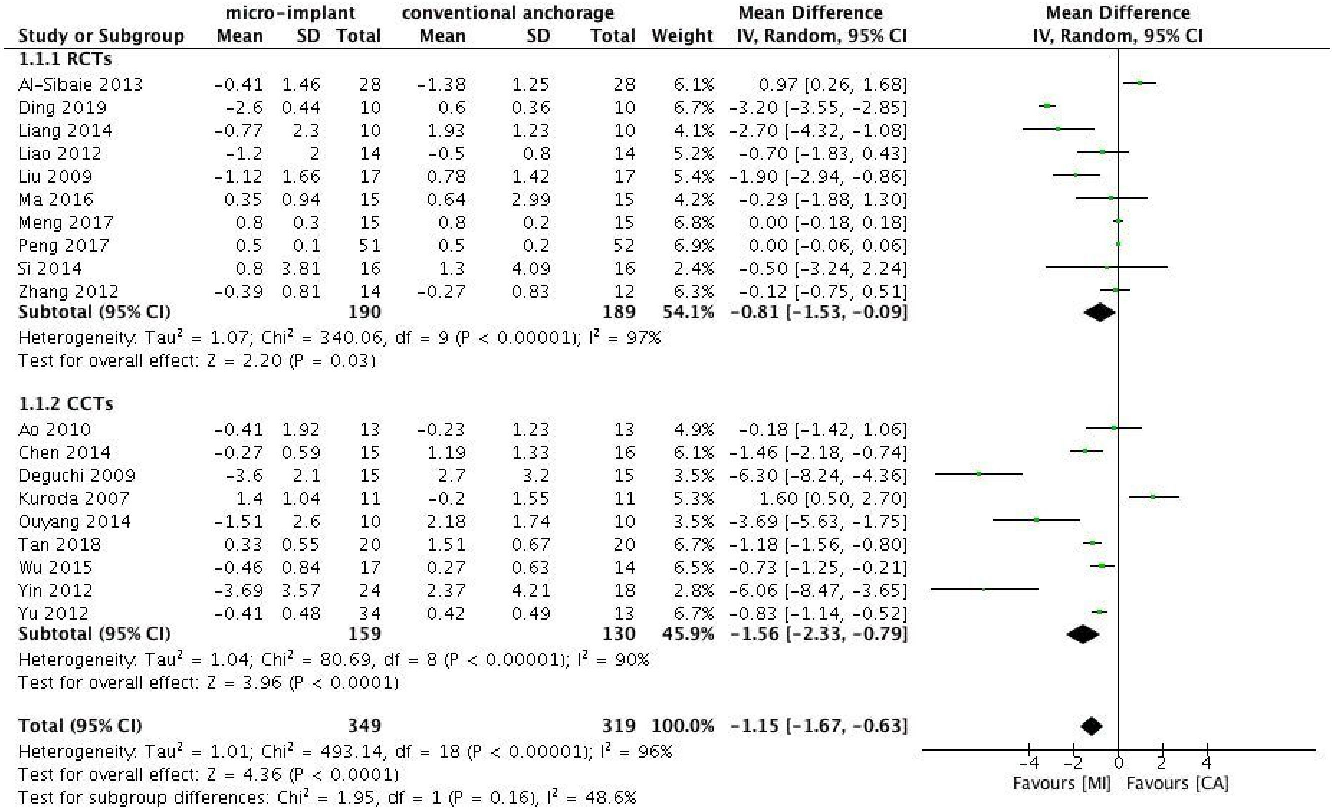

Figure 3

Forest plots for the meta-analyses of MI versus CA considering change of mandibular plane

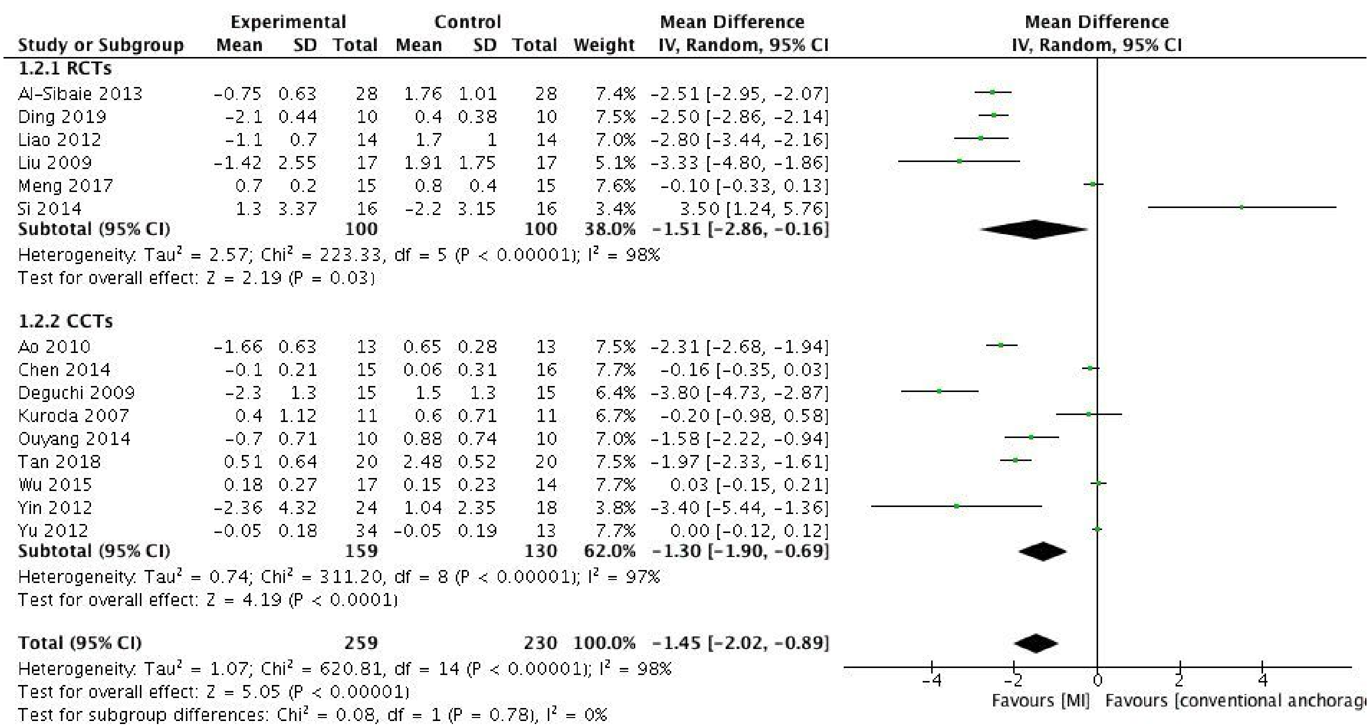

Figure 4

Forest plots for the meta-analyses of MI versus CA considering vertical change of upper molar

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Deguchi 2009	−0.8	1.3	15	1.5	0.6	15	26.9%	−2.30 [−3.02, −1.58]
Kuroda 2007	1.8	0.91	11	1.1	0.92	11	26.6%	0.70 [−0.06, 1.46]
Ouyang 2014	0.27	1.6	10	−0.28	2.57	10	17.1%	0.55 [−1.33, 2.43]
Wu 2015	−0.52	0.41	17	0.39	0.37	14	29.5%	−0.91 [−1.18, −0.64]
Total (95% CI)			**53**			**50**	**100.0%**	**−0.61 [−1.79, 0.57]**

Heterogeneity: $Tau^2 = 1.21$; $Chi^2 = 33.43$, df = 3 ($P < 0.00001$); $I^2 = 91\%$
Test for overall effect: Z = 1.01 (P = 0.31)

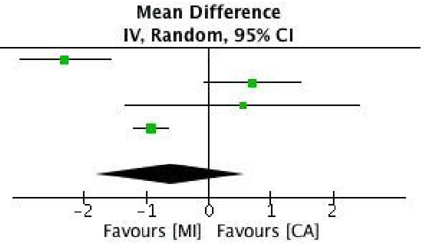

Figure 5

Forest plots for the meta-analyses of MI versus CA considering vertical change of lower molar

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.5.1 RCTs								
Liang 2014	−0.21	0.56	10	3.01	1.08	10	19.4%	−3.22 [−3.97, −2.47]
Si 2014	−1	4.25	16	1.1	2.87	16	13.8%	−2.10 [−4.61, 0.41]
Subtotal (95% CI)			**26**			**26**	**33.2%**	**−3.13 [−3.85, −2.41]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.70$, df = 1 (P = 0.40); $I^2 = 0\%$								
Test for overall effect: Z = 8.49 ($P < 0.00001$)								
1.5.2 CCTs								
Chen 2014	0.27	0.59	15	0.5	1.03	16	19.7%	−0.23 [−0.82, 0.36]
Deguchi 2009	−1.4	1.6	15	1.8	2.9	15	16.7%	−3.20 [−4.88, −1.52]
Kuroda 2007	4.6	2.66	11	3.2	2.27	11	15.4%	1.40 [−0.67, 3.47]
Tan 2018	3.87	3.58	20	3.23	3.35	20	15.1%	0.64 [−1.51, 2.79]
Subtotal (95% CI)			**61**			**62**	**66.8%**	**−0.42 [−2.11, 1.26]**
Heterogeneity: $Tau^2 = 2.24$; $Chi^2 = 14.84$, df = 3 (P = 0.002); $I^2 = 80\%$								
Test for overall effect: Z = 0.49 (P = 0.62)								
Total (95% CI)			**87**			**88**	**100.0%**	**−1.18 [−2.83, 0.47]**

Heterogeneity: $Tau^2 = 3.51$; $Chi^2 = 52.71$, df = 5 ($P < 0.00001$); $I^2 = 91\%$
Test for overall effect: Z = 1.40 (P = 0.16)
Test for subgroup differences: $Chi^2 = 8.38$, df = 1 (P = 0.004), $I^2 = 88.1\%$

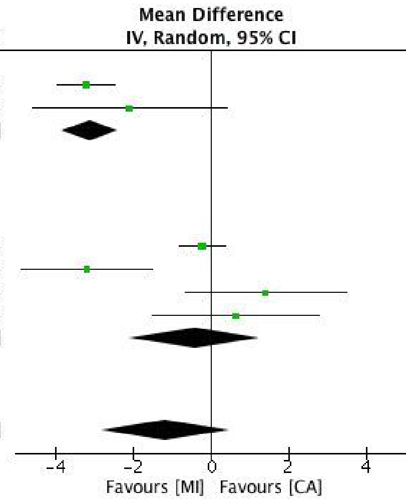

Figure 6

Forest plots for the meta-analyses of MI versus CA considering change of occlusal plane

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	conventional anchorage Mean	conventional anchorage SD	conventional anchorage Total	Weight	Mean Difference IV, Random, 95% CI
1.4.1 RCTs								
Al-Sibaie 2013	−0.42	1.16	28	−0.07	0.68	28	9.4%	−0.35 [−0.85, 0.15]
Liang 2014	−0.39	0.42	10	−0.22	1.43	10	6.5%	−0.17 [−1.09, 0.75]
Liao 2012	0.9	1.2	14	0.7	1.2	14	6.7%	0.20 [−0.69, 1.09]
Liu 2009	−0.32	1.06	17	−0.63	0.79	17	8.5%	0.31 [−0.32, 0.94]
Ma 2016	−0.44	0.93	15	−0.31	1.28	15	7.3%	−0.13 [−0.93, 0.67]
Si 2014	0.3	1.37	16	0.4	1.49	16	6.1%	−0.10 [−1.09, 0.89]
Zhang 2012	−0.45	0.45	14	0.1	0.3	12	10.6%	−0.55 [−0.84, −0.26]
Subtotal (95% CI)			**114**			**112**	**55.0%**	**−0.23 [−0.50, 0.04]**
Heterogeneity: $Tau^2 = 0.03$; $Chi^2 = 8.10$, df = 6 (P = 0.23); $I^2 = 26\%$								
Test for overall effect: Z = 1.66 (P = 0.10)								
1.4.2 CCTs								
Chen 2014	−0.13	0.35	15	−0.19	0.66	16	10.2%	0.06 [−0.31, 0.43]
Deguchi 2009	1.4	1.1	15	−0.2	1	15	7.6%	1.60 [0.85, 2.35]
Kuroda 2007	−0.8	0.48	11	−0.6	1.18	11	7.6%	−0.20 [−0.95, 0.55]
Tan 2018	−0.76	0.85	20	−0.73	0.96	20	8.9%	−0.03 [−0.59, 0.53]
Wu 2015	0.45	1.04	17	−0.96	0.97	14	7.9%	1.41 [0.70, 2.12]
Yin 2012	0.21	2.35	24	−0.19	3.47	18	2.8%	0.40 [−1.46, 2.26]
Subtotal (95% CI)			**102**			**94**	**45.0%**	**0.53 [−0.10, 1.15]**
Heterogeneity: $Tau^2 = 0.45$; $Chi^2 = 25.38$, df = 5 (P = 0.0001); $I^2 = 80\%$								
Test for overall effect: Z = 1.64 (P = 0.10)								
Total (95% CI)			**216**			**206**	**100.0%**	**0.15 [−0.20, 0.51]**

Heterogeneity: $Tau^2 = 0.29$; $Chi^2 = 49.94$, df = 12 ($P < 0.00001$); $I^2 = 76\%$
Test for overall effect: Z = 0.84 (P = 0.40)
Test for subgroup differences: $Chi^2 = 4.70$, df = 1 (P = 0.03), $I^2 = 78.7\%$

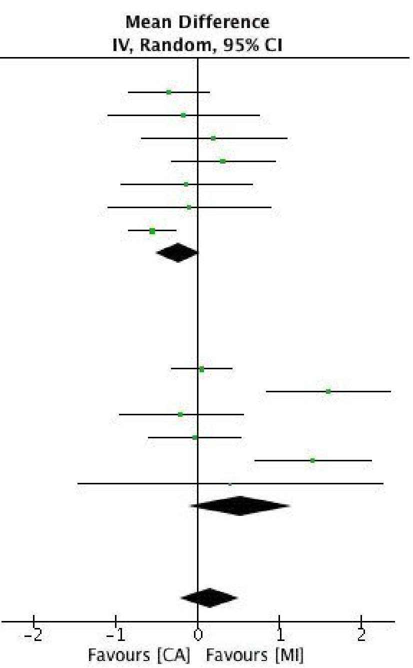

Figure 7

Forest plots for the meta-analyses of MI versus CA considering change of SNB

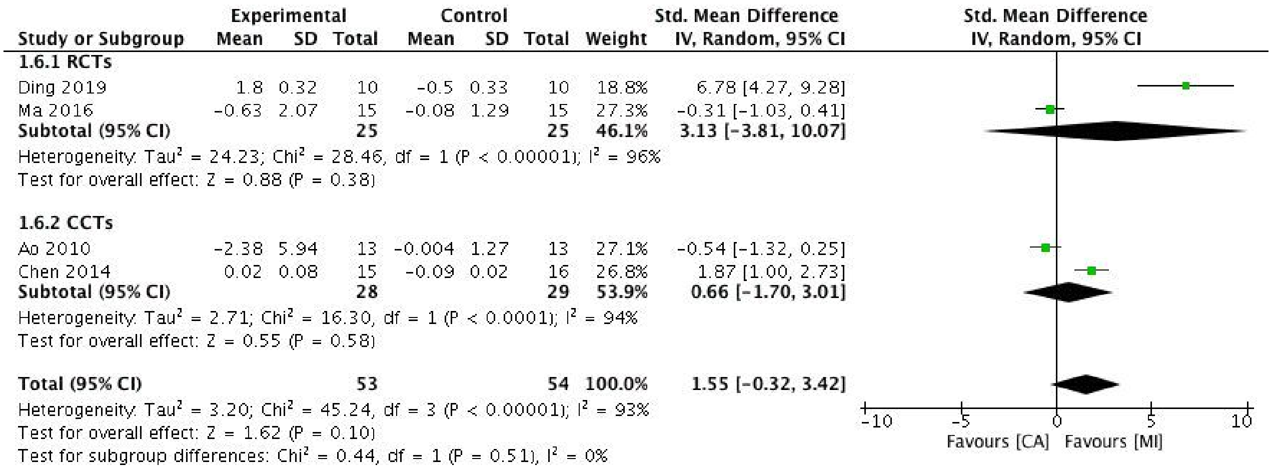

Figure 8

Forest plots for the meta-analyses of MI versus CA considering change of chin position

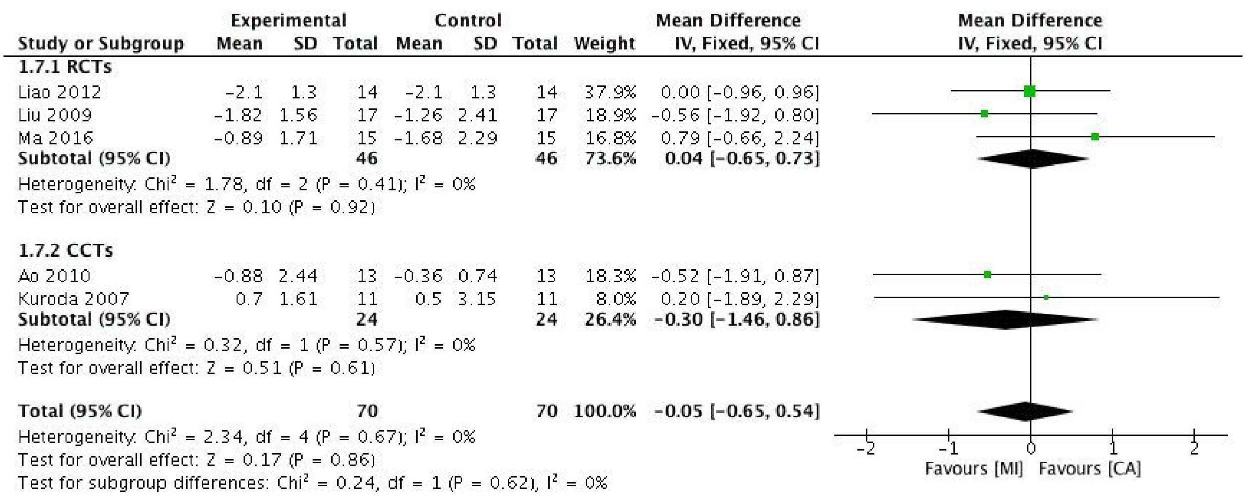

Figure 9

Forest plots for the meta-analyses of MI versus CA considering change of profile

Supplementary Files

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- table3.jpg