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REVIEW ARTICLE

The effectiveness of low-level laser therapy in accelerating orthodontic tooth movement: a meta-analysis

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Abstract Low-level laser therapy is claimed to accelerate bone remodeling. The aim of this meta-analysis was to critically appraise current evidence and to determine the effectiveness of low-level laser therapy in accelerating orthodontic tooth movement. PubMed, Web of Knowledge, Embase, CENTRAL, ProQuest Dissertations &Theses, and SIGLE were electronically searched from Jan 1990 to Jun 2013. Article screening, data extraction, assessment of risk of bias and evaluation of evidence quality through GRADE were conducted independently and in duplicate by two reviewer authors. Outcome of interest in this meta-analysis was accumulative moved distance (AMD). Meta-analyses were performed in Comprehensive Meta-Analysis Version 2.2.064 (Biostat, Englewood, NJ, USA). Finally, five studies were included in this meta-analysis. The meta-analysis revealed that the pooled difference in mean (DM) was 0.33 [95 % CI: (0.03–0.64)], 0.76 [95 % CI: (−0.14, 1.65)] and 0.43 [95 % CI: (−0.05, 0.91)] for AMD within 1 month, AMD within 2 months and AMD within 3 months, respectively. However, significant heterogeneities and instability of the pooled results were detected. Moreover, publication bias was found for AMD within 3 months. The subgroup analysis on the wavelength of 780 nm revealed that the pooled DM of AMD were 0.54 (95 % CI=0.18–0.91), 1.11 (95 % CI=0.91–1.31) and 1.25 (95 % CI=0.68–1.82) for 1, 2, and 3 months, respectively. For the output power of 20 mW, the subgroup analysis showed that the pooled DM of AMD was 0.45 (95 % CI=0.26–0.64), 1.11 (95 % CI=0.91–1.31), and 1.25 (95 % CI=0.68–1.82) for 1, 2, and 3 months, respectively. Weak evidence suggests that low-level laser irradiations at the wavelength of 780 nm, at the fluence of 5 J/cm^2 and/or the output power of 20 mW could accelerate orthodontic tooth movement within 2 months and 3 months. However, we cannot determine its effectiveness within 1 month due to potential measurement errors.

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Introduction

Orthodontic treatment, a common dental treatment for malaligned teeth, requires about 2 years of treatment [1, 2]. This long duration of treatment may lead to root resorption, caries, and even decreased patient compliance [3–7]. Thus, accelerating orthodontic tooth movement and the subsequent efficient orthodontic treatment would be beneficial for both practitioners and patients.

Nowadays, the versatility of low-level laser therapy has been extensively applied in clinical practice [8–15]. In particular, in the field of orthodontics, it has been used for the alleviation of orthodontic pain and acceleration of orthodontic tooth movement [16, 17]. Orthodontic treatment is per se a process of alveolar bone remodeling [18] and it has been well documented by Altan et al. and others that low-level laser irradiation can accelerate bone remodeling in orthodontic tooth movement [19–22]. Several clinical trials have determined the effectiveness of low-level laser therapy in accelerating orthodontic tooth movement [17, 23–25]. However, divergent and controversial results still exist, which would mislead clinical practice. Thus, a critical systematic review would be helpful for an unbiased understanding of the effectiveness of low-level therapy for accelerating orthodontic tooth movement.

In this study, we conducted a critical meta-analysis on randomized controlled trials (RCT) or controlled clinical trials (CCT) to assess the efficacy of low-level laser therapy in accelerating orthodontic tooth movement.

Materials and methods

Inclusion criteria for included studies

Types of participants

Participants in the included studies should be otherwise healthy patients who require orthodontic treatments. Specifically, they needed the extractions of first premolars and retraction of anterior teeth due to protrusion or dental crowding.

Types of interventions

Interventions should be low-level laser therapy or low-level laser irradiation.

Types of studies

We included studies which evaluate the effectiveness of low-level laser therapy in accelerating orthodontic tooth movement. Both randomized and non-randomized controlled trials were eligible.

Search strategy

PubMed, Web of Knowledge, Embase, CENTRAL, and ProQuest Dissertations & Theses were electronically searched. Moreover, the grey literature database of SIGLE was searched for grey literature. The specific search strategy is presented in Table 1. Specifically, the electronic searching was conducted from Jan 1990 to Jun 2013 with no language restriction. This process was conducted independently and in duplicate by two reviewer authors.

Table 1 Search strategies for each database

Database	Search strategy
PubMed	(Laser therapy, low-level [mesh] OR laser therapy OR laser irradiation OR laser) AND (Orthodontics [mesh] OR orthodontic*) AND (Tooth movement [mesh] OR movement OR move OR moving OR retract*) AND (accelerat* OR short* OR speed OR rate)
Embase	(low-level laser therapy OR laser therapy OR laser irradiation OR laser) AND (orthodontic*) AND (tooth movement OR movement OR move OR moving OR retract*) AND (accelerat* OR short* OR speed OR rate)
Web of Knowledge	(low-level laser therapy OR laser therapy OR laser irradiation OR laser) AND (orthodontic*) AND (tooth movement OR movement OR move OR moving OR retract*) AND (accelerat* OR short* OR speed OR rate)
CENTRAL	(low-level laser therapy OR laser therapy OR laser irradiation OR laser) AND (orthodontic*) AND (tooth movement OR movement OR move OR moving OR retract*)
ProQuest Dissertation & Theses	(low-level laser therapy OR laser therapy OR laser irradiation OR laser) AND (orthodontic*) AND (tooth movement OR movement OR move OR moving OR retract*)
SIGLE	(laser) AND (tooth movement)

Limits: publication date from Jan 1980 to Jun 2013

Data extraction and analysis

The data regarding study design, participant details, intervention outcome were extracted and recorded independently and in duplicate by two reviewer authors. The outcome of interest in this meta-analysis was accumulated moved distance of teeth.

Risk of bias of all the included studies were assessed independently and in duplicate by two reviewer authors according to Cochrane Collaboration's tool for assessing risk of bias [26, 27]. Specifically, the main items included: (1) random sequence generation; (2) allocation concealment; (3) blinding of participants and personnel; (4) blinding of outcome assessment; (5) incomplete outcome data; (6) selective outcome reporting; (7) other sources of bias. Studies with two or more items being assessed as high risk were identified as high risk of bias; those with one item being assessed as high risk were viewed as medium risk of bias; those with no item being assessed as high risk were considered as low risk of bias.

Moreover, the quality of evidence was assessed by using GRADE system of rating quality of evidence [28–33].

Original outcome data, if possible, would be statistically pooled and all the meta-analyses were performed in Comprehensive Meta-Analysis Version 2.2.064 (Biostat, Englewood, NJ, USA). Differences in mean were employed for statistical pooling for continuous data; odds ratios were used for dichotomous data. Heterogeneity across studies was evaluated through I^2 statistic and an I^2 greater than 50 % was considered as substantial heterogeneity. If substantial heterogeneity existed, a meta-regression or subgroup analysis would be performed to explore the potential heterogeneity. Egger's test [34] and Begg's test [35] were employed to assess publication bias or small study effect. Moreover, sensitivity analysis was conducted to evaluate the robustness of the pooled results in the meta-analysis. Cumulative meta-analysis was performed to determine the chronological changes of the pooled results from the year of first publication to the latest one.

Results

Description of studies

Initially, we retrieved 62 articles from the database and excluded 55 irrelevant ones. The remaining seven studies were further assessed for eligibility and 5 studies [17, 23–25, 36] (4 RCT and 1 CCT) were finally included in this meta-analysis. The procedures of electronic searching are displayed in Fig. 1. Sample sizes ranged from 11 to 20 with the age being between 12 and 23 years old. All the studies used canine retraction as the study model. Two studies [23, 25] specified that canine retraction started 3 months after the first premolar extraction while the others [17, 24, 36] did not specify. Moreover, posterior anchorage (strategies which prevent the mesial movement of molars) was applied in four studies [17, 23, 24, 36] while not specified in one study [25]. Among the five included studies, two [24, 25] were high risk of bias, two [17, 36] were medium risk of bias, and one [23] was low risk of bias. The details of each included study and the assessment of risk of bias were presented in Tables 2 and 3, respectively.

Description of outcomes

Our predefined outcome—accumulative moved distance of teeth—was studied in all the included studies. Specifically, in this meta-analysis, accumulative moved distances were available for 1, 2, and 3 month. Thus, the outcomes in this study included accumulative moved distance within 1 month, accumulative moved distance within 2 months and accumulative moved distance within 3 months. Unfortunately, the quality of evidence of the outcomes in this meta-analysis was evaluated to be very low. The GRADE assessments for quality of evidence for each outcome were shown in Table 4.

Description of interventions

All the included studies compared low-level laser irradiations and control for accelerating orthodontic tooth movement. Different wavelengths were used in the included studies: 650 nm was used in Gui 2008 [24]; 780 nm was employed in Cruz 2004 and Sousa 2011 [17, 25]; 800 nm was applied in Doshi-Mehta 2012 [36]; 860 nm was used in Limpanichkul 2006 [23]. For output power, 0.25 mW was used in Doshi-Mehta 2012[36], 20 mW was applied in three studies [17, 24, 25] and 100 mW was employed in Limpanichukul 2006 [23]. For fluence of laser irradiation, 5 J/cm^2 was used in Cruz 2004 and Sousa 2011; 25 J/cm^2 was applied in Limpanichjul 2006 and Gui 2008; Doshi-Mehta 2012 did not mention this parameter. Furthermore, laser irradiations were applied in the first 3 days after force applications in Limpanichkul 2006 while were extended to at least 7 days after force applications in other studies.

Effects of interventions

Accumulative moved distance within 1 month

Among the five included studies, four [17, 23–25] investigated this outcome. However, due to different laser irradiation protocols applied in these studies (Table 2), random effect model was employed for statistical pooling. As presented in Fig. 2, the meta-analysis revealed that the pooled difference in means (DM) was 0.33 (95 % CI=0.03–0.64). However, a

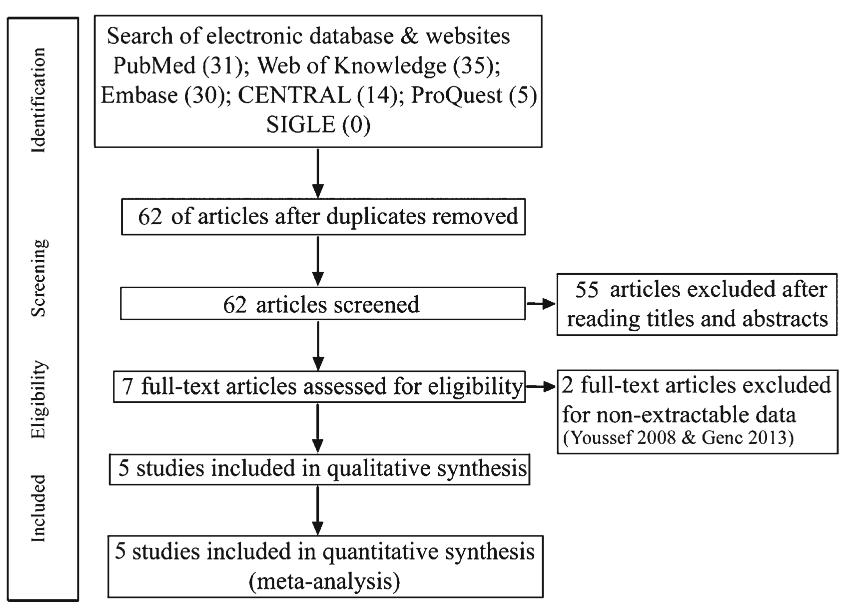


Fig. 1 PRISMA flow diagram for retrieving studies through the searching and selection processes

Table 2 Detailed information of the included studies

Study	Study design	Participants (*n*)	Laser irradiation details	The start time of canine retraction	Anchorage augmentation
Cruz 2004	RCT	11 (12–18 years)	780 nm, 20 mW 0, 3, 7, and 14 days	Not specified	Nance arch and transpalatal arch
Limpanichkul 2006	RCT	12 (20±3 years)	860 nm, 100 mW First 3 days	3 months after premolar extraction	Vertical loops mesial to molar tubes
Gui 2008	CCT	20 (12–17 years)	650 nm, 20 mW 0, 7, 14, and 21 days	Not specified	Nance arch
Sousa 2011	RCT	10 (11–20 years)	780 nm, 20 mW 0, 3, and 7 days	3 months after premolar extraction	Not specified
Doshi-Mehta 2012	RCT	20 (12–23 years)	800 nm, 0.25 mW 0, 3, 7, 14, and 29 days in first month, then every 15 days	Not specified	Transpalatal arch

significant heterogeneity was presented across studies (I^2= 97.9 %, p <0.001).

Accumulative moved distance within 2 months

Three included studies [17, 23, 25] have examined this outcome. Likewise, due to different protocols of laser irradiations, random effect model was used. The results showed that the pooled MD was 0.76 [95 % CI: (−0.14, 1.65)] and that a significant heterogeneity was detected across studies (I^2= 97.9 %, p <0.001) (Fig. 2).

Accumulative moved distance within 3 months

In this meta-analysis, three studies [23, 25, 36] investigated this outcome. As shown in Fig. 2, the meta-analysis (random effect model) showed that the pooled DM was 0.43 [95 % CI: (−0.05, 0.91)]. Unfortunately, a significant heterogeneity was detected across studies (I^2=91.4 %, p <0.001).

Meta-regression

For all the three aforementioned outcomes, significant heterogeneity existed (I^2=97.9, 97.9, and 91.4 %, respectively). Thus, we performed a meta-regression to explore the heterogeneity. The meta-regression revealed that wavelength and output power were significantly associated with the pooled DM (all p <0.001). Thus, different wavelengths and output powers of laser irradiations may account for the detected heterogeneity across studies.

Subgroup analysis

Due to paucity of original data for all the subgroups regarding wavelengths and output power, we could only perform subgroup analyses on a wavelength of 780 nm and an output power of 20 mW. As displayed in Fig. 3, the results showed that the pooled DM of accumulative moved distances for the wavelength of 780 nm were 0.54 (95 % CI=0.18–0.91), 1.11 (95 % CI=0.91–1.31) and 1.25 (95 % CI=0.68–1.82) for 1, 2, and 3 months, respectively (Fig. 3). Moreover, the pooled DM of accumulative moved distances for the output power of 20 mW were 0.45 (95 % CI=0.26–0.64), 1.11 (95 % CI= 0.91–1.31) and 1.25 (95 % CI=0.68–1.82) for 1, 2, and 3 months, respectively (Fig. 4).

We performed subgroup analyses on the fluence of 5 J/cm^2 and 25 J/cm^2. The subgroup analysis for the fluence of 5 J/cm^2 was exactly the subgroup analysis on the wavelength of 780 nm since the same studies (Cruz 2004 and Sousa 2011) were in these two subgroups. As displayed in Fig. 3, the pooled DM of accumulative moved distances for the fluence of 5 J/cm^2 were 0.54 (95 % CI=0.18–0.91), 1.11 (95 % CI= 0.91–1.31) and 1.25 (95 % CI=0.68–1.82) for 1, 2, and

Table 3 Risk of bias in each included study

Study	Sequence generation	Allocation concealment	Blinding of participants	Blinding of outcomes	Incomplete outcome	Selective reporting	Other bias
Cruz 2004	Unclear	Low	Unclear	Unclear	Unclear	Low	High
Limpanichkul 2006	Unclear	Low	Low	Unclear	Unclear	Low	Low
Gui 2008	High	Low	High	High	Unclear	Low	High
Sousa 2011	Unclear	Low	High	Unclear	Unclear	Low	High
Doshi-Mehta 2012	Unclear	Low	Low	Low	Low	Low	High

Table 4 GRADE assessment for quality of evidence

Outcome	Downgrade					Upgrade	Overall quality
	Study limitations	Imprecision	Inconsistency	Indirectness	Publication bias		
AMD (1 month)	Serious	Serious	Serious	None	None	None	1 (very low)
AMD (2 month)	Serious	Serious	Serious	None	None	None	1 (very low)
AMD (3 month)	Serious	Serious	Serious	None	Serious	None	0 (very low)

3 months, respectively. While the pooled DM of accumulative moved distances for the fluence of 25 J/cm^2 were 0.16 [95 % CI: (−0.27, 0.58)], −0.01 [95 % CI: (−0.11, 0.09)] and −0.01 [95 % CI: (−0.01, −0.09)] for 1, 2, and 3 months, respectively.

Sensitivity analysis

As mentioned above, two studies (Gui 2008 and Sousa 2011) were high risk of bias (Table 3). Thus, we conducted a sensitivity analysis by excluding them in the meta-analysis and found a significant change from the original estimates for accumulative moved distance within 1 month (Table 5).

Among the included studies, laser irradiations were applied only in the first 3 days after force application in Limpanichkul 2006, others extended at least to 7 days. Moreover, a relatively high output power (100 mW) was used in Limpanichkul 2006 as compared to that in other studies (20 and 0.25 mW). Thus, we conducted a sensitivity analysis by excluding Limpanichkul 2006 and found a significant change for accumulative moved distance within 2 months (Table 5).

A relatively low output power (0.25 mW) was employed in Doshi-Mehta 2012 as compared with that in other studies (20 and 100 mW). Thus, we performed a sensitivity analysis but failed to find any significant change (Table 5).

Since most of the measurements were the distances between canines and first molars, posterior anchorage was very important for data accuracy. Except for Sousa 2011 which did not specify whether posterior anchorage augmentation was used, other studies employed anchorage augmentation strategies, i.e., Nance arch, stop loop, transpalatal arch. Thus, we did a sensitivity analysis by excluding Sousa 2011 and found a significant change for accumulative moved distance within 1 month (Table 5).

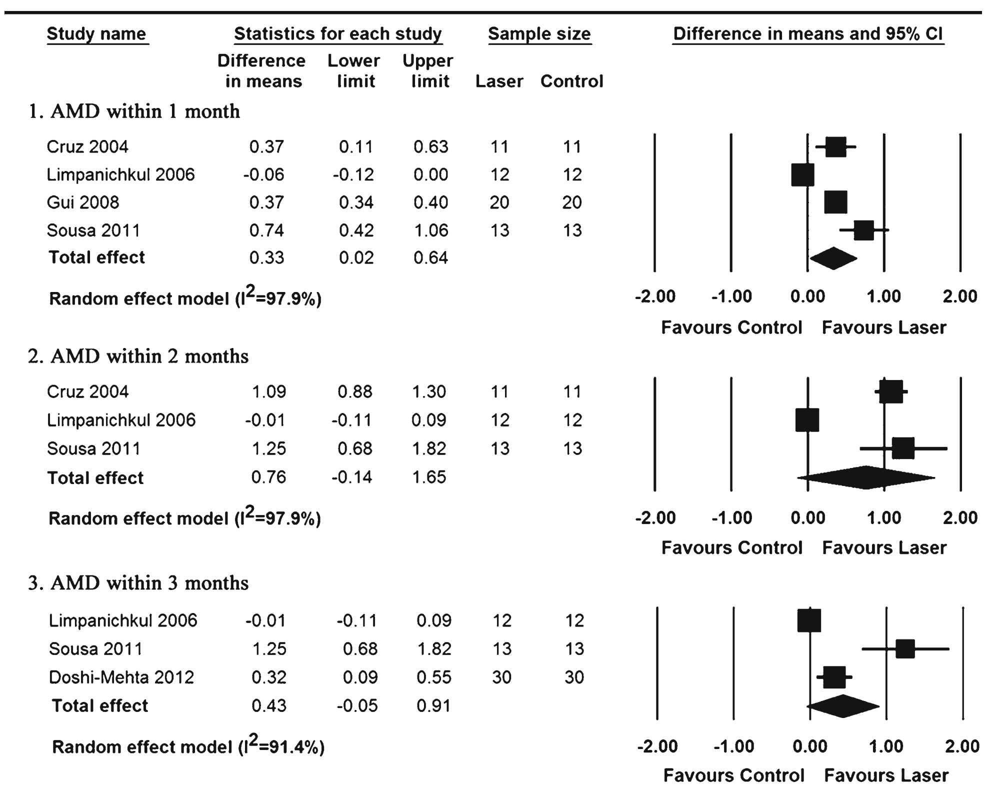
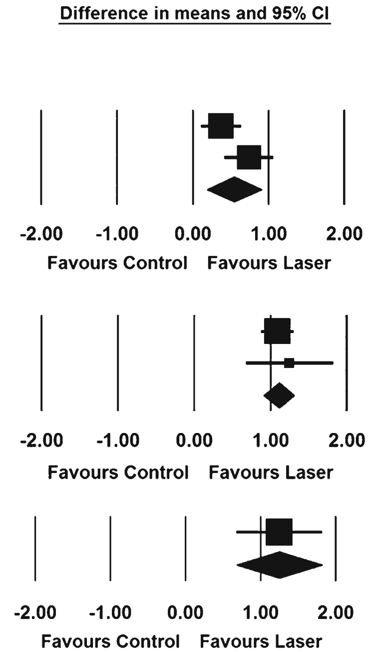


Fig. 2 Forest plot of the pooled difference in means regarding accumulative moved distance (AMD) within 1 month, AMD within 2 months and AMD within 3 months for low-level laser therapy versus control

Fig. 3 Subgroup analysis regarding the wavelength of 780 nm or the fluence of 5 J/cm^2

Study name	Difference in means	Lower limit	Upper limit	Laser	Control
1. AMD within 1 month					
Cruz 2004	0.37	0.11	0.63	11	11
Sousa 2011	0.74	0.42	1.06	13	13
Total effect	0.54	0.18	0.91		
Random effect model (I^2=67.5%)					
2. AMD within 2 months					
Cruz 2004	1.09	0.88	1.30	11	11
Sousa 2011	1.25	0.68	1.82	13	13
Total effect	1.11	0.91	1.31		
Random effect model (I^2=0%)					
3. AMD within 3 months					
Sousa 2011	1.25	0.68	1.82	13	13
Total effect	1.25	0.68	1.82		
Random effect model (I^2=0%)					



Cumulative meta-analysis

For accumulative moved distance within 1 month, the cumulative meta-analysis showed low-level laser therapy was effective in accelerating orthodontic tooth movement in the year of its first publication but later was found to be ineffective in 2006 and was recently revealed to be effective since 2011; for accumulative moved distance within 2 months, the results showed that low-level laser therapy was initially found to be effective in 2004 but was later found to be ineffective since 2006; for accumulative moved distance within 3 months, the cumulative meta-analysis revealed that low-level laser therapy was found to be ineffective since its first publication (2004) (Fig. 5). However, due to existing significant heterogeneities and instability of the pooled results, these results from the cumulative meta-analysis should be interpreted with caution.

Fig. 4 Subgroup analysis regarding the output power of 20 mW

Study name	Difference in means	Lower limit	Upper limit	Laser	Control
1. AMD within 1 month					
Cruz 2004	0.37	0.11	0.63	11	11
Gui 2008	0.37	0.34	0.40	20	20
Sousa 2011	0.74	0.42	1.06	13	13
Total effect	0.45	0.26	0.64		
Random effect model (I^2=60.8%)					
2. AMD within 2 months					
Cruz 2004	1.09	0.88	1.30	11	11
Sousa 2011	1.25	0.68	1.82	13	13
Total effect	1.11	0.91	1.31		
Random effect model (I^2=0%)					
3. AMD within 3 months					
Sousa 2011	1.25	0.68	1.82	13	13
Total effect	1.25	0.68	1.82		
Random effect model (I^2=0%)					

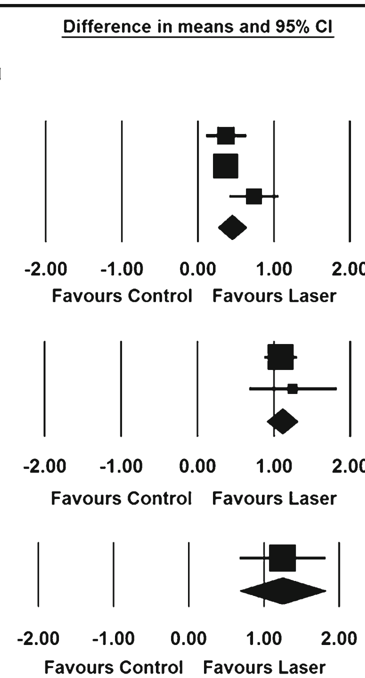


Table 5 Sensitivity analysis

Item	AMD within 1 month	AMD within 2 months	AMD within 3 months
Original estimates	0.33 (0.03, 0.64)	0.76 (−0.14, 1.65)	0.43 (−0.05, 0.91)
Exclusion of studies with high risk of bias	0.14 (−0.28, 0.56)[a]	−0.01 (−0.11, 0.09)	0.14 (−0.18, 0.46)
Exclusion of Limpanichkul et al.	0.45 (0.26, 0.64)	1.11 (0.91, 1.31)[a]	0.75 (−0.16, 1.66)
Exclusion of Doshi-Mehta et al.	–	–	0.59 (−0.65, 1.82)
Exclusion of Sousa et al.	0.22 (−0.12, 0.56)[a]	0.54 (−0.54, 1.61)	0.14 (−0.18, 0.46)

Data were presented as pooled differences in mean (95 % CI)

AMD accumulative moved distance

[a] Indicates significant changes from original estimates

Publication bias

Neither Egger's test nor Begg's test detected any evidence of publication bias for accumulative moved distance within 1 month ($p=0.88$ and $p=1.00$) and 2 months ($p=0.42$ and $p=1.00$). For accumulative moved distance within 3 months, although Begg's test failed to find any publication bias ($p=0.30$), Egger's test found a significant publication bias ($p=0.01$).

Discussion

In this meta-analysis, the included five studies evaluated three outcomes: AMD within 1 month, AMD within 2 months and AMD within 3 months. The meta-analysis revealed that the pooled DM was 0.33 [95 % CI: (0.03–0.64)], 0.76 [95 % CI: (−0.14, 1.65)] and 0.43 [95 % CI: (−0.05, 0.91)] for AMD within 1 month, AMD within 2 months and AMD within 3 months, respectively. However, at this stage, we cannot draw a conclusion based on the aforementioned results since we did not know whether the results were robust or whether the pooled results suffered from significant heterogeneity.

In order to test the robustness of the pooled results, we performed sensitivity analyses. Since risk of bias can directly influence the reliability of data, the pooled results may be influenced by studies with high risk of bias. Thus, we excluded two studies (Gui 2008 and Sousa 2011) in the sensitivity analysis and found a significant change, suggesting that the pooled results were biased by the studies with high risk of bias. It is conceivable that the effectiveness of laser irradiations depends on irradiation protocols, e.g., irradiation frequency, dosage, etc. After each force application, teeth started to move and kept moving until next force application, with half of the distance moved during the first 7 days [17]. As presented in Table 2, laser irradiation was applied only in the first 3 days in Limpanichkul 2006 while it was extended at least to 7 days in other studies. This insufficient laser application in Limpanichkul 2006 may explain why negative results were obtained in only Limpanichkul 2006. Thus, we performed a sensitivity analysis by excluding this study and

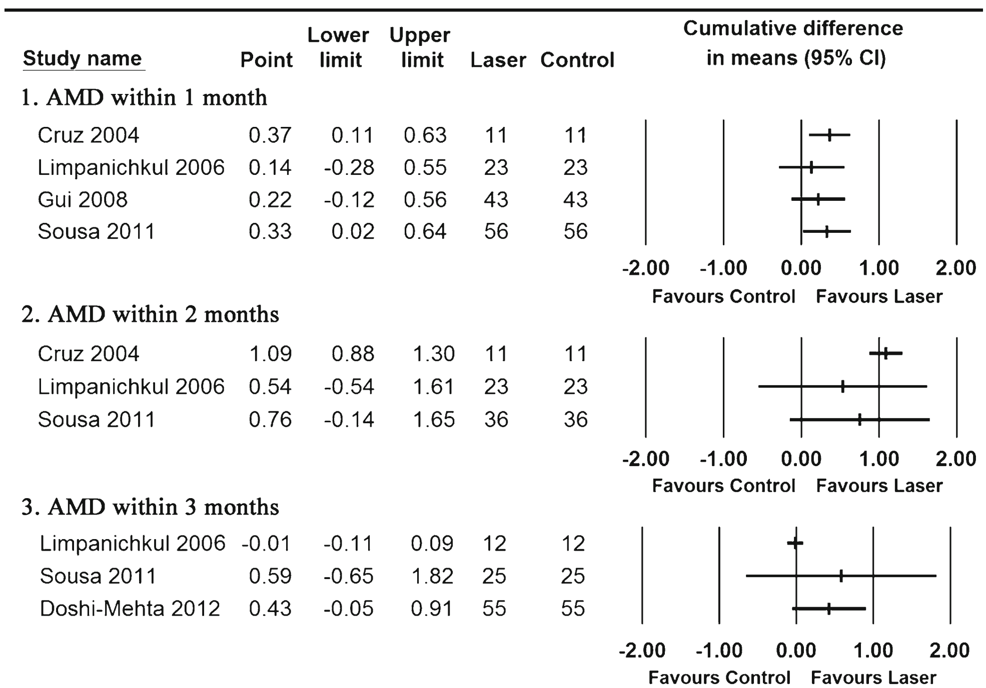


Fig. 5 Cumulative meta-analysis of AMD within 1 month, AMD within 2 months and AMD within 3 months

found that a significant change, suggesting that the pooled results were unstable. Although exclusion of low output power (0.25 mW, Doshi-Mehta 2012) failed to find any significant change, the exclusion of high output power (100 mW, Limpanichkul 2006) resulted in a significant change, as mentioned above. This further supports the instability of the pooled results. Moreover, the pooled results were significantly influenced by Sousa 2011 that did not specify whether posterior anchorage was used. Therefore, the aforementioned pooled results were unstable.

The meta-analysis revealed significant heterogeneity across studies for all the three outcomes (I^2=97.9, 97.9, and 91.4 %, respectively) (Fig. 2). Thus, the instability of the pooled results, as mentioned above, and the detected significant heterogeneity prevented us from drawing a conclusion based on the aforementioned pooled results.

In order to explore the potential heterogeneities across studies, we performed a meta-regression and found different wavelengths and output powers of laser irradiations could explain the detected heterogeneity ($p<0.001$). Then, we performed subgroup analyses on wavelength of 780 nm and output power of 20 mW. It has been well documented that different wavelengths of laser irradiations have differing penetration distances and different biostimulation effects [37, 38]. Specifically, lasers at the wavelength of 665 and 675 nm could stimulate cell proliferation while exert inhibitory effects at the wavelength of 810 nm [38]. In this present meta-analysis, four wavelengths were used: 650, 780, 800, and 860 nm. The meta-regression revealed a negative correlation between AMD and wavelength ($p<0.001$ for 1, 2, and 3 months). However, due to no enough original data, we can only perform the subgroup analysis on the wavelength of 780 nm. For the wavelength of 780 nm, we found that the pooled DM of AMD were 0.54 (95 % CI=0.18–0.91), 1.11 (95 % CI=0.91–1.31), and 1.25 (95 % CI=0.68–1.82) for 1, 2, and 3 months, respectively (Fig. 3). Ironically, significant heterogeneity was only detected for AMD within 1 month (I^2=67.5 %) while not in 2 months (I^2=0 %) or 3 months (I^2=0 %) (Fig. 4). Since AMD within 1 month was smaller and would be more susceptible to measurement errors, we attribute this significant heterogeneity to measurement error for AMD within 1 month. Thus, we suggest that low-level laser therapy would be effective in accelerating orthodontic tooth movement at the wavelength of 780 nm within 2 and 3 months while its effectiveness cannot be determined within 1 month due to potential measurement errors. However, we cannot determine the effectiveness of low-level laser therapy at the wavelength of 650, 800, and 860 nm due to insufficient data.

Since the same studies were in the subgroup analyses for both the wavelength of 780 nm and the fluence of 5 J/cm^2, similarly, we suggest that low-level laser therapy would be effective in accelerating orthodontic tooth movement at the fluence of 5 J/cm^2 within 2 and 3 months while its effectiveness cannot be determined within 1 month. Moreover, the subgroup analysis regarding the fluence of 25 J/cm^2 indicated that laser irradiation at the fluence of 25 J/cm^2 was ineffective. Limpanichkul 2006 was included in all the three analyses (1, 2, and 3 months). As mentioned above, since laser application was only performed in the first 3 days, the results of the subgroup analysis regarding the fluence of 25 J/cm^2 would be confounded by the insufficient laser application in Limpanichkul 2006. Thus, we cannot determine the effectiveness of laser irradiation at the fluence of 25 J/cm^2 in this meta-analysis.

Moreover, in this meta-analysis, three output powers were employed: 0.25, 20, and 100 mW. Likewise, due to no enough original data, we can only perform a subgroup analysis on the output power of 20 mW. The results revealed that the pooled DM of AMD was 0.45 (95 % CI=0.26–0.64), 1.11 (95 % CI=0.91–1.31) and 1.25 (95 % CI=0.68–1.82) for 1, 2, and 3 months, respectively (Fig. 4). Significant heterogeneity existed only for AMD within 1 month (I^2=60.8 %, Fig. 4), which was, likewise, due to potential measurement errors. Thus, we suggest that low-level laser therapy would be effective in accelerating orthodontic tooth movement at the output power of 20 mW within 2 and 3 months while its effectiveness cannot be determined within 1 month due to potential measurement errors. However, similarly, we cannot know the effectiveness of low-level laser therapy at the output power of 0.25 and 100 mW due to insufficient data.

Cumulative meta-analysis helps us to see how the evidence has shifted over time [39]. Although the cumulative meta-analysis revealed the trends of the pooled results for all the three outcomes, due to existing significant heterogeneities and instability of the pooled results, we suggest that it should be interpreted with caution.

The limitations of this meta-analysis included limited number of included studies, low quality of evidence, and moderate evidence of publication bias. Thus, future studies with high quality of evidence are called for.

Conclusion

Weak evidence suggests that low-level laser irradiations at the wavelength of 780 nm, the fluence of 5 J/cm^2 and/or the output power of 20 mW could accelerate orthodontic tooth movement within 2 and 3 months. However, the effectiveness of low-level laser therapy at other wavelengths (e.g., 650 and 800 nm), fluences (e.g., 25 J/cm^2) and output powers (e.g., 0.25 and 100 mW) cannot be determined due to insufficient data or potential bias in this meta-analysis. Moreover, we cannot determine its effectiveness within 1 month due to potential measurement errors. Due to low quality of evidence and potential publication bias, this conclusion should be interpreted with caution.

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