Systematic Review Article

Effectiveness of miniscrew-supported maxillary molar distalization according to temporary anchorage device features and appliance design: systematic review and meta-analysis

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ABSTRACT

Objectives: To evaluate the effectiveness of distalizing maxillary first molars (U6) by temporary anchorage devices (TADs) according to their location (palatal, buccal, and zygomatic), their number, and appliance design.

Materials and Methods: An electronic search of maxillary molar distalization with TADs was done through April 2023. After study selection, data extraction, and risk-of-bias assessment, meta-analyses were performed for the extent of distalization, distal tipping, and vertical movement of U6 using the generic inverse variance and random-effects model. The significance level was set at 0.05.

Results: Forty studies met the inclusion criteria: 4 randomized controlled trials (RCTs), 13 prospective studies, and 23 retrospective studies (total of 1182 patients). Distalization of the U6 was not significantly greater ($P = .64$) by palatal (3.74 mm) and zygomatic (3.68 mm) than by buccal (3.23 mm) TADs. Distal tipping was significantly higher ($P < .001$) in nonrigid (9.84°) than in rigid (1.97°) appliances. Vertical movement was mostly intrusive and higher but not significantly different ($P = .28$) in zygomatic anchorage (−1.16 mm).

Conclusions: Distalization of U6 with TADs can be an effective and stable treatment procedure, especially when performed with rigid palatal appliances. However, further RCTs or prospective cohort studies are strongly recommended to provide more clinical evidence. (*Angle Orthod*. 2024;94:107–121.)

KEY WORDS: Class II malocclusion; Molar distalization; Orthodontic miniscrew; Systematic review

INTRODUCTION

Maxillary molar distalization is the most frequently performed treatment for correcting Class II malocclusion and achieving Class I molar and canine relationships without extractions.[1] However, finding appropriate anchorage to avoid side effects is fundamental. Anchorage is crucial for the successful treatment of Class II malocclusion,[2] as instability of anchor teeth can result in unfavorable occlusal relationships and an unsatisfactory outcome.[3]

Extraoral appliances (e.g., headgear) and intraoral options (e.g., Nance button) are commonly used to reinforce anchorage. However, extraoral traction poses compliance challenges, while intraoral methods often result in anchorage loss.[4] To address this, intraoral distalization devices have been used and supported by skeletal anchorage. Dental implants have emerged as a stable solution for orthodontic purposes, benefiting from their osteointegration capabilities[5]; implants have demonstrated resilience against forces and remain stable following orthodontic loading over time.[6]

Although implants offer clear advantages in preserving anchorage, their invasive insertion and removal techniques hinder widespread adoption in daily practice. To address this limitation, temporary anchorage devices (TADs), including mini-implants,[7] miniscrews,[8] and onplants,[9] have emerged as promising alternatives. Miniscrews especially utilize less-invasive methods

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Table 1. Eligibility and Inclusion Criteria[a]

Inclusion Criteria	Exclusion Criteria
P (population): patients with Class II malocclusion who received distalization treatment of the maxillary molars	Case reports or case series, editorials, personal opinions, and narrative reviews
I (intervention): distalization of U6 with TADs	No sample or an insufficient sample (fewer than 5 patients)
C (comparison): between pre- and posttreatment	Distalization without the use of TAD
O (outcomes): assessment of distalization (mm), distal tipping (°), and vertical displacement movements (mm)	Nonhuman subjects, non-English written
S (study design): RCTs and nonrandomized prospective or retrospective clinical studies that included at least pre- and posttreatment measurements	Non-Class II malocclusion

[a] U6 indicates maxillary first molars; TAD, temporary anchorage device; RCT, randomized controlled trials.

than conventional implants and hold great potential for providing stable skeletal anchorage, particularly for posterior tooth distalization.[10]

TAD-supported appliances can be placed buccally in interdental spaces, palatally[11] in the retromolar region,[12] or even in the zygomatic area.[13] The varied bone characteristics in these regions require smaller implants, particularly in length, while ensuring stability to withstand orthodontic forces. Factors such as ease of insertion, active treatment and removal, reliable wire fixation, and ease of handling are crucial for successful implant application in orthodontics.[14]

Recent reviews have examined the use of TAD-supported appliances for nonextraction treatment of Class II malocclusion and highlighted their advantages.[15–18] All of the reviews agreed regarding the advantages provided by TADs, but to date, no systematic reviews have evaluated and compared the overall efficacy of molar distalization performed with different TAD-supported appliances categorized by the location of placement, rigidity of the appliance, and number of TADs used. It is interesting and important to evaluate which types of anchorage and appliance can be used more effectively and efficiently for different malocclusions. Clinically, this information may affect the choice of appliance, depending on specific side effects in terms of changes in molar tipping, vertical movement, or inclination of the occlusal plane. The studies included in this review were stratified based on the location of placement and rigidity of the device used. Therefore, it was possible to evaluate various dental effects and propose a new, different analysis from previous systematic reviews. Therefore, this systematic review and meta-analysis aimed to evaluate the treatment effects of TAD-supported maxillary molar distalization in Class II malocclusion, considering the amount of distalization, tipping, and vertical movement of the maxillary first molars (U6).

MATERIALS AND METHODS

Protocol and Registration

This review followed the PRISMA standards of quality for reporting systematic reviews and meta-analyses.[19] The protocol was registered in PROSPERO (CRD420 22333115).

Inclusion Criteria and Search Strategy

An electronic search of PubMed and MEDLINE, Google Scholar, and the Cochrane Oral Health trial registry was conducted from January 2011 to April 2023. Studies with the following characteristics were selected: studies on human subjects, studies published in English, sample size mentioned (at least five patients); prospective and retrospective studies, and random clinical trials (RCTs) that included descriptions of the distalization appliance. Table 1 describes the inclusion and exclusion criteria.

The search strategy included the following terms: *Maxillary_molar_distalization_AND_Class_II_AND_skeletal_anchorage_AND_miniscrew_OR_mini-implants_AND_(y_10[Filter"]). ((((“maxilla”[MeSH_Terms]_OR”_“maxilla”[All_Fields]_OR_“maxillary”[All_Fields]_OR_“maxillaries”[All_Fields]_OR_“maxillaris”[All_Fields])_AND_(“molar”[MeSH_Terms]_OR_“molar”[All_Fields]_OR_“molars”[All_Fields]_OR_“molars”[All_Fields])_AND_(“distal”[All_Fields]_OR_“distalization”[All_Fields]_OR_“distalize”[All_Fields]_OR_“distalized”[All_Fields]_OR_“distalizer”[All_Fields]_OR_“distalizers”[All_Fields]_OR_“distalizes”[All_Fields]_OR_“distalizing”[AllFields]_OR_“distally”[All_Fields]_OR_“distals”[All_Fields])_AND_(”“class”[All_Fields]_OR_“classe”[All_Fields]_OR_“classed”[All_Fields]_OR_“classes”[All_Fields])_AND_“II”[All_Fields])_AND_((“skeletal”[All_Fields]_OR_“skeletals”[All_Fields])_AND_(“anchorage”[All_Fields]_OR_“anchorages”[All_Fields]))_AND_(“miniscrew”[All_Fields]_OR_“miniscrews”[All_Fields]))_OR_“mini-implants”[All Fields])_AND_((y_10[Filter])_AND_(humans[Filter]))*.

Manual searches were performed using reference lists in full-text articles deemed appropriate for inclusion in the study and other relevant systematic reviews. Two authors conducted the search for studies to be included independently, and differences were resolved by discussion and consensus with a third, trained researcher. Data were finally extracted according to the PICOS questions and categorized.

Assessment of Study Quality

The quality of the included studies was assessed independently by two independent researchers. The Joanna Briggs Institute (JBI) checklist was used for randomized trials (7 questions) and nonrandomized cohort studies (11 questions).[20]

Data Collection and Analysis

The study design, sample size, age, type of appliance, location of placement, number of miniscrews, and material used for measurements were obtained. The means and standard deviations (SDs) of distalization, distal tipping, and vertical movement of the U6 were calculated. All data were extracted into an Excel spreadsheet by one author and reviewed by another author to confirm accuracy. Studies whose mean was more than double the mean of the subgroups were excluded from the meta-analysis after testing them by analysis of variance.

Meta-analysis was performed using Review Manager software (RevMan version 5.4; The Cochrane Collaboration, 2020) with a generic inverse variance approach. The random-effects method was used because the studies included in the analysis had a high degree of heterogeneity and were quite diverse in terms of the entity of the forces applied. Heterogeneity was first assessed from a clinical perspective based on the position of the TADs, their number, and the rigidity of the distalization system. The significance level was set at 0.05. For meta-analysis, the standard error (SE) value of the SD of the individual results was also calculated.

RESULTS

Study Selection and Trial Flow

The database search identified 805 studies, and after the removal of duplicates, titles and abstracts were independently evaluated for inclusion. After the study selection, the percentage of agreement between reviewers reached a Cohen's kappa coefficient value of 0.93. A third author was consulted for resolution of the disagreements to obtain the final list of included studies. Ultimately, 40 studies met the inclusion criteria for qualitative and quantitative analyses (Figure 1).

Characteristics of the Studies

The studies included in this review were published between January 2011 and April 2023: 4 RCTs, 13 prospective studies, and 23 retrospective studies.

Distalization groups included 1182 patients. Studies were divided into palatal,[21–47] buccal,[10,28,32,48–52] and zygomatic[53–59] according to the position of TADs. For studies with palatal TADs, a distinction was made between rigid[21–23,25,26,28,29,38,47] and nonrigid[21,30,35] appliances and between 2-TAD-supported[21–23,25,26,28–30,35,38,47] and 3-TAD-supported[24,27,31–34,36,37,39–46] appliances. The characteristics of the 40 studies included in the qualitative analysis are summarized in Table 2.

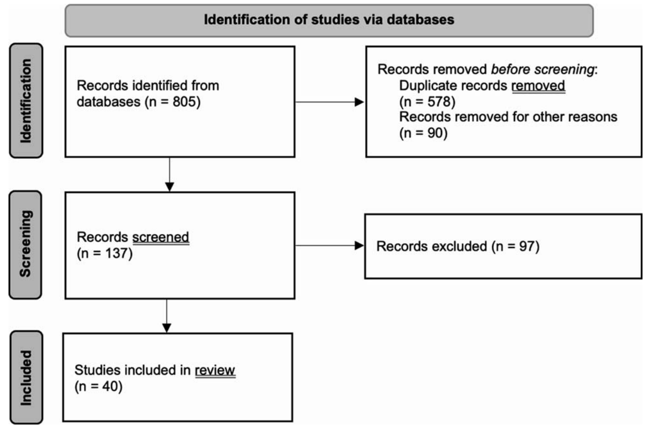

Figure 1. PRISMA flow diagram of the study selection process.

Risk of Bias

The JBI checklist was used. In the analysis of retrospective and prospective cohort studies, 10 studies were classified as "low" risk, 17 studies as "moderate," 7 studies as "serious," and 2 studies as "critical." The risk of bias (ROB) in the included RCTs was "serious" in two studies and "moderate" in the other two. Tables 3 and 4 show the summary of ROB for nonrandomized and RCT studies, respectively.

Quantitative Analysis

U6 distalization with palatal anchorage ranged from 1.65 mm[32] to 5.4 mm,[44] with tipping values ranging from 0.1°[38,47] to 11.24°.[30] Most studies reported U6 intrusion (−0.04 mm[43] to −2.6 mm[46]), while some reported extrusion (0.2 mm[28] to 1.6 mm[39]).

Using buccal TADs, U6 distalization ranged from 1.29 mm[48] to 5.05 mm,[28] with tipping ranging from 0.6°[51] to 7.2°.[32] Vertical movement varied from intrusion of −1.4 mm[48] to extrusion of 1.3 mm.[10]

U6 distalization with zygomatic anchorage ranged from 2.93 mm[54] to 5.31 mm.[55] Distal tipping varied from 1.21°[54] to 11.29°.[59] Vertical movement ranged from −3.7 mm[56] (intrusion) to 0.6 mm[58] (extrusion).

Devices with 2 TADs had a distalization range of 2.3 mm[26] to 5.3 mm,[38] while the distalization range of devices with 3 TADs ranged from 1.65 mm[36] to 5.4 mm.[44] Distal tipping for devices with 2 TADs was 0.1°[38] to 11.24°[30], and for devices with 3 TADs, it was 0.28°[41] to 5.09°.[46] Vertical movement values for the 2-TAD-supported subgroup ranged from −1 mm[22,28] (intrusion) to 0.7 mm[23] (extrusion), and the values for

Table 2. Qualitative and Quantitative Analyses of the 40 Included Studies[a]

Study	Type of Study	Sample Size	Age, Years		Measuring Material	Appliance Design
			Mean	SD		
Nur et al.,[53] 2012	PS	15	15.87	1.09	Ceph	Zygoma gear
Sar et al.,[21] 2013	PS	14	14.8	3.6	Ceph	MISDS
		14	14.5	1.5		BAPA
Bechtold et al.,[48] 2013	RCT	12	23.58	6.92	Ceph	Miniscrew between 2P and 1M
		13	22.92	7.1		Miniscrews between 1P and 2P and between 2P and 1M
Suzuki and Suzuki,[22] 2013	PS	20	23.2	4.7	Ceph	2 miniscrews in the midpalatal suture (iPanda)
El-Dawlatly et al.,[54] 2014	RCT	10	N/A	N/A	CBCT	IZC screw
Cozzani et al.,[23] 2014	RCT	18	11.5	1.7	Ceph	Distal screw
Mariani et al.,[10] 2014	RS	30	13.3	2.3	Ceph	MGBM system
Kook et al.,[24] 2014	RS	20	22.9	N/A	CBCT	MPAP
Caprioglio et al.,[25] 2015	RS	19	11.3	1.9	Ceph	Distal screw
Miresmaeili et al.,[26] 2015	PS	26	19.8	6.3	3D cast CBCT	Palatal miniscrews between 2P and 1M
Sa'aed et al.,[27] 2015	RS	24	12.42	1.69	Ceph	MPAP
Cozzani et al.,[28] 2016	RS	29	12.3	1.5	Ceph	MGBM system
		24	11.3	1.2		Distal screw
Duran et al.,[29] 2016	PS	21	13.6	N/A	3D cast	Miniscrew-supported hyrax screw
Kilkis et al.,[55] 2016	PS	21	15.68	2.18	Ceph	Zygoma gear
Ali et al.,[49] 2016	RS	17	26.4	10.8	3D cast	Miniscrew between 2P and 1M
Cambiano et al.,[30] 2017	PS	18	14	1.08	Ceph	BAPA
Park et al.,[31] 2017	RS	22	24.7	7.77	Ceph	MCPP
Lee et al.,[32] 2018	RS	22	21.9	6.6	Ceph	MCCP
		18	24.2	6.8		Interradicular miniscrew
Wu et al.,[56] 2018	RS	20	23	5	CBCT	IZC screw
Jo et al.,[33] 2018	RS	20	22.4	6.3	Ceph	MCPP
Park et al.,[34] 2018	RS	17	21.5	3.99	CBCT	MCPP exo group
		16	22.9	3.99		MCPP nonexo group
Kırcalı and Yüksel,[35] 2018	PS	20	14.05	2.4	Ceph	BAPA
Lee et al.,[36] 2019	RS	20	12.5	1.2	Ceph	MCPP
Shoaib et al.,[37] 2019	RS	23	20.1	N/A	Ceph	MCPP
Shahani et al.,[57] 2019	PS	6	>18	N/A	Ceph	IZC screw + passive self-ligating
		6	>18	N/A		IZC screw + clear aligner
Cassetta et al.,[38] 2019	RCT	10	13.1	N/A	3D cast Ceph	Distal screw
Abdelhady et al.,[50] 2020	PS	11	12.4	N/A	Ceph	Miniscrew between 2P and 1M
Bechtold et al.,[51] 2020	RS	19	24.9	5.0	Ceph	Miniscrew between 2P and 1M
Alfaifi et al.,[39] 2020	RS	21	11.7	1.3	Ceph	MCPP
Chou et al.,[40] 2021	RS	20	12.9	1.0	CBCT	MCPP
Jung et al.,[41] 2021	RS	20	12.1	1.1	Ceph	MCPP hyperdivergent
		20	12.3	1.5		MCPP hypodivergent
Park et al.,[42] 2021	RS	284	N/A	N/A	3D cast	MCPP
Park et al.,[43] 2021	RS	15	13.2	1.32	CBCT	MCPP
		12	12.0	1.24		MCPP
Shaikh et al.,[58] 2021	PS	10	N/A	N/A	Ceph	IZC screw between 1M and 2M + interradicular miniscrew
Song et al.,[52] 2022	RS	39	24.5	5.38	Ceph Dental cast	Miniscrews between 2P and 1M or between 1M and 2M
Alfawaz et al.,[44] 2022	RS	25	22.5	7.2	Ceph	MCPP
Kim et al.,[45] 2022	RS	30	25.1	–	CBCT	MCPP
Lim et al.,[46] 2022	RS	24	19.0	7.9	Ceph 3D model	MCPP
Altieri et al.,[47] 2022	PS	22	13.2	1.7	Ceph 3D model	Distal screw
Rosa et al.,[59] 2023	PS	25	13.6	1.5	Ceph 3D model	IZC screw

[a] Data extracted for quantitative analysis included the means of T0-T1 changes and standard deviations, description of the TAD site, and type of device: palatal (subsets according to numbers [#] of TADs between rigid and nonrigid devices), buccal, and zygomatic. TAD indicates temporary anchorage device; SD, standard deviation; PS, prospective study; RS, retrospective study; RCT, randomized controlled trial; N/A, not applicable; P, palatal; B, buccal; Z, zygomatic; R, rigid device; NR, nonrigid device; MISDS, miniscrew implant-supported distalization system; BAPA, bone-anchored pendulum appliance; IZC, infrazygomatic crest; MGBM system, Maino-Giannelly-Bednar-Mura system; MPAP, modified palatal anchorage plate; MCPP, modified C-palatal plate; 1M, first molar; 2M, second molar; 1P, first premolar; 2P, second premolar; CBCT, Cone Beam Computed Tomography; and Ceph, cephalometry.

Table 2. Extended

Site	# of TADs	Appliance Type	U6 Distalization, mm		U6 Tipping, °		U6 Vertical, mm	
			Mean	SD	Mean	SD	Mean	SD
Z	–	–	4.36	2.15	3.3	2.31	−0.5	0.46
P	2	R	2.81	2.7	1.65	7.29	N/A	N/A
	2	NR	2.93	1.74	9.0	6.74	N/A	N/A
B	–	–	1.29	0.66	3.19	4.61	−0.84	1.09
	–		2.91	0.96	1.55	1.32	−1.4	0.99
P	2	R	4.5	1.5	1.8	4.0	−1.0	0.8
Z	–	–	2.93	0.7	1.21	0.89	−1.57	1.18
P	2	R	4.7	1.6	2.8	2.2	0.7	1.9
B	–	–	4.6	0.3	9.75	0.75	1.3	0.9
P	3	–	3.3	1.8	3.42	5.79	−1.75	1.35
P	2	R	4.2	1.4	3.2	3.0	0.3	0.8
P	2	R	2.3	1.1	0.6	4.3	−0.53	0.56
P	3	–	3.06	0.54	1.53	0.98	−1.66	0.55
B	–	–	5.5	1.8	10.3	2.9	−1.0	0.3
P	2	R	3.2	0.7	3.0	1.5	0.2	0.3
P	2	R	4.1	1.57	11.02	5.32	−0.59	0.5
Z	–	–	5.31	2.46	6.39	5.39	−0.76	2.85
B	–	–	2.04	1.41	4.59	7.97	−0.11	1.39
P	2	NR	3.45	1.54	11.24	3.44	−0.74	0.868
P	3	–	4.22	2.0	3.85	3.11	−2.53	1.40
P	3	–	4.2	1.25	2.0	4.20	−1.64	2.06
B	–		2.0	1.26	7.2	5.22	−0.13	1.88
Z	–	–	3.1	1.0	N/A	N/A	−3.7	3.0
P	3	–	3.97	0.67	2.93	1.90	−1.31	1.33
P	3	–	3.41	1.25	3.68	4.97	−1.02	1.67
			3.24	1.79	3.07	6.67	−1.41	2.07
P	2	NR	4.2	0.8	8.9	3.1	−0.6	1.0
P	3	–	1.65	3.74	0.93	8.26	−0.35	2.13
P	3	–	3.44	1.08	2.35	6.74	1.42	1.12
Z	–	–	3.80	1.16	7.41	1.5	−2.50	1.64
	–		3.20	0.43	3.33	1.75	−0.93	0.16
P	2	R	5.3	2.1	0.1	12.4	−0.9	0.2
B	–	–	4.09	0.92	2.48	6.16	0.11	0.63
B	–	–	4.2	2.0	0.6	3.8	−0.8	2.6
P	3	–	3.96	1.46	1.86	1.94	1.60	1.45
P	3	–	4.66	2.23	1.48	6.68	−0.25	3.48
P	3	–	2.69	1.76	0.28	3.24	−0.57	1.90
			4.26	1.68	2.18	2.82	−0.15	1.76
P	3	–	3.35	0.42	N/A	N/A	N/A	N/A
P	3	–	4.36	4.26	0.94	6.59	0.04	2.54
			3.18	3.33	4.36	8.54	0.95	2.55
Z	–	–	4.0	4.5	N/A	N/A	0.6	0.3
B	–	–	2.46	1.97	2.66	3.97	−0.92	1.16
P	3	–	5.4	1.1	3.3	1.4	−1.3	1.8
P	3	–	3.48	2.20	5.09	4.23	−2.53	2.39
P	3	–	4.4	2.6	0.8	1.0	−2.6	3.6
P	2	R	3.9	1.2	0.1	3.0	0.6	1.1
Z	–	–	4.0	1.04	11.3	5.31	−1.22	1.44

the 3-TAD-supported subgroup ranged from −2.6 mm[46] (intrusion) to 1.6 mm[39] (extrusion).

Nonrigid devices had a slightly smaller distalization range (2.93 mm[21] to 4.2 mm[35]) than rigid devices (2.3 mm[26] to 5.3 mm[38]). Distal tipping was greater in nonrigid devices (8.9°[35] to 11.24°[30]) than in rigid devices (0.1°[38] to 11.02°[29]). Vertical movement values were similar between nonrigid and rigid palatal devices, ranging from −0.74 mm[30] to −0.6 mm[35] and from −1 mm[22] to 0.7 mm[23], respectively.

Meta-analysis

Treatment comparison among buccal, palatal, and zygomatic TAD-supported appliances. Figure 2 compares devices with palatal, buccal, and zygomatic TADs in terms of distalization, tipping, and vertical

Table 3. ROB Table and Summary for the Nonrandomized Controlled Studies Included[a]

Study	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	Overall
Nur et al.,[53] 2012	+	+	+	+	+/−	+	+	+	+	+	+	+/−
Sar et al.,[21] 2013	+	+	+	+	+	+	+	+	+	×	+	+
Suzuki and Suzuki,[22] 2013	+	+	+	+/−	+/−	+	+	+	+	×	+	+/−
Mariani et al.,[10] 2014	+	+	+	+	+	+	+	+	+	×	+	+
Kook et al.,[24] 2014	+	+	+	+/−	+	+	+	+	+	×	×	+/−
Caprioglio et al.,[25] 2015	+	+	+	+	+	+	+	+	+	×	+	+
Miresmaeili et al.,[26] 2015	+	+	+	+/−	+/−	+	+	+	+	×	+	+/−
Sa'aed et al.,[27] 2015	+	+	+	+	+	+	+	+	+	×	+	+
Cozzani et al.,[28] 2016	+	+	+	+	+	+	+	+	+	×	+	+
Duran et al.,[29] 2016	+	+	+	+/−	+/−	+	+	+	+	×	+	+/−
Kilkis et al.,[55] 2016	+	+	+	+	+	+	+	+	+	+	+	+
Ali et al.,[49] 2016	+	+	+	+/−	+	+	+	+	+	×	×	+/−
Cambiano et al.,[30] 2017	+	+	+	+/−	+/−	+	+	+	+	+/−	+	−
Park et al.,[31] 2017	+	+	+	+	+/−	+	+	+	+	×	×	+/−
Lee et al.,[32] 2018	+	+	+	+	+/−	+	+	+	+	×	+	+/−
Wu et al.,[56] 2018	+	+	+	+/−	+	+	+	+	+	×	+	+/−
Jo et al.,[33] 2018	+	+	+	+	+	+	+	+	+	×	+	+
Park et al.,[34] 2018	+	+	+	+/−	+	+	+	+	+	×	+	+/−
Kırcalı and Yüksel,[35] 2018	+	+	+	+/−	+/−	+	+	+	+	×	+	+/−
Lee et al.,[36] 2019	+	+	+	+	+	+	+	+	+	+	+	+
Shoaib et al.,[37] 2019	+/−	+/−	+	+/−	+	+	+	+	+	×	+	−
Shahani et al.,[57] 2019	+/−	+/−	+	?	+/−	+	+	+	+	×	×	?
Abdelhady et al.,[50] 2020	+	+	+	+/−	+/−	+	+	+	+	+/−	+	−
Bechtold et al.,[51] 2020	+	+	+	+/−	+	+	+	+	+	×	+	+/−
Alfaifi et al.,[39] 2020	+	+	+	+	+/−	+	+	+	+	×	+	+/−
Chou et al.,[40] 2021	+/−	+/−	+	+/−	+	+	+	+	+	×	+	−
Jung et al.,[41] 2021	+	+	+	+/−	+	+	+	+	+	×	×	+/−
Park et al.,[42] 2021	+/−	+/−	+	+/−	+	+	+	+	+	×	+	−
Park et al.,[43] 2021	+	+	+	?	+	+	+	+	+	+	+/−	?
Shaikh et al.,[58] 2021	+/−	+/−	+	+/−	+	+	+	+	+	×	×	−
Song et al.,[52] 2022	+/−	+/−	+	+/−	+/−	+	+	+	+	×	+	−
Alfawaz et al.,[44] 2022	+	+	+	+	+/−	+	+	+	+	×	+	+/−
Kim et al.,[45] 2022	+/−	+	+	+/−	+	+	+	+	+	×	+	+/−
Lim et al.,[46] 2022	+	+	+	+	+	+	+	+	+	×	+	+
Altieri et al.,[47] 2022	+	+	+	+/−	+/−	+	+	+	+	×	+	+/−
Rosa et al.,[59] 2023	+	+	+	+	+	+	+	+	+	×	+	+

[a] D1, were the two groups similar and recruited from the same population?; D2, were the exposures measured similarly to assign people to both exposed and unexposed groups?; D3, was the exposure measured in a valid and reliable way?; D4, were cofounding factors identified?; D5, were strategies to deal with confounding factors started?; D6, were the groups/participants free of the outcome at the start of the study?; D7, were the outcomes measured in a valid and reliable way?; D8, was the follow-up time reported and sufficient to be long enough for outcomes to occur?; D9, was the follow-up complete, and if not, were the reasons for loss to follow-up described and explored?; D10, were the strategies to address incomplete follow-up utilized?; D11, was the appropriate statistical analysis used?. ROB indicates risk of bias; +, low ROB; +/−, moderate ROB; −, serious ROB;? , critical ROB; and ×, no information.

movements. High heterogeneity ($I^2 = 95\%$) and no significant differences in the amount of distalization ($P = .64$) were found among palatal (3.74 mm; 95% confidence interval [CI], [3.51, 3.98]; $P < .0001$; $I^2 = 87\%$), zygomatic (3.68 mm; 95% CI, [3.21, 4.14]; $P < .0001$; $I^2 = 95\%$), and buccal (3.23 mm; 95% CI, [2.16, 4.30]; $P < .0001$; $I^2 = 98\%$) anchorage locations.

Table 4. ROB Graph and Summary for the Randomized Controlled Studies Included[a]

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Bechtold et al.,[48] 2013	+	+	+/−	+/−	+	+/−	+/−	+/−
Cozzani et al.,[23] 2014	+	−	+/−	+/−	+	+	+/−	−
El-Dawlatly et al.,[54] 2014	+	+	+/−	+/−	+	+	+/−	+/−
Cassetta et al.,[38] 2019	+	+	+/−	−	+	+	+/−	−

[a] D1, was true randomization used for assignment of participants to a treatment group? (selection bias); D2, was allocation to treatment groups concealed? (selection bias); D3, were participants blind to treatment assignment? (performance bias); D4, were outcomes measured in a reliable way? (detection bias); D5, was the follow-up complete, and if not, were differences between groups in terms of their follow-up adequately described and analyzed? (attrition bias); D6, was appropriate statistical analysis used? (reporting bias); D7, was the trial design appropriate, and were any deviations from the standard RCT design accounted for in the conduct and analysis of the trial? (statistical conclusion validity). ROB indicates risk of bias; −, low ROB; +/−, moderate ROB; and −, serious ROB.

a

Study or Subgroup	Mean Difference	SE	T0 Total	T1 Total	Weight	Mean Difference IV, Random, 95% CI	Year
Palatal							
Sar et al. 2013b	2.93	0.47	14	14	1.9%	2.93 [2.01, 3.85]	2013
Sar et al. 2013a	2.81	0.7	14	14	1.5%	2.81 [1.44, 4.18]	2013
Suzuki et al. 2013	4.5	0.33	20	20	2.2%	4.50 [3.85, 5.15]	2013
Cozzani et al. 2014	4.7	0.38	18	18	2.1%	4.70 [3.96, 5.44]	2014
Kook et al 2014	3.3	0.4	20	20	2.1%	3.30 [2.52, 4.08]	2014
Caprioglio et al. 2015	4.2	0.32	19	19	2.2%	4.20 [3.57, 4.83]	2015
Miresmaelli et al. 2015	2.3	0.22	26	26	2.4%	2.30 [1.87, 2.73]	2015
Sa'aed et al 2015	3.06	0.11	24	24	2.6%	3.06 [2.84, 3.28]	2015
Cozzani et al. 2016b	3.2	0.14	24	24	2.5%	3.20 [2.93, 3.47]	2016
Duran et al. 2016	4.1	0.34	21	21	2.2%	4.10 [3.43, 4.77]	2016
Cambiano et al. 2017	3.45	0.36	18	18	2.2%	3.45 [2.74, 4.16]	2017
Park et al 2017	4.22	0.43	22	22	2.0%	4.22 [3.38, 5.06]	2017
Park et al 2018a	3.41	0.3	17	17	2.3%	3.41 [2.82, 4.00]	2018
Park et al 2018b	3.24	0.45	16	16	2.0%	3.24 [2.36, 4.12]	2018
Kircali et al. 2018	4.2	0.18	20	20	2.5%	4.20 [3.85, 4.55]	2018
Jo et al 2018	3.97	0.15	20	20	2.5%	3.97 [3.68, 4.26]	2018
Lee et al 2018a	4.2	0.27	22	22	2.3%	4.20 [3.67, 4.73]	2018
Shoaib et al 2019	3.44	0.22	23	23	2.4%	3.44 [3.01, 3.87]	2019
Cassetta et al. 2019	5.3	0.66	10	10	1.5%	5.30 [4.01, 6.59]	2019
Lee et al 2019	1.65	0.84	20	20	1.2%	1.65 [0.00, 3.30]	2019
Alfaifi et al 2020	3.96	0.32	21	21	2.2%	3.96 [3.33, 4.59]	2020
Jung et al 2021a	2.69	0.39	20	20	2.1%	2.69 [1.93, 3.45]	2021
Jung et al 2021b	4.26	0.37	20	20	2.1%	4.26 [3.53, 4.99]	2021
Park et al 2021a	3.35	0.03	284	284	2.6%	3.35 [3.29, 3.41]	2021
Park et al 2021b	4.36	1.1	15	15	0.9%	4.36 [2.20, 6.52]	2021
Park et al 2021c	3.18	0.96	12	12	1.1%	3.18 [1.30, 5.06]	2021
Chou et al 2021	4.66	0.5	20	20	1.9%	4.66 [3.68, 5.64]	2021
Alfawaz et al 2022	5.4	0.22	25	25	2.4%	5.40 [4.97, 5.83]	2022
Altieri et al. 2022	3.9	0.26	22	22	2.3%	3.90 [3.39, 4.41]	2022
Kim et al. 2022	3.48	0.4	30	30	2.1%	3.48 [2.70, 4.26]	2022
Lim et al. 2022	4.4	0.89	24	24	1.2%	4.40 [2.66, 6.14]	2022
Subtotal (95% CI)			**881**	**881**	**63.5%**	**3.74 [3.51, 3.98]**	
Heterogeneity: Tau² = 0.29; Chi² = 239.22, df = 30 (P < 0.00001); I² = 87%							
Test for overall effect: Z = 31.40 (P < 0.00001)							
Buccal							
Bechtold et al 2013a	1.29	0.19	12	12	2.5%	1.29 [0.92, 1.66]	2013
Bechtold et al 2013b	2.91	0.26	13	13	2.3%	2.91 [2.40, 3.42]	2013
Mariani et al. 2014	4.6	0.05	30	30	2.6%	4.60 [4.50, 4.70]	2014
Ali et al 2016	2.04	0.34	17	17	2.2%	2.04 [1.37, 2.71]	2016
Cozzani et al 2016a	5.5	0.33	29	29	2.2%	5.50 [4.85, 6.15]	2016
Lee et al 2018b	2	0.29	18	18	2.3%	2.00 [1.43, 2.57]	2018
Abdelhady et al 2020	4.09	0.28	11	11	2.3%	4.09 [3.54, 4.64]	2020
Bechtold et al 2020	4.2	0.46	19	19	1.9%	4.20 [3.30, 5.10]	2020
Song et al 2022	2.46	0.31	39	39	2.3%	2.46 [1.85, 3.07]	2022
Subtotal (95% CI)			**188**	**188**	**20.6%**	**3.23 [2.16, 4.30]**	
Heterogeneity: Tau² = 2.60; Chi² = 468.15, df = 8 (P < 0.00001); I² = 98%							
Test for overall effect: Z = 5.91 (P < 0.00001)							
Zygomatic							
Nur et al 2012	4.36	0.55	15	15	1.8%	4.36 [3.28, 5.44]	2012
El-Dawlaty et al 2014	2.93	0.22	10	10	2.4%	2.93 [2.50, 3.36]	2014
Kilkis et al 2016	5.31	0.53	21	21	1.8%	5.31 [4.27, 6.35]	2016
Wu et al 2018	3.1	0.22	20	20	2.4%	3.10 [2.67, 3.53]	2018
Shahani et al 2019a	3.8	0.47	6	6	1.9%	3.80 [2.88, 4.72]	2019
Shahani et al. 2019b	3.2	0.17	6	6	2.5%	3.20 [2.87, 3.53]	2019
Shahikh et al 2021	4	1.42	10	10	0.6%	4.00 [1.22, 6.78]	2021
Rosa et al. 2023	4	0.21	25	25	2.4%	4.00 [3.59, 4.41]	2023
Subtotal (95% CI)			**113**	**113**	**15.9%**	**3.68 [3.21, 4.14]**	
Heterogeneity: Tau² = 0.30; Chi² = 32.83, df = 7 (P < 0.0001); I² = 79%							
Test for overall effect: Z = 15.40 (P < 0.00001)							
Total (95% CI)			**1182**	**1182**	**100.0%**	**3.64 [3.38, 3.89]**	
Heterogeneity: Tau² = 0.63; Chi² = 977.83, df = 47 (P < 0.00001); I² = 95%							
Test for overall effect: Z = 28.39 (P < 0.00001)							
Test for subgroup differences: Chi² = 0.88, df = 2 (P = 0.64), I² = 0%							

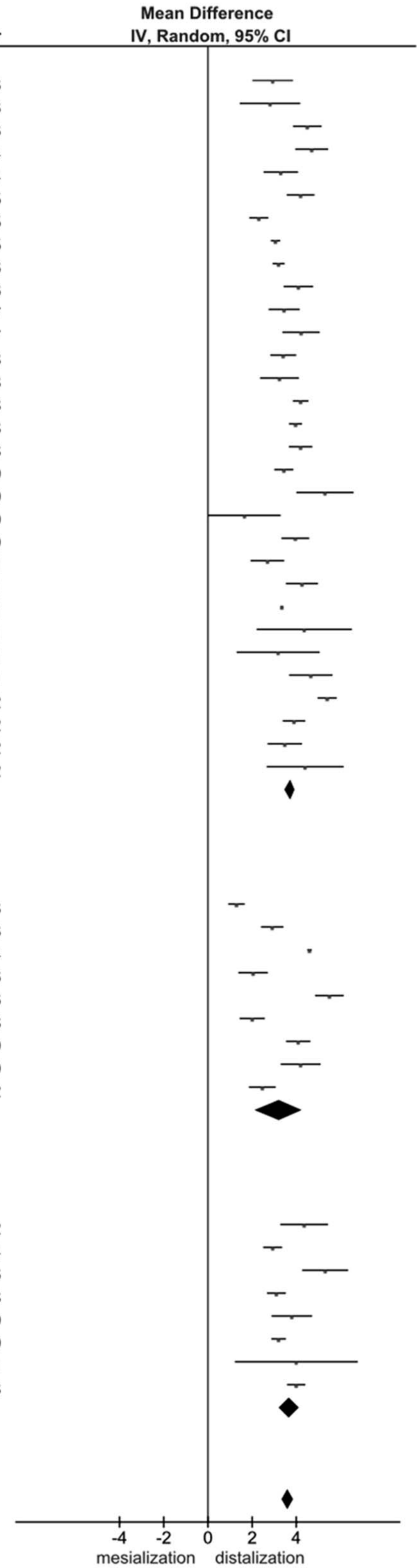

Figure 2. Forest plot of U6 distalization (a), tipping (b), and vertical movement (c) of the palatal, buccal, and zygomatic subgroups.

b

Study or Subgroup	Mean Difference	SE	T0 Total	T1 Total	Weight	Mean Difference IV, Random, 95% CI	Year
Palatal							
Sar et al. 2013a	1.65	1.94	14	14	1.3%	1.65 [-2.15, 5.45]	2013
Suzuki et al. 2013	1.8	0.89	20	20	2.7%	1.80 [0.06, 3.54]	2013
Sar et al. 2013b	9	1.8	14	14	1.4%	9.00 [5.47, 12.53]	2013
Cozzani et al. 2014	2.8	0.52	18	18	3.4%	2.80 [1.78, 3.82]	2014
Kook et al 2014	3.42	1.29	20	20	2.0%	3.42 [0.89, 5.95]	2014
Caprioglio et al. 2015	3.2	0.69	19	19	3.1%	3.20 [1.85, 4.55]	2015
Miresmaelli et al. 2015	0.6	0.84	26	26	2.8%	0.60 [-1.05, 2.25]	2015
Sa'aed et al 2015	1.53	0.2	24	24	3.8%	1.53 [1.14, 1.92]	2015
Cozzani et al. 2016b	3	0.3	24	24	3.7%	3.00 [2.41, 3.59]	2016
Park et al 2017	3.85	0.66	22	22	3.1%	3.85 [2.56, 5.14]	2017
Jo et al 2018	2.93	0.42	20	20	3.5%	2.93 [2.11, 3.75]	2018
Lee et al 2018a	2	0.89	22	22	2.7%	2.00 [0.26, 3.74]	2018
Park et al 2018a	3.68	1.2	17	17	2.2%	3.68 [1.33, 6.03]	2018
Park et al 2018b	3.07	1.69	16	16	1.5%	3.07 [-0.24, 6.38]	2018
Cassetta et al. 2019	0.1	3.92	10	10	0.4%	0.10 [-7.58, 7.78]	2019
Lee et al 2019	0.93	1.84	20	20	1.4%	0.93 [-2.68, 4.54]	2019
Shoaib et al 2019	2.35	1.4	23	23	1.9%	2.35 [-0.39, 5.09]	2019
Alfaifi et al 2020	1.86	0.42	21	21	3.5%	1.86 [1.04, 2.68]	2020
Chou et al 2021	1.48	1.49	20	20	1.8%	1.48 [-1.44, 4.40]	2021
Jung et al 2021a	0.28	0.72	20	20	3.0%	0.28 [-1.13, 1.69]	2021
Jung et al 2021b	2.18	0.63	20	20	3.2%	2.18 [0.95, 3.41]	2021
Park et al 2021b	0.94	1.7	15	15	1.5%	0.94 [-2.39, 4.27]	2021
Park et al 2021c	4.36	2.46	12	12	0.9%	4.36 [-0.46, 9.18]	2021
Lim et al. 2022	0.8	0.2	24	24	3.8%	0.80 [0.41, 1.19]	2022
Alfawaz et al 2022	3.3	0.28	25	25	3.7%	3.30 [2.75, 3.85]	2022
Altieri et al. 2022	0.1	0.64	22	22	3.2%	0.10 [-1.15, 1.35]	2022
Kim et al. 2022	5.09	0.77	30	30	2.9%	5.09 [3.58, 6.60]	2022
Subtotal (95% CI)			**538**	**538**	**68.3%**	**2.37 [1.82, 2.92]**	
Heterogeneity: Tau² = 1.27; Chi² = 146.78, df = 26 (P < 0.00001); I² = 82%							
Test for overall effect: Z = 8.40 (P < 0.00001)							
Buccal							
Bechtold et al 2013a	3.19	1.33	12	12	2.0%	3.19 [0.58, 5.80]	2013
Bechtold et al 2013b	1.55	0.36	13	13	3.6%	1.55 [0.84, 2.26]	2013
Ali et al 2016	4.59	1.93	17	17	1.3%	4.59 [0.81, 8.37]	2016
Lee et al 2018b	7.2	1.23	18	18	2.1%	7.20 [4.79, 9.61]	2018
Abdelhady et al 2020	2.48	1.86	11	11	1.3%	2.48 [-1.17, 6.13]	2020
Bechtold et al 2020	0.6	0.87	19	19	2.7%	0.60 [-1.11, 2.31]	2020
Song et al 2022	2.66	0.63	39	39	3.2%	2.66 [1.43, 3.89]	2022
Subtotal (95% CI)			**129**	**129**	**16.3%**	**2.91 [1.49, 4.33]**	
Heterogeneity: Tau² = 2.40; Chi² = 25.67, df = 6 (P = 0.0003); I² = 77%							
Test for overall effect: Z = 4.02 (P < 0.0001)							
Zygomatic							
Nur et al 2012	3.3	0.59	15	15	3.3%	3.30 [2.14, 4.46]	2012
El-Dawlaty et al 2014	1.21	0.28	10	10	3.7%	1.21 [0.66, 1.76]	2014
Kilkis et al 2016	6.39	1.17	21	21	2.2%	6.39 [4.10, 8.68]	2016
Shahani et al 2019a	7.41	0.61	6	6	3.2%	7.41 [6.21, 8.61]	2019
Shahani et al. 2019b	3.33	0.71	6	6	3.0%	3.33 [1.94, 4.72]	2019
Subtotal (95% CI)			**58**	**58**	**15.4%**	**4.26 [1.74, 6.78]**	
Heterogeneity: Tau² = 7.75; Chi² = 99.68, df = 4 (P < 0.00001); I² = 96%							
Test for overall effect: Z = 3.31 (P = 0.0009)							
Total (95% CI)			**725**	**725**	**100.0%**	**2.73 [2.21, 3.26]**	
Heterogeneity: Tau² = 1.85; Chi² = 280.08, df = 38 (P < 0.00001); I² = 86%							
Test for overall effect: Z = 10.22 (P < 0.00001)							
Test for subgroup differences: Chi² = 2.41, df = 2 (P = 0.30), I² = 16.9%							

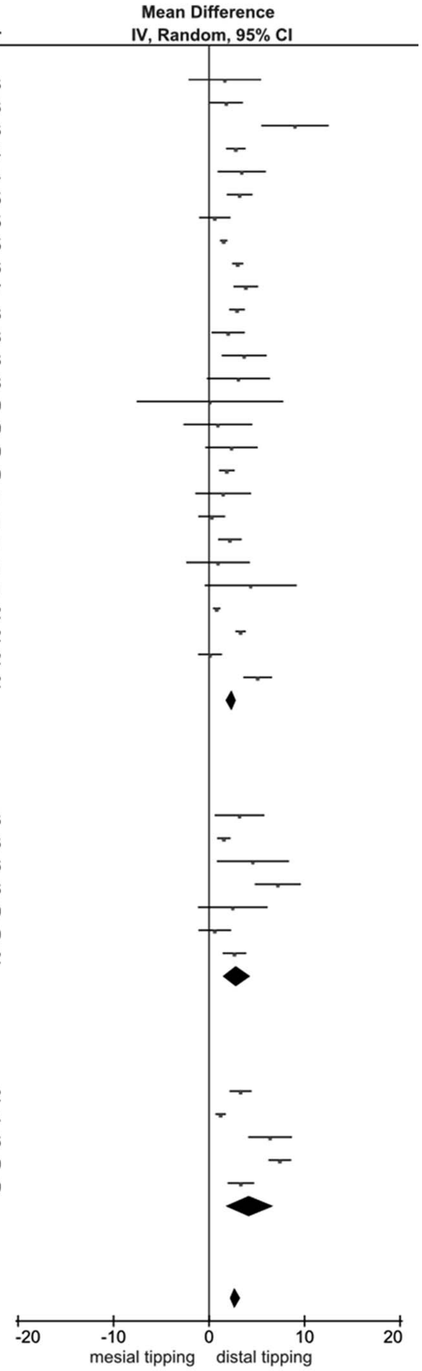

Figure 2. (Continued)

Distal tipping was higher, although not significantly ($P = .30$), in the zygomatic group than in the others (4.26 mm; 95% CI, [1.74, 6.78]; $P < .0001$; $I^2 = 96\%$) despite four studies being excluded because they had mean values strikingly outside the mean of the single subgroup.[10,28,29,59] Intrusion was also higher (-1.16 mm; 95% CI, [-1.84, -0.48]; $P < .0001$; $I^2 = 97\%$) but not significantly ($P = .28$) different for zygomatic TADs than the other two groups.

Treatment comparison between 2-TAD-supported and 3-TAD-supported appliances. Figure 3 shows the comparison between 2-TAD-supported and 3-TAD-supported appliances in terms of distalization, tipping, and vertical movement. The comparison showed high heterogeneity between subgroups ($I^2 = 87\%$) and no significant differences ($P = .86$) between the 2-TAD (3.78 mm; 95% CI, [3.31, 4.24]; $P < .0001$; $I^2 = 87\%$) and 3-TAD (3.73 mm; 95% CI, [3.43, 4.03]; $P < .0001$; $I^2 = 88\%$) subgroups.

C

Study or Subgroup	Mean Difference	SE	T0 Total	T1 Total	Weight	Mean Difference IV, Random, 95% CI	Year
Palatal							
Suzuki et al. 2013	-1	0.18	20	20	2.6%	-1.00 [-1.35, -0.65]	2013
Cozzani et al. 2014	0.7	0.45	18	18	2.0%	0.70 [-0.18, 1.58]	2014
Kook et al 2014	-1.75	0.3	20	20	2.3%	-1.75 [-2.34, -1.16]	2014
Sa'aed et al 2015	-1.66	0.11	24	24	2.6%	-1.66 [-1.88, -1.44]	2015
Caprioglio et al. 2015	0.3	0.18	19	19	2.6%	0.30 [-0.05, 0.65]	2015
Miresmaelli et al. 2015	-0.53	0.11	26	26	2.6%	-0.53 [-0.75, -0.31]	2015
Cozzani et al. 2016b	0.2	0.06	24	24	2.7%	0.20 [0.08, 0.32]	2016
Duran et al. 2016	-0.59	0.11	21	21	2.6%	-0.59 [-0.81, -0.37]	2016
Cambiano et al. 2017	-0.74	0.16	18	18	2.6%	-0.74 [-1.05, -0.43]	2017
Park et al 2017	-2.53	0.3	22	22	2.3%	-2.53 [-3.12, -1.94]	2017
Park et al 2018b	-1.41	0.51	16	16	1.9%	-1.41 [-2.41, -0.41]	2018
Jo et al 2018	-1.31	0.3	20	20	2.3%	-1.31 [-1.90, -0.72]	2018
Kircali et al. 2018	-0.6	0.22	20	20	2.5%	-0.60 [-1.03, -0.17]	2018
Lee et al 2018a	-1.64	0.44	22	22	2.0%	-1.64 [-2.50, -0.78]	2018
Park et al 2018a	-1.02	0.4	17	17	2.1%	-1.02 [-1.80, -0.24]	2018
Shoaib et al 2019	1.42	0.23	23	23	2.5%	1.42 [0.97, 1.87]	2019
Cassetta et al. 2019	-0.9	0.06	10	10	2.7%	-0.90 [-1.02, -0.78]	2019
Lee et al 2019	-0.35	0.47	20	20	1.9%	-0.35 [-1.27, 0.57]	2019
Alfaifi et al 2020	1.6	0.31	21	21	2.3%	1.60 [0.99, 2.21]	2020
Park et al 2021b	-0.04	0.65	15	15	1.5%	-0.04 [-1.31, 1.23]	2021
Park et al 2021c	-0.95	0.74	12	12	1.4%	-0.95 [-2.40, 0.50]	2021
Chou et al 2021	-0.25	0.78	20	20	1.3%	-0.25 [-1.78, 1.28]	2021
Jung et al 2021a	-0.57	0.42	20	20	2.1%	-0.57 [-1.39, 0.25]	2021
Jung et al 2021b	-0.15	0.39	20	20	2.1%	-0.15 [-0.91, 0.61]	2021
Alfawaz et al 2022	-1.3	0.36	25	25	2.2%	-1.30 [-2.01, -0.59]	2022
Altieri et al. 2022	0.6	0.13	22	22	2.6%	0.60 [0.35, 0.85]	2022
Kim et al. 2022	-2.53	0.44	30	30	2.0%	-2.53 [-3.39, -1.67]	2022
Lim et al. 2022	-2.6	0.73	24	24	1.4%	-2.60 [-4.03, -1.17]	2022
Subtotal (95% CI)			**569**	**569**	**61.8%**	**-0.66 [-0.99, -0.34]**	
Heterogeneity: Tau² = 0.65; Chi² = 634.38, df = 27 (P < 0.00001); I² = 96%							
Test for overall effect: Z = 3.98 (P < 0.0001)							
Buccal							
Bechtold et al 2013a	-0.84	0.31	12	12	2.3%	-0.84 [-1.45, -0.23]	2013
Bechtold et al 2013b	-1.4	0.27	13	13	2.4%	-1.40 [-1.93, -0.87]	2013
Mariani et al. 2014	1.3	0.16	30	30	2.6%	1.30 [0.99, 1.61]	2014
Ali et al 2016	-0.11	0.33	17	17	2.3%	-0.11 [-0.76, 0.54]	2016
Cozzani et al 2016a	-1	0.05	29	29	2.7%	-1.00 [-1.10, -0.90]	2016
Lee et al 2018b	-0.13	0.44	18	18	2.0%	-0.13 [-0.99, 0.73]	2018
Abdelhady et al 2020	0.11	0.19	11	11	2.5%	0.11 [-0.26, 0.48]	2020
Bechtold et al 2020	-0.8	0.6	19	19	1.7%	-0.80 [-1.98, 0.38]	2020
Song et al 2022	-0.92	0.18	39	39	2.6%	-0.92 [-1.27, -0.57]	2022
Subtotal (95% CI)			**188**	**188**	**21.0%**	**-0.41 [-1.07, 0.24]**	
Heterogeneity: Tau² = 0.91; Chi² = 222.16, df = 8 (P < 0.00001); I² = 96%							
Test for overall effect: Z = 1.23 (P = 0.22)							
Zygomatic							
Nur et al 2012	-0.5	0.12	15	15	2.6%	-0.50 [-0.74, -0.26]	2012
El-Dawlaty et al 2014	-1.57	0.37	10	10	2.2%	-1.57 [-2.30, -0.84]	2014
Kilkis et al 2016	-0.76	0.62	21	21	1.6%	-0.76 [-1.98, 0.46]	2016
Wu et al 2018	-3.7	0.67	20	20	1.5%	-3.70 [-5.01, -2.39]	2018
Shahani et al 2019a	-2.5	0.67	6	6	1.5%	-2.50 [-3.81, -1.19]	2019
Shahani et al. 2019b	-0.93	0.06	6	6	2.7%	-0.93 [-1.05, -0.81]	2019
Shahikh et al 2021	0.6	0.09	10	10	2.7%	0.60 [0.42, 0.78]	2021
Rosa et al. 2023	-1.22	0.29	25	25	2.4%	-1.22 [-1.79, -0.65]	2023
Subtotal (95% CI)			**113**	**113**	**17.1%**	**-1.16 [-1.84, -0.48]**	
Heterogeneity: Tau² = 0.80; Chi² = 246.87, df = 7 (P < 0.00001); I² = 97%							
Test for overall effect: Z = 3.36 (P = 0.0008)							
Total (95% CI)			**870**	**870**	**100.0%**	**-0.68 [-0.93, -0.44]**	
Heterogeneity: Tau² = 0.56; Chi² = 1132.56, df = 44 (P < 0.00001); I² = 96%							
Test for overall effect: Z = 5.54 (P < 0.00001)							
Test for subgroup differences: Chi² = 2.57, df = 2 (P = 0.28), I² = 22.1%							

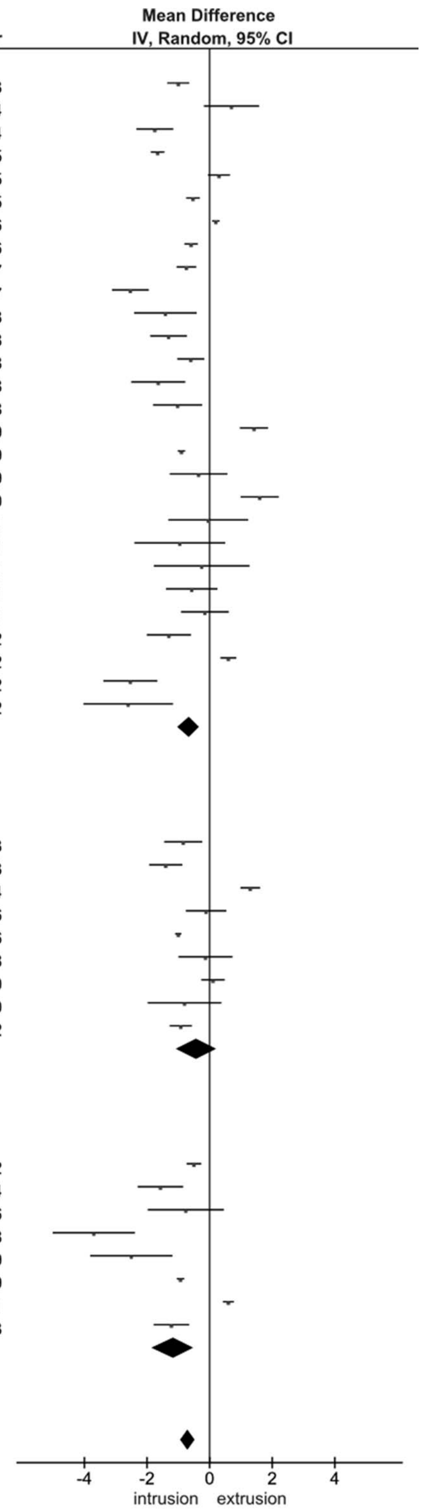

Figure 2. (Continued)

There was heterogeneity ($I^2 = 82\%$) but no significant differences ($P = .99$) between the 2-TAD (2.37°; 95% CI, [1.26, 3.49]; $P < .0001$; $I^2 = 88\%$) and 3-TAD (2.38°; 95% CI, [1.72, 3.04]; $P < .0001$; $I^2 = 83\%$) subgroups in terms of distal tipping, even though one study was dropped from the analysis due to a value outside the mean of the subgroup.[35] There was also heterogeneity within subgroups for vertical movement

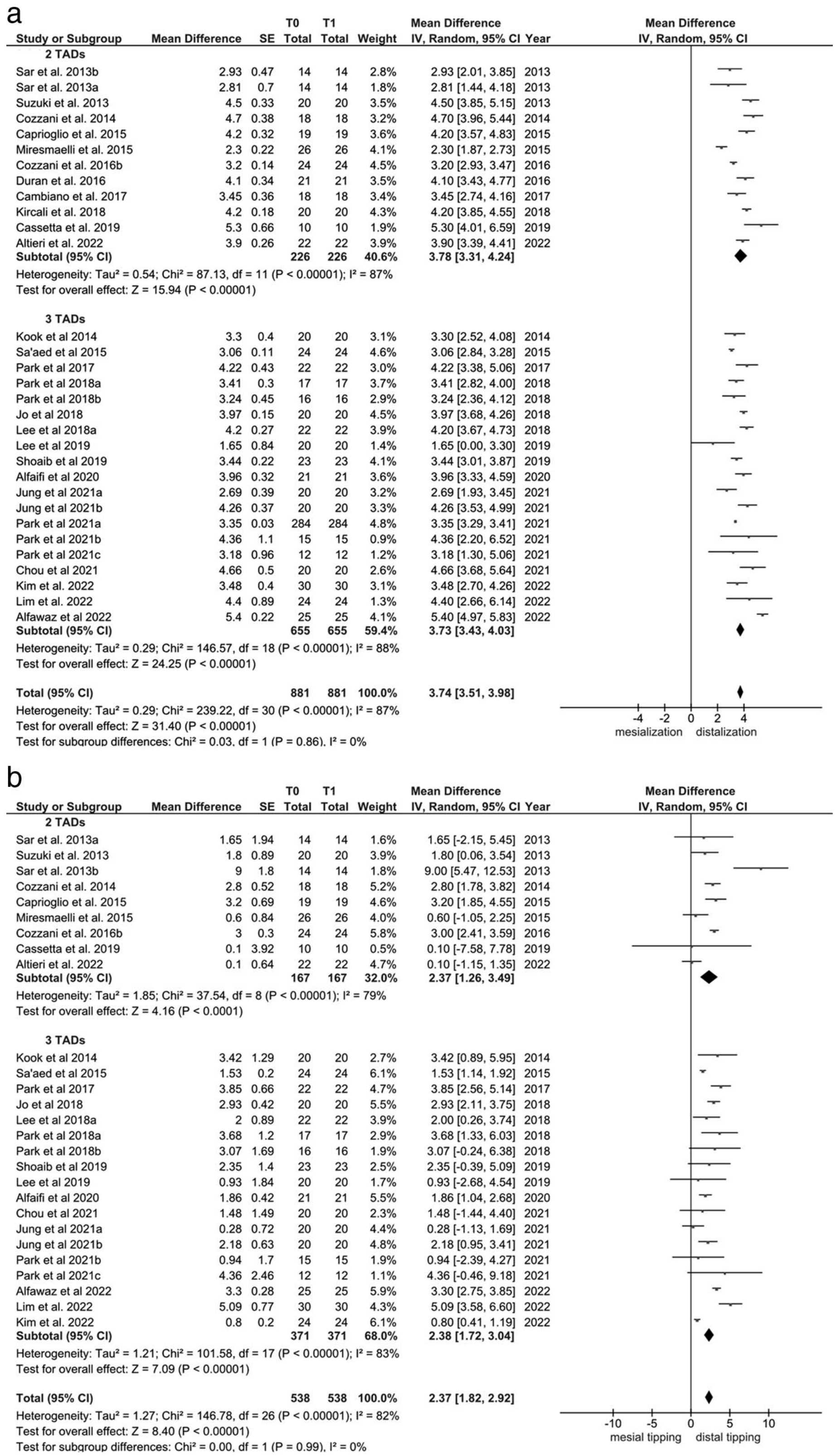

Figure 3. Forest plot of U6 distalization (a), tipping (b), and vertical movement (c) of the 2-TAD and 3-TAD subgroups.

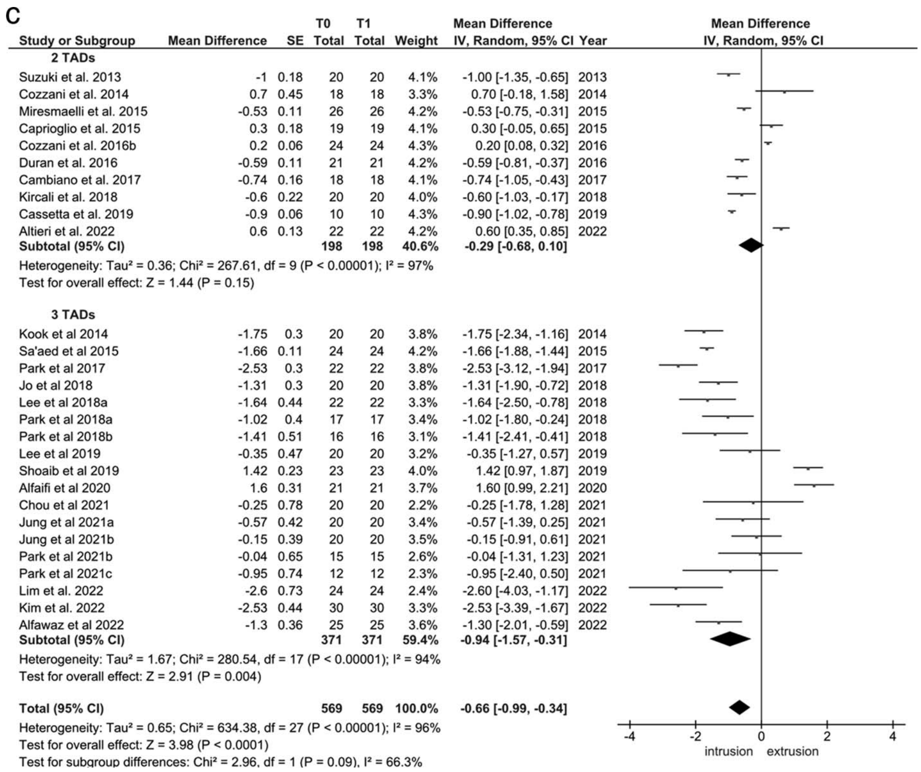

Figure 3. (Continued)

($I^2 = 96\%$); no significant difference in intrusion ($P = .09$) was found between devices with 2 TADs (-0.29 mm; 95% CI, [-0.68, 0.10]; $P < .0001$; $I^2 = 97\%$) and those with 3 TADs (-0.94 mm; 95% CI, [-1.57, -0.31]; $P < .0001$; $I^2 = 94\%$).

Treatment comparison between rigid and nonrigid TAD-supported appliances. Figure 4 shows the comparison between rigid and nonrigid appliances in terms of distalization, tipping, and vertical movement. High heterogeneity ($I^2 = 87\%$) and no significant differences ($P = .63$) between the nonrigid (3.61 mm; 95% CI, [2.85, 4.38]; $P < .0001$; $I^2 = 77\%$) and rigid (3.85 mm; 95% CI, [3.27, 4.44]; $P < .0001$; $I^2 = 89\%$) appliances were found regarding distalization amount.

Distal tipping was significantly higher ($P < .0001$) in nonrigid (9.84°; 95% CI, [8.08, 11.60]; $P < .0001$; $I^2 = 60\%$) than in rigid (1.97°; 95% CI, [1.01, 2.92]; $P < .0001$; $I^2 = 71\%$) appliances, with high heterogeneity within subgroups ($I^2 = 95\%$); one study with mean values outside the mean of the group was excluded.[29]

Finally, for vertical movements, there was considerable heterogeneity ($I^2 = 97\%$) and no significant difference ($P = .06$) within the nonrigid (-0.69 mm; 95% CI, [-0.95, -0.44]; $P < .61$; $I^2 = 0\%$) and rigid (-0.19 mm; 95% CI, [-0.64, 0.26]; $P < .0001$; $I^2 = 97\%$) subgroups.

DISCUSSION

TADs may reduce the need for tooth extraction for orthodontic purposes and orthognathic surgery. Maxillary molar distalization may be able to correct Class II malocclusion using different TAD-supported appliances. This review assessed the effectiveness of molar distalization based on TAD number, TAD position, and device design.

Distalization Movement

Data analysis revealed nonsignificant differences in the magnitude of distalization for the subgroup using palatal TADs (3.74 mm) compared to buccal (3.23 mm) and zygomatic (3.68 mm) TADs. Therefore, no significant clinical differences were observed among the different device positions. These results were similar to those of a 2021 review that found distalization values of 2.75 mm for buccal TADs, 4.07 mm for palatal TADs, and 4.17 mm for zygomatic anchorage.[17] A 2022 systematic review also reported similar values for the distalization of molars by buccal TADs (2.44 mm) and palatal appliances (modified C-palatal plates [MCPPs]) in adults (4.00 mm) and adolescents (3.54 mm).[18]

One possible explanation for any differences would be that buccal TAD root proximity may be a factor limiting distalization, in contrast to extra-alveolar anchorage, which could allow greater movement. Also, palatal appliances allow force application closer to the center

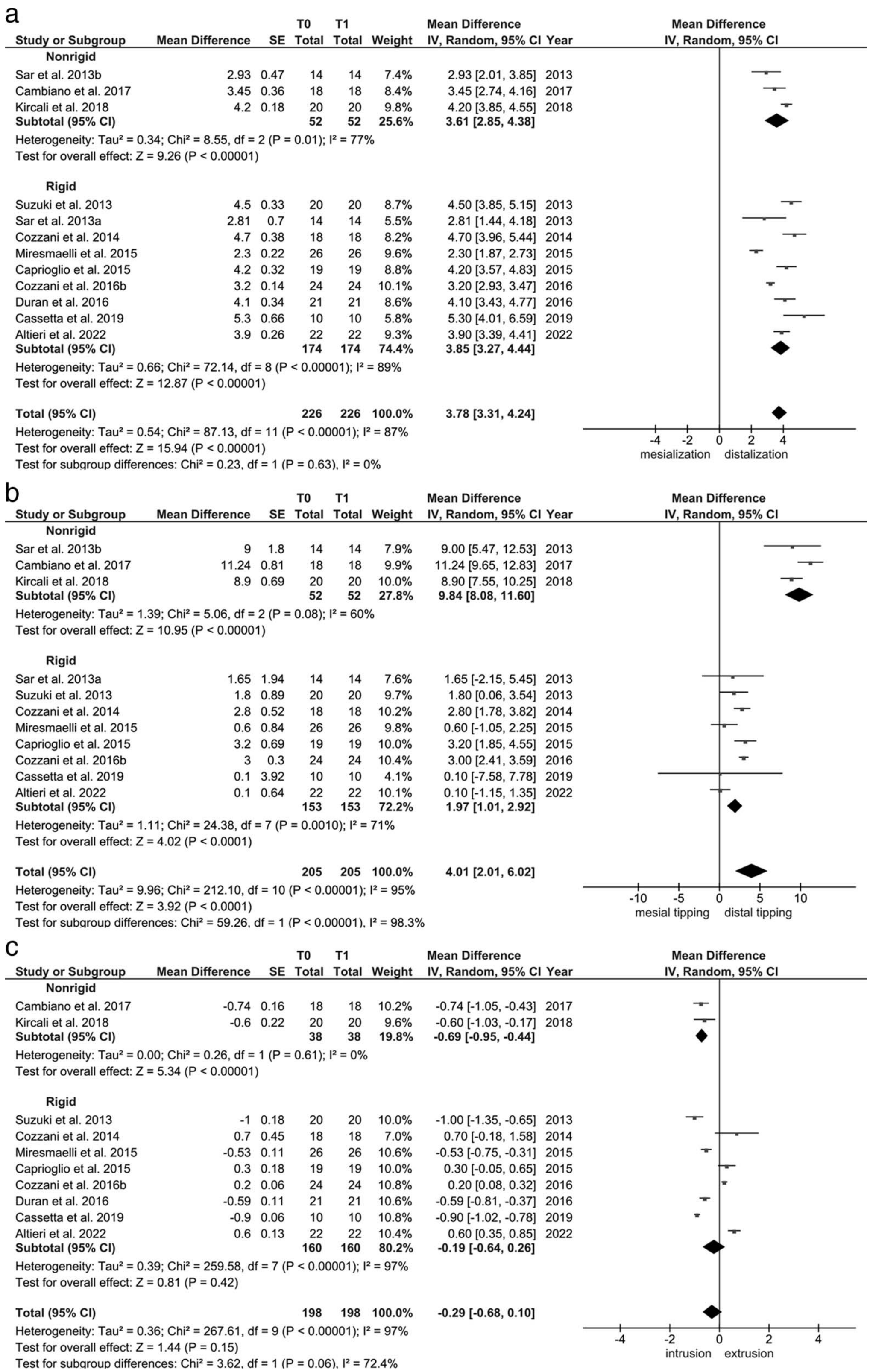

Figure 4. Forest plot of U6 distalization (a), tipping (b), and vertical movement (c) of the rigid and nonrigid subgroups.

of resistance, leading to more distalization. No differences were found between 2-TAD-supported and 3-TAD-supported appliances as well as when comparing nonrigid and rigid devices.

Tipping Movement

Distal tipping is a common effect of molar distalization. There were no significant differences in distal tipping when comparing by position and number of TADs, but the difference was statistically and clinically significant when rigid (1.97°) and nonrigid (9.84°) appliances were compared. These results were consistent with the specific biomechanical properties involved. Palatal devices with pendulum arms result in distal tipping because the force is applied to the clinical crown, far from the center of resistance.[60]

Among all rigid palatal devices, the tipping values were generally low, as expected. The least tipping was shown by 3-TAD-supported devices (MCPPs) that used a controlled force vector that passed through the center of resistance of the U6, increasing distal movement while reducing distal tipping simultaneously.[61] Therefore, the direction of the force vector applied to the distalization system can certainly alter the tipping of teeth during distalization.

Vertical Movement

In this meta-analysis, no significant differences were found for vertical movements among the buccal, palatal, and zygomatic TADs, but zygomatic TADs showed the greatest degree of intrusion (−1.16 mm). These findings contradicted those reported in two previous reviews.[17,18] It was expected that rigid appliances would provide better vertical control of maxillary molars due to their nonelastic nature, ensuring complete control over vertical movements. However, in a few cases, there was slight extrusive movement (ranging from 0.2 mm[28] to 0.70 mm[23]), observed exclusively with rigid palatal appliances. As discussed above, the direction of the resultant force vector plays a role in the effectiveness of the intrusion of teeth connected to the appliance.

Zygomatic anchorage should allow better vertical control and intrusion since the resulting vector force is above the center of resistance of the U6 and maxilla, therefore enabling intrusion of the upper arch simultaneously with a clockwise rotation of the occlusal plane.

Limitations

Only 4 RCTs were eligible to be reviewed. To enhance our understanding of distalization effects, prospective and retrospective cohort studies were included. Bias and study design differences may influence the effect estimation, so the results should be interpreted cautiously.

The methods used to assess U6 movement varied among the studies reviewed. Most commonly, measurements were made on lateral cephalograms, cone beam computed tomography (CBCT) images, and three-dimensional (3D) dental models using different landmarks. Although each method was validated and accurate, variations among studies may limit generalizations and comparisons.

Additionally, the limited information provided on the severity of the Class II molar relationships within the studies could confound the meta-analysis.

CONCLUSIONS

- There were no significant differences in the magnitude of molar distalization, molar distal tipping, or molar intrusion among distalization appliances using palatal, zygomatic, or buccal TAD anchorages.
- The use of 3-TAD-supported appliances compared to 2-TAD-supported appliances for appliance anchorage did not improve the molar distalization magnitude or modify the extent of tipping and intrusion observed.
- Nonrigid palatal appliances resulted in significantly greater distal tipping than rigid appliances, although rigid and nonrigid appliances showed similar magnitudes of molar distalization and molar intrusion.
- Further well-designed, high-quality RCTs or prospective cohort studies are needed to provide clinical evidence of the efficacy of molar distalization with TADs.

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