Cureus
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Open Access Review Article

The Clinical Efficacy and Stability of Skeletal Anchorage Devices in Managing Class II Malocclusion: A Systematic Review and Meta-Analysis

Review began 11/03/2026
Review ended 11/08/2026
Published 11/10/2026

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DOI: 10.7759/cureus.119443

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Abstract

This systematic review and meta-analysis aimed to quantify whether skeletal anchorage alters the dentoskeletal response, device stability, and efficiency of Class II correction compared with conventional anchorage. Following a protocol registered in the International Prospective Register of Systematic Reviews (PROSPERO) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement, seven databases and registers were searched without language restriction. Randomized controlled trials (RCTs) comparing skeletal anchorage with conventional anchorage, alternative protocols, or untreated controls in Class II patients were eligible. Risk of bias was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool. Mean differences (MDs) were pooled with restricted maximum-likelihood random-effects models and Hartung-Knapp-Sidik-Jonkman confidence intervals (CIs); certainty was rated with the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. Twenty-four RCTs (27 reports; at least 871 randomized participants) were included; 21 raised some concerns, and three were at high risk of bias. Versus conventional anchorage (15 trials), skeletal anchorage produced a more distal maxillary first-molar position (MD 0.95 mm; 95% CI 0.08 to 1.82), less maxillary incisor proclination (-3.37°; -6.08 to -0.67), less mandibular incisor proclination (-4.20°; -6.54 to -1.85) and protrusion (-1.09 mm; -1.91 to -0.27), less mandibular molar mesialization (-0.68 mm; -1.26 to -0.09), and greater overjet reduction (-0.74 mm; -1.39 to -0.08). Maxillary restraint was marginal (sella-nasion-A point angle (SNA) -0.28°; -0.48 to -0.07), whereas the A point-nasion-B point angle (ANB), the sella-nasion-B point angle (SNB), mandibular length, and the mandibular plane angle did not differ. Pooled device failure was 8.3% (5.6% to 12.0%); active treatment duration was unchanged (0.54 months; -0.68 to 1.75). Certainty was low to very low. Skeletal anchorage improves dentoalveolar anchorage control, particularly by limiting incisor compensation, rather than enhancing skeletal Class II correction.

Categories: Pediatrics, Oral Medicine, Dentistry
Keywords: anchorage control, class ii malocclusion, fixed functional appliances, meta-analysis, miniplates, molar distalization, orthodontic miniscrews, skeletal anchorage, systematic review, temporary anchorage devices

Introduction And Background

Class II malocclusion is among the most frequent sagittal discrepancies encountered in orthodontic practice, affecting one in five individuals worldwide and accounting for a large share of treatment demand [1]. Whether managed with functional appliances, intraoral distalizers, Class II elastics, or camouflage retraction, its correction depends on the reciprocal reaction forces generated within the dental arches. A substantial proportion of the overjet reduction obtained with conventional mechanics is dentoalveolar rather than skeletal: removable and fixed functional appliances produce clinically modest mandibular effects, with most of the change attributable to proclination of the mandibular incisors, retroclination of the maxillary incisors, and mesial migration of the mandibular dentition [2-4]. These compensations limit the attainable skeletal correction, may compromise the periodontium over the mandibular incisors, and contribute to relapse once appliances are removed [5].

Skeletal anchorage, provided by miniscrews, mini-implants, miniplates, or palatal plates, was introduced to make anchorage independent of the dentition and patient compliance [6]. In tooth-borne mechanics, temporary anchorage devices (TADs) reinforce anchorage during space closure and en masse retraction [7-10] and allow maxillary molars to be distalized without the incisor flaring and anchorage loss characteristic of Nance-supported distalizers [11,12]. In functional and orthopedic protocols, TADs or miniplates are used either to stabilize the mandibular dentition indirectly or to deliver the appliance force directly to the basal bone, with the explicit aim of converting dentoalveolar compensation into skeletal change [13-15]. Despite acceptable device failure rates [8], skeletal anchorage adds surgical steps, cost, and morbidity; its justification rests on whether it produces measurable clinical advantages over conventional anchorage.

Existing syntheses leave this question unresolved for three reasons. First, they were restricted to single mechanics, such as fixed functional appliances [13-15], maxillary distalization [11,12], or bimaxillary miniplates [16,17], and therefore cannot show whether the anchorage benefit is a general property of skeletal anchorage or specific to one appliance. Second, several pooled randomized and non-randomized designs, which may introduce selection bias because skeletal anchorage is often reserved for more severe or less compliant patients. Few quantified between-trial variability with prediction intervals or graded the certainty of evidence, so the effect to be expected in a new clinical setting and the confidence it deserves remain unclear. Third, the most recent meta-analysis comparing microimplant and traditional anchorage across Class II therapy [18] predates several randomized controlled trials (RCTs) published since 2023, including the first three-arm trials comparing bone-anchored force systems with untreated controls. Consequently, no synthesis restricted to randomized evidence has weighed dentoskeletal efficacy against device stability and treatment efficiency across the full range of mechanics, which is the trade-off clinicians face when deciding whether the additional surgical step, cost, and morbidity of skeletal anchorage are justified for a Class II patient. An updated review was needed to incorporate the recent trials, to distinguish effects that generalize across mechanics from those confined to particular appliances, and to state explicitly how certain the evidence is.

Therefore, we conducted a systematic review and meta-analysis restricted to RCTs to answer four questions: (i) Does skeletal anchorage, compared with conventional anchorage, increase the skeletal component of Class II correction? (ii) Does it reduce the dentoalveolar side effects that conventional anchorage produces, specifically maxillary molar mesialization, incisor proclination, and mandibular molar mesialization? (iii) How frequently do skeletal anchorage devices fail? (iv) Does skeletal anchorage modify the duration of active treatment? We also examined whether these effects differ by treatment mechanics, device type, and growth status and rated the certainty of each body of evidence.

Review

Methods

Protocol and Reporting

The review was registered prospectively in the International Prospective Register of Systematic Reviews (PROSPERO), conducted according to the Cochrane Handbook for Systematic Reviews of Interventions, and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [19,20].

Eligibility Criteria

Eligibility was defined a priori using the Population, Intervention, Comparator, Outcome, and Study (PICOS) design framework (Appendix 1) [20]. Participants were children, adolescents, or adults with Class II malocclusion diagnosed by recognized clinical or cephalometric criteria, irrespective of division or severity; patients with craniofacial syndromes, clefts, or systemic conditions affecting bone metabolism were excluded. The intervention was any orthodontic treatment using skeletal anchorage (miniscrews, mini-implants, microimplants, miniplates, or palatal plates), alone or combined with fixed appliances, functional appliances, distalizers, or Class II elastics. The comparators were conventional anchorage (headgear, transpalatal arch, Nance or splint anchorage, or the same appliance without skeletal anchorage), alternative treatment protocols such as extraction, an alternative skeletal anchorage system, or untreated Class II controls. Only parallel-group or split-mouth RCTs were eligible; conference abstracts and abstract-only records were included when they reported extractable outcome data. Non-randomized, observational, and laboratory studies were excluded. Restriction to RCTs was chosen because, in non-randomized designs, allocation to skeletal anchorage is commonly influenced by malocclusion severity, anticipated compliance, or operator preference, which would confound comparisons between anchorage strategies. Abstract-only records were retained to reduce the risk of publication bias, because several recent trials had not yet been published in full.

Information Sources and Search

The Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE via PubMed, Embase, Scopus, Google Scholar, ClinicalTrials.gov, and the World Health Organization (WHO) International Clinical Trials

Registry Platform (ICTRP) were searched from inception to September 2026, without language or date restrictions (Appendix 2) [20]. Strategies combined controlled vocabulary and free-text terms for Class II malocclusion and skeletal anchorage (e.g., "Malocclusion, Angle Class II", "orthodontic anchorage procedures", miniscrew*, mini-implant*, microimplant*, miniplate*, "temporary anchorage device*", "skeletal anchorage") with a randomized-trial filter. Reference lists of included trials and previous reviews were hand-searched, forward citation tracking was performed, and trial authors were contacted for missing information [11-18,20].

Study Selection and Data Extraction

Two reviewers independently screened titles and abstracts and full texts against the eligibility criteria; disagreements were resolved by a third reviewer [19,20]. Data were extracted independently and in duplicate using a piloted form recording design, setting, registration, participant characteristics, growth status, anchorage device and site, appliance and mechanics, force, timepoints, outcome definitions, arm-level means and standard deviations (SDs), events, adverse effects, and funding [20]. Multiple reports of the same trial were collated and analyzed once. For multi-arm trials, skeletally anchored arms sharing a comparator were combined using the Cochrane formulae to avoid double counting, and untreated arms were used only in the comparison against untreated controls; non-randomized untreated groups were not analyzed [20]. When change-score SDs were not reported, they were derived from baseline and final SDs assuming a within-patient correlation of 0.5 [20,21], a midpoint value adopted because trial-specific correlations could not be derived from the reports; its influence was tested with values of 0.2 and 0.8.

Outcomes and Comparisons

Primary outcomes were sagittal skeletal changes (sella-nasion-A point angle (SNA), sella-nasion-B point angle (SNB), A point-nasion-B point angle (ANB), and Wits appraisal) and dentoalveolar anchorage control: sagittal position of the maxillary first molar (U6) and incisor (U1), maxillary incisor inclination, mandibular incisor sagittal position (L1) and inclination, and mandibular first molar (L6) sagittal position. Secondary outcomes were vertical changes (sella-nasion to mandibular plane angle (SN-MP), maxillo-mandibular plane angle, U6 and U1 vertical position), effective mandibular (condylion-gnathion (Co-Gn)) and maxillary (condylion-A point (Co-A)) length, overjet, overbite, soft-tissue profile, active treatment duration, skeletal anchorage device failure, adverse events, dropout, and patient-reported outcomes. All outcomes were extracted as changes from the start to the end of the active anchorage phase. Measurements were harmonized so that positive U6 values indicate a more distal molar position and negative inclination or sagittal values for the incisors indicate less proclination or protrusion; skeletal outcomes retained their conventional sign.

The primary comparison was skeletal versus conventional (non-skeletal) anchorage, pooled across trials of fixed functional appliances, molar distalization, and incisor retraction/Class II elastics/intrusion, with treatment mechanics examined as a subgroup factor. Mechanics-specific comparisons, skeletal anchorage versus untreated controls, skeletal anchorage versus extraction-based camouflage, and head-to-head comparisons of skeletal anchorage systems were analyzed separately. Pooling across mechanics was prespecified because the review question concerns the source of anchorage rather than a particular appliance: in each group of mechanics, the comparator relies on dental or extraoral anchorage that permits reciprocal movement of the anchor teeth, and skeletal anchorage aims to eliminate that movement, so the outcomes measure the same construct (anchorage loss) in each setting. Because the anchorage demand differs between mechanics, the pooled estimate was interpreted as the average effect across the included settings rather than as the effect expected in any single setting, and it is reported together with its prediction interval and with the mechanics-specific estimates.

Risk of Bias

Two reviewers independently assessed each trial using the Cochrane Risk of Bias 2 (RoB 2) tool across the five domains (randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selection of the reported result) and assigned an overall judgement of low risk, some concerns, or high risk; disagreements were resolved by consensus [22]. Results were visualized using robvis (Luke A. McGuinness and Julian P. T. Higgins, Bristol, UK) [23].

Data Synthesis

Continuous outcomes were summarized as mean differences (MDs) (skeletal minus comparator) with 95% confidence intervals (CIs). Random-effects models were fitted with the restricted maximum-likelihood (REML) estimator of between-trial variance (τ^2) [24,25], and CIs were computed with the Hartung-Knapp-Sidik-Jonkman (HKSJ) method with the ad hoc variance correction that prevents intervals narrower than the standard Wald interval [26-28]. REML was preferred because it estimates τ^2 with less bias than the DerSimonian-Laird method when trials are few, and HKSJ intervals were used because Wald-type intervals are too narrow in this situation and do not maintain nominal coverage [25,27,28]. Heterogeneity was quantified with Cochran's Q, I^2, and τ^2, and 95% prediction intervals were calculated when at least three

trials contributed [29,30]. Prediction intervals were used to judge how consistently an effect would occur in a new setting: an effect was described as consistent only when its prediction interval excluded no effect, whereas effects with a CI excluding zero but a prediction interval including it were described as present on average but not in every setting. Dichotomous outcomes were pooled as risk ratios (RRs). Device failure proportions were pooled on the logit scale with REML and HKSJ intervals, with device type examined by meta-regression and a binomial-normal generalized linear mixed model as an alternative specification [31]. Outcomes reported by a single trial were presented without pooling.

Three prespecified subgroup factors were examined using between-subgroup Q tests and random-effects meta-regression: treatment mechanics (fixed functional appliance, molar distalization, retraction/elastics/intrusion), device type (miniscrew/mini-implant vs. miniplate), and growth status (growing vs. post-pubertal). These analyses were prespecified but exploratory: they rely on between-trial comparisons, which are observational and may be confounded by other trial characteristics; each level contained few trials; and 42 between-subgroup tests (15 outcomes and three factors) were performed without adjustment for multiplicity, so about two significant results would be expected by chance alone. In interpreting them, a subgroup difference was regarded as more credible when the between-subgroup Q test and meta-regression agreed, each subgroup contained at least two trials, and the difference was biologically plausible; all other differences were treated as hypothesis-generating.

Robustness was examined through prespecified sensitivity analyses: common-effect and DerSimonian-Laird models [32], untruncated Knapp-Hartung intervals, standardized MDs (Hedges' g) [33], exclusion of trials with imputed SDs, alternative correlation coefficients (0.2 and 0.8) for SD imputation, exclusion of trials at high overall risk of bias, exclusion of comparisons in which the experimental and control appliances differed, and leave-one-out analysis [34]. For device failure, alternative failure counts and the exclusion of a trial with an uncertain denominator were tested. Because several devices were placed in each patient, device-level failures are clustered within patients, whereas the primary analysis treats devices as independent. As patient-level device data were not reported, this unit-of-analysis issue was addressed by reporting the proportion of patients with at least one failure where available and by a sensitivity analysis in which each trial's numbers of devices and failures were divided by a design effect, $1 + (m - 1) \times ICC$, where m is the mean number of devices per patient and ICC the intra-patient correlation, assumed to be 0.1, 0.3, 0.5, or 1.0 (the last equivalent to counting each patient once) [20].

When at least 10 trials contributed, small-study effects were explored with funnel plots and Egger's regression test, supplemented by trim-and-fill and limit meta-analysis [35-38]. Analyses used R version 4.6.1 (R Foundation for Statistical Computing, Vienna, Austria) with the metafor package (version 5.0-1); two-sided $p < 0.05$ denoted statistical significance [24].

Certainty of Evidence

Certainty was rated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach for each primary outcome and for treatment duration [39]. Evidence from RCTs started at high certainty and was downgraded one level for risk of bias when most of the analytic weight came from trials with some concerns or high risk, by one or two levels for inconsistency (I^2 of 50-75% or >75% with a significant Q test), for imprecision when the total sample was below an optimal information size of 400 participants or the CI included both no effect and a clinically important effect, for indirectness, and for suspected publication bias [39-41].

Results

Study Selection and Characteristics

Database searching identified 1464 records and citation searching identified a further 10. After removal of 266 duplicates, 1208 records were screened, and 64 reports were sought for retrieval, of which four could not be obtained. Of the 60 reports assessed in full text, 33 were excluded, 26 of them because of an ineligible study design, leaving 24 RCTs reported in 27 publications (Figure *1*) [42-68]. Three trials contributed companion reports (patient acceptance, soft tissue, and dentoalveolar outcomes), and four trials were available only as indexed abstracts [47,50,65,67]. Nineteen trials contributed to at least one meta-analysis.

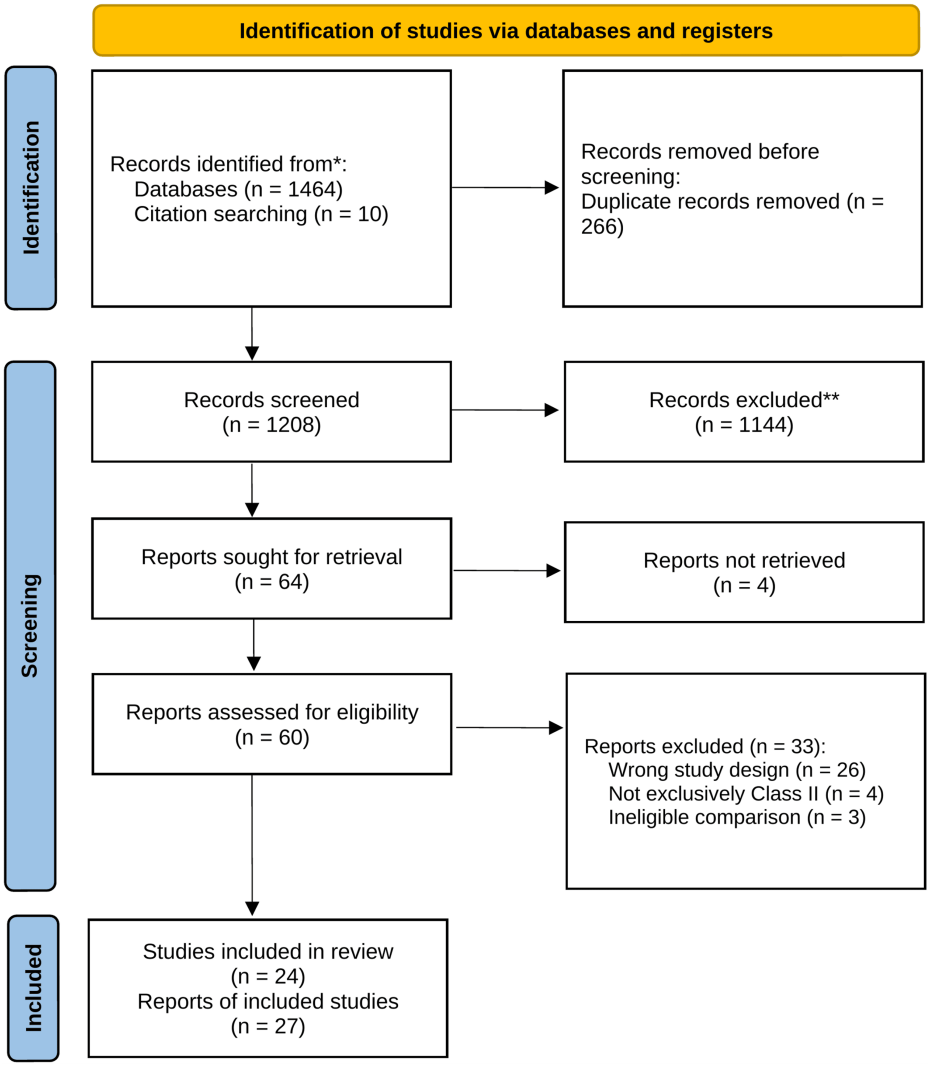


FIGURE 1: PRISMA 2020 flow diagram of trial identification, screening, and inclusion.

*Records identified from the databases and registers listed in Appendix 2 (CENTRAL, MEDLINE via PubMed, Embase, Scopus, Google Scholar, ClinicalTrials.gov, and WHO ICTRP). **Records excluded by human reviewers at title-and-abstract screening.

The trials were published between 2012 and 2026 and conducted in Egypt (n = 11), Syria (n = 3), Italy (n = 3), Turkey (n = 2), Brazil (n = 2), India (n = 2), and China (n = 1) (Table *1*). At least 871 participants were randomized in 23 trials (one abstract did not report its sample size), with arm sizes of 10-52. Fifteen trials enrolled growing patients, eight enrolled post-pubertal adolescents or adults, and one enrolled both; five recruited females only. Skeletal anchorage consisted of miniscrews or mini-implants in 20 trials, symphyseal or bimaxillary miniplates in three, and a palatal plate in one. Nine trials compared a fixed functional appliance with and without skeletal anchorage, five compared skeletally anchored with Nance- or headgear-anchored molar distalization, four compared skeletal with conventional anchorage for incisor retraction, Class II elastics, or intrusion, two compared skeletal anchorage with extraction-based camouflage, and six included head-to-head comparisons of skeletal anchorage systems. Four trials randomized an untreated Class II control arm. Outcomes were assessed on lateral cephalograms in 15 trials, cone-beam computed tomography in eight, and digital casts in one; all assessments ended at the completion of the active anchorage phase, and no trial reported post-retention stability.

Trial	Country	Participants: age (years); growth	Randomized (n)	Skeletal anchorage: device, site	Comparator(s)	Mechanics
Abdeldayem et al. 2022 [42]	Egypt	11-14; growing (CVM 3); females	26	Miniscrews, mandibular 5-6	Same splint-Forsus without miniscrews	Fixed functional (Forsus)

Abo-Elmahasen et al. 2024 [43]	Egypt	15-18; post-pubertal	20	Miniplates, symphysis (direct)	Twin Force Bite Corrector	Fixed functional (Herbst)
Afify et al. 2021 [44]	Egypt	10-12; growing (CS2-3); males	22	Miniscrews, infrazygomatic crest	High-pull headgear	Molar distalization/intrusion
Aksoy et al. 2025 [45]	Turkey	≈14; adolescents	30	One or two palatal miniscrews	Nance-anchored pendulum	Molar distalization
Al-Sibaie et al. 2014 [46]	Syria	Mean 22; adults	56	Mini-implants, maxillary 5-6	Transpalatal arch, two-step retraction	En masse retraction
Ali et al. 2025 [47]	Egypt	≈13; growing	20	TADs, direct (pull distal slider)	TADs, indirect (dual-force distalizer)	Molar distalization
Altieri et al. 2022 [48]	Italy	Mean 13; adolescents	46	Two paramedian palatal miniscrews	Nance-anchored distal jet	Molar distalization
Aslan et al. 2014 [49]	Turkey	≈14; circumpubertal	33	Miniscrews, mandibular 3-4	Same Forsus without miniscrews	Fixed functional (Forsus)
da Costa et al. Barreto 2026 [50]	Brazil	Mean 12.6; pubertal peak	40	Mandibular miniscrews	Dentally anchored Herbst	Fixed functional (Herbst)
Brandão et al. 2024 [51]	Brazil	10-14; pubertal peak	30	Mandibular miniscrews	Dentally anchored Herbst; Twin Block	Fixed functional (Herbst)
Cassetta et al. 2019 [52]	Italy	>12; adolescents	20	Two paramedian palatal miniscrews	Nance-anchored distal jet	Molar distalization
Eissa et al. 2017 [53]	Egypt	≈12.7; circumpubertal	45	Miniscrews, mandibular 3-4	Forsus alone; untreated	Fixed functional (Forsus)
El-Dawlatly et al. 2021 [54]	Egypt	≈15.4; post-pubertal; females	28	Mini-implants, mandibular 5-6	Class II elastics alone	Class II elastics
Elkordy et al. 2015, 2016 [55,56]	Egypt	11-14; growing; females	46	Mini-implants, mandibular 3-4	Forsus alone; untreated	Fixed functional (Forsus)
Elkordy et al. 2018, 2019 [57,58]	Egypt	10-13; CVM 3-4; females	48	Miniplates, symphysis (direct)	Forsus alone; untreated	Fixed functional (Forsus)
Fouda et al. 2022 [59]	Egypt	≈18; post-pubertal; females	24	Miniscrews, mandibular 5-6	Essix anchorage	Carrière Motion + Class II elastics
Kochar et al. 2023 [60]	India	≈13; circumpubertal	46	Mini-implants, maxillary 5-6	Forsus without extraction	Extraction en masse retraction
Kumar et al. 2017 [61]	India	15-20; post-pubertal	30	Miniscrews, maxillary 1-2	Connecticut intrusion arch	Incisor intrusion
Mahmoud et al. 2025 [62,63]	Egypt	11-13; CVM 3-4	39	Bimaxillary miniplates (SARA or coil spring)	Alternative miniplate system; untreated	Bone-anchored functional
Manni et al. 2012 [64]	Italy	Mean 11.8; growing	50	Miniscrews, mandibular 5-6	Same Herbst without miniscrews	Fixed functional (Herbst)
Owayda et al. 2026 [65]	Syria	16-30; adults	NR	Maxillary or mandibular TADs	Premolar extraction with TADs	Total-arch distalization
Raghis et al. 2023 [66]	Syria	≈20; adults	40	Casted palatal plate	Buccal miniscrews	Total-arch distalization
Zaher et al. 2023 [67]	Egypt	Mean 16; non-growing	28	Palatal mini-implants	Buccal mini-implants	Segmental incisor retraction
Zhao et al. 2024 [68]	China	15-40; mixed	104	Mini-implants, maxillary 5-6	Headgear	Extraction retraction

TABLE 1: Characteristics of the included randomized controlled trials.

Numerals denote interradicular sites by tooth (e.g., 5-6, between the second premolar and first molar).

CVM, cervical vertebral maturation; CS, cervical stage; NR, not reported; SARA, Sabbagh Advanced Repositioning Appliance; TAD, temporary anchorage device

Risk of Bias

Twenty-one trials raised some concerns, and three were at high overall risk of bias (Figure *2*). Bias arising from deviations from intended interventions raised concerns in all trials because participants and operators could not be blinded; the trial with differential attrition (40% in the skeletal arm) and per-protocol analysis was rated high risk in domains 2 and 3 [51], one pilot trial was rated high overall because of concerns across several domains [61], and one trial was rated high for selective reporting [68]. Only two trials were judged at low risk in the selection-of-the-reported-result domain, reflecting the scarcity of registered protocols with prespecified analyses.



FIGURE 2: Risk of bias of the included trials assessed with RoB 2.

(A) Domain-level and overall judgements for each trial. (B) Proportion of trials in each judgement category per domain. D1, randomization process; D2, deviations from intended interventions; D3, missing outcome data; D4, measurement of the outcome; D5, selection of the reported result.

Skeletal Versus Conventional Anchorage: Dentoskeletal Effects

Fifteen trials compared skeletal with conventional anchorage, with up to 13 trials (424 participants) per outcome (Figure 3, Table 2). Skeletal anchorage did not increase the sagittal skeletal correction: ANB (MD -0.22°; 95% CI -0.52 to 0.08; 11 trials), SNB (-0.05°; -0.41 to 0.31), and effective mandibular length (Co-Gn 1.12 mm; -0.31 to 2.56) did not differ, whereas SNA showed a small, homogeneous additional restraint (-0.28°; -0.48 to -0.07; $I^2 = 0\%$). Vertical skeletal changes were unaffected (SN-MP 0.42°; -0.10 to 0.93).

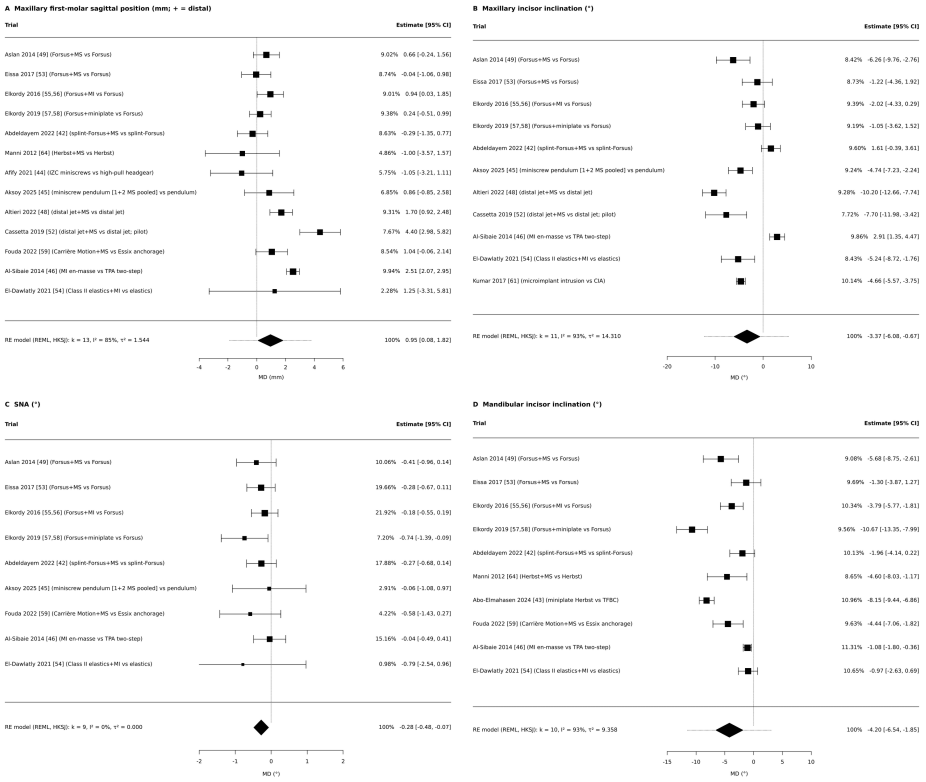


FIGURE 3: Forest plots of skeletal versus conventional anchorage for maxillary first-molar sagittal position (A), maxillary incisor inclination (B), sella-nasion-A point angle (SNA) (C), and mandibular incisor inclination (D).

Squares show trial mean differences (skeletal minus comparator) with 95% CIs and random-effects weights; diamonds show restricted maximum-likelihood (REML) estimates with Hartung-Knapp-Sidik-Jonkman 95% CIs, and dotted lines show 95% prediction intervals. Positive U6 values denote a more distal molar position; negative incisor values denote less proclination.

CIA, Connecticut intrusion arch; IZC, infrazygomatic crest; MI, mini-implant; MS, miniscrew; TFBC, Twin Force Bite Corrector; TPA, transpalatal arch

Outcome	Trials (participants)	MD (95% CI)	I^2	Certainty (GRADE)	Reasons for downgrading
ANB (°)	11 (351)	-0.22 (-0.52 to 0.08)	47%	Low	Risk of bias; imprecision
SNA (°)	9 (286)	-0.28 (-0.48 to -0.07)	0%	Low	Risk of bias; imprecision
SNB (°)	9 (286)	-0.05 (-0.41 to 0.31)	56%	Very low	Risk of bias; inconsistency; imprecision
U6 sagittal (mm; + distal)	13 (424)	0.95 (0.08 to 1.82)	85%	Very low	Risk of bias; serious inconsistency (-2)
U1 sagittal (mm)	9 (313)	-0.94 (-1.74 to -0.14)	74%	Very low	Risk of bias; inconsistency; imprecision
U1 inclination (°)	11 (359)	-3.37 (-6.08 to -0.67)	93%	Very low	Risk of bias; serious inconsistency (-2); imprecision
L1 inclination (°)	10 (325)	-4.20 (-6.54 to -1.85)	93%	Very low	Risk of bias; serious inconsistency (-2); imprecision
L1 sagittal (mm)	8 (250)	-1.09 (-1.91 to -0.27)	73%	Very low	Risk of bias; inconsistency; imprecision
L6 sagittal (mm)	7 (221)	-0.68 (-1.26 to -0.09)	0%	Low	Risk of bias; imprecision
Active treatment duration (months)	8 (230)	0.54 (-0.68 to 1.75)	91%	Very low	Risk of bias; serious inconsistency (-2); serious imprecision (-2)

TABLE 2: Summary of findings: skeletal versus conventional anchorage for Class II malocclusion.

Restricted maximum-likelihood (REML) random effects with Hartung-Knapp-Sidik-Jonkman (HKSJ) 95% CI. Imprecision: total sample below an optimal information size of 400 participants; for duration, the CI also included a one-month difference.

MD, mean difference (skeletal minus conventional anchorage)

In contrast, dentoalveolar anchorage control was better with skeletal anchorage. The maxillary first molar ended in a more distal position (0.95 mm; 0.08 to 1.82; 13 trials), maxillary incisors were less protrusive (-0.94 mm; -1.74 to -0.14) and less proclined (-3.37°; -6.08 to -0.67), mandibular incisors were less proclined (-4.20°; -6.54 to -1.85) and less protrusive (-1.09 mm; -1.91 to -0.27), and the mandibular first molar migrated less mesially (-0.68 mm; -1.26 to -0.09; $I^2 = 0\%$). Overjet reduction was greater by 0.74 mm (-1.39 to -0.08). Vertical positions of the maxillary molar (-0.01 mm; -0.29 to 0.27) and incisor (-0.16 mm; -1.21 to 0.89) did not differ. Heterogeneity was substantial for most dental outcomes. Only the SNA and mandibular molar estimates had prediction intervals excluding zero; for maxillary molar position (-1.89 to 3.79 mm), maxillary incisor position (-2.75 to 0.87 mm) and inclination (-12.22° to 5.48°), mandibular incisor inclination (-11.50° to 3.11°) and position (-3.09 to 0.91 mm), and overjet (-2.20 to 0.72 mm), the prediction intervals crossed zero. These dentoalveolar benefits are therefore present on average but cannot be expected in every clinical setting.

Subgroup Analyses

In exploratory subgroup analyses, treatment mechanics appeared to modify some effects, although few differences were supported by both the between-subgroup test and meta-regression. The molar benefit was larger in retraction (2.50 mm; -0.35 to 5.34; two trials) and distalization trials (1.48 mm; -0.89 to 3.86) than with fixed functional appliances (0.31 mm; -0.22 to 0.84), but none of these estimates excluded zero, and the difference was significant by the Q test ($p < 0.001$) but not by meta-regression ($p = 0.10$). Maxillary incisor inclination differed most with distalizers (-7.54°; -15.06 to -0.02; three trials; between-subgroup $p = 0.019$, meta-regression $p = 0.11$), and the mandibular incisor benefit was concentrated in fixed functional appliance trials (-5.18°; -8.31 to -2.05; between-subgroup $p = 0.001$, meta-regression $p = 0.28$), within which heterogeneity remained high ($I^2 = 89\%$). Device type was associated with mandibular incisor inclination in both tests (meta-regression $p = 0.001$): the reduction in proclination was larger with directly loaded miniplates than with miniscrews (-9.13° vs. -2.64°), although the miniplate estimate rested on two trials and was imprecise (-24.72 to 6.47). Miniplates were also associated with a slightly larger increase in SN-MP

(1.91° vs. 0.32°; meta-regression p = 0.020). Growth status did not modify any sagittal outcome; maxillary incisor vertical change differed between growing (0.47 mm) and post-pubertal patients (-1.73 mm; p = 0.005). Overall, 12 of 42 between-subgroup tests and four of 42 meta-regressions reached p < 0.05, against about two expected by chance; these findings are hypothesis-generating and do not establish effect modification.

Mechanics-Specific Comparisons

With fixed functional appliances (up to seven trials), skeletal anchorage restrained SNA slightly (-0.31°; -0.59 to -0.03) and reduced mandibular incisor proclination (-5.18°), without detectable differences in ANB (-0.35°; -0.74 to 0.03), SNB, Co-Gn (1.17 mm; -0.45 to 2.79; I^2 = 94%), mandibular incisor protrusion (-1.05 mm; -2.10 to 0.01), or soft-tissue profile measures. One trial reported a larger right condylar volume with miniplate-anchored Herbst therapy (MD 161.9 mm^3; 0.07 to 323.7) [43]. With distalizers (five trials), molar distalization was greater (1.48 mm) and incisor proclination lower (-7.54°), but pooled first-premolar distal movement (4.41 mm; -1.64 to 10.46; two trials) and molar tipping (-0.38°; -3.24 to 2.48) were imprecise. Among retraction trials, mini-implant en masse retraction increased the nasolabial angle (3.15°; 0.88 to 5.42) and retruded the lower lip (-1.08 mm; -1.98 to -0.18) [46], miniscrew-assisted intrusion produced greater incisor intrusion (3.10 vs. 2.07 mm; p = 0.001) [61], and microimplant-supported retraction improved overall efficacy compared with headgear (RR 1.24; 1.02 to 1.52) [68].

Comparisons With Untreated Controls, Extraction, and Alternative Skeletal Systems

Against randomized untreated controls (four trials, 108 participants), skeletally anchored treatment produced marked maxillary incisor retraction (-3.42 mm; -5.05 to -1.80) and retroclination (-8.50°; -16.90 to -0.10), whereas changes in ANB (-1.75°; -4.79 to 1.29), Wits (-3.01 mm; -6.38 to 0.36), SNB (1.27°; -1.95 to 4.50), and Co-Gn (1.70 mm; -2.74 to 6.15) were imprecise and highly heterogeneous (I^2 0-99%). Compared with non-extraction Forsus therapy, mini-implant-anchored extraction produced greater maxillary incisor retraction (-1.73 mm), less mandibular incisor proclination (-3.18°), and greater lip retraction, but less ANB reduction (1.00°; 0.17 to 1.83) [60]. In adults, intra- and inter-jaw TAD-anchored total-arch distalization achieved overjet reductions similar to extraction-based retraction (4.1 vs. 4.6 mm) with less incisor retroclination (5.2° and 8.0° vs. 11.0°) [65]. Head-to-head trials showed greater molar distalization with a palatal plate than with buccal miniscrews (2.45 mm; 1.48 to 3.42) [66], shorter distalization with two rather than one palatal miniscrew (-0.90 months; -1.34 to -0.46) [45] and with direct rather than indirect anchorage (-2.00 months; -3.39 to -0.61) [47], faster early incisor retraction from palatal than buccal mini-implants that converged by 12 weeks [67], and system-specific skeletal and vertical differences between two bimaxillary miniplate appliances [62,63].

Device Failure, Adverse Events, Treatment Duration, and Patient-Reported Outcomes

Across 11 trials, 35 of 558 skeletal anchorage devices failed, giving a pooled failure rate of 8.3% (95% CI 5.6-12.0%; I^2 = 13%) (Figure *4A*). Failure rates were 7.1% (4.0-12.3%) for miniscrews and mini-implants and 9.8% (0.5-71.8%) for miniplates (meta-regression p = 0.37). At the patient level, three of 134 participants (2.2%) in seven trials experienced failure. When device counts were deflated by a design effect to allow for clustering of devices within patients, the pooled failure rate changed little, from 8.2% (5.4-12.1%) with an intra-patient correlation of 0.1 to 7.7% (4.2-13.6%) when each patient was counted once, with progressively wider CIs. Failed devices were replaced or repositioned without reported abandonment of treatment, except one withdrawal for repeated miniplate mobility [62]. Peri-implant gingival inflammation (RR 6.56; 0.37 to 116.70) was reported by one trial [53], while appliance breakage (RR 0.87; 0.07 to 11.47; three trials) and dropout (RR 1.82; 0.38 to 8.61; five trials) did not differ. The active treatment phase was not prolonged by skeletal anchorage overall (0.54 months; -0.68 to 1.75; eight trials), although it was longer with fixed functional appliances (1.27 months; -0.15 to 2.70) and shorter with distalizers (-1.16 months; -4.50 to 2.18) (Figure *4B*). In the only trial reporting patient acceptance, satisfaction, pain, eating, speech, oral hygiene, and willingness to recommend the appliance did not differ between Forsus therapy with and without mini-implants (all p > 0.12) [55].

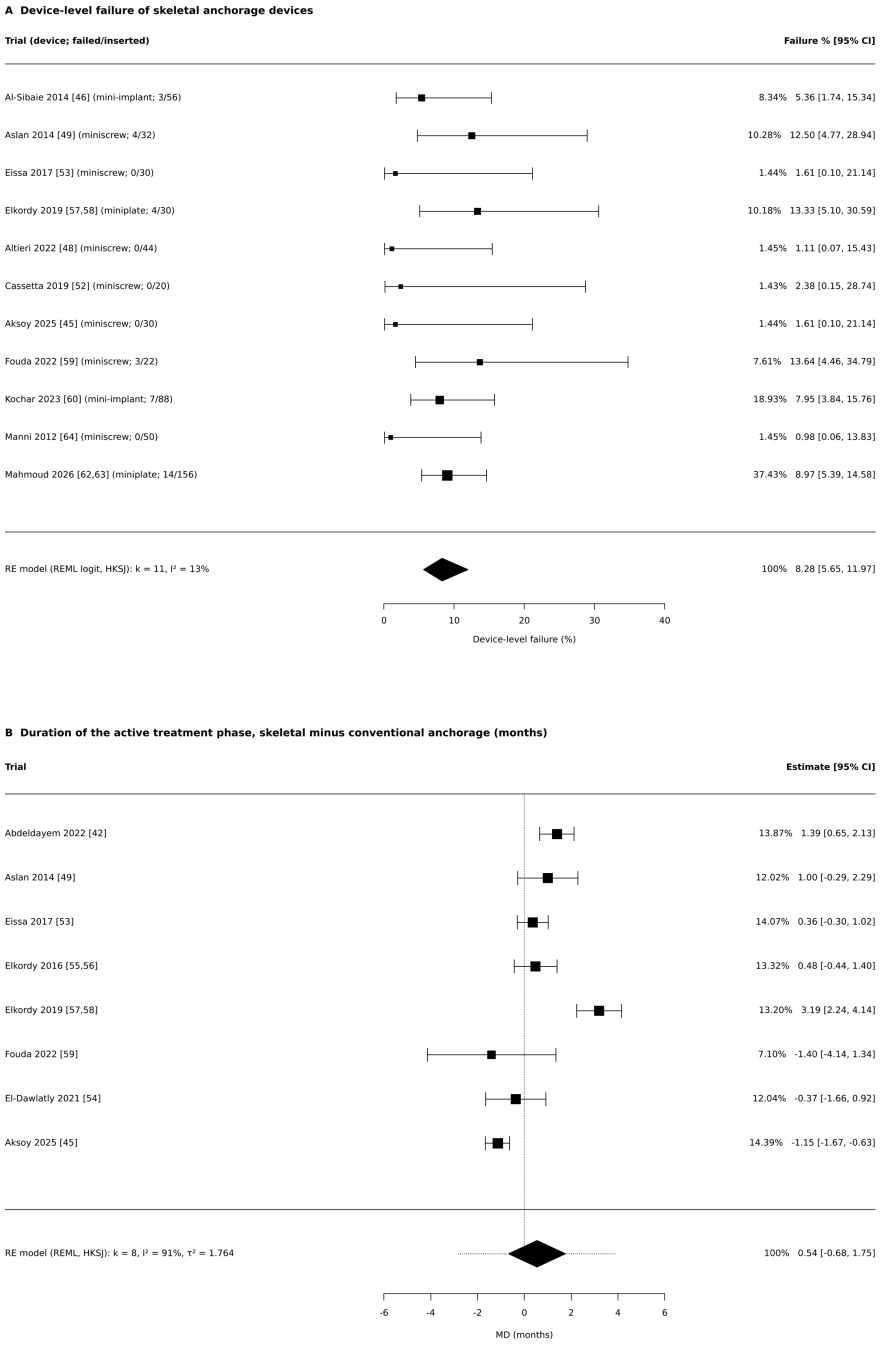


FIGURE 4: Device failure, adverse events, treatment duration, and patient-reported outcomes.

(A) Device-level failure of skeletal anchorage devices by trial (device type; failed/inserted), with logit-transformed proportions pooled by REML with Hartung-Knapp-Sidik-Jonkman 95% CIs; a continuity correction of 0.5 was applied to trials without failures. (B) Duration of the active treatment phase, skeletal minus conventional anchorage (months), with the 95% prediction interval shown as a dotted line.

Sensitivity Analyses and Small-Study Effects

The direction and significance of the SNA, maxillary incisor inclination, mandibular incisor inclination, and mandibular incisor protrusion effects were preserved under all alternative estimators, standardized MDs, SD-imputation correlations of 0.2 and 0.8, exclusion of imputed or high-risk trials, exclusion of the different-appliance comparison, and every leave-one-out iteration. The molar effect remained significant under alternative models (DerSimonian-Laird 0.95 mm; 0.19 to 1.72; Hedges' g 0.64; 0.02 to 1.25) but lost significance in four of 13 leave-one-out iterations (range 0.73-1.08 mm). The mandibular molar and overjet

effects lost significance when expressed as standardized MDs, and SN-MP and Co-Gn reached significance only under common-effect models. The device failure estimate was stable when alternative counts were used (8.0%), or a trial with an uncertain denominator was excluded (7.9%), and lower under a binomial-normal model (4.2%; 1.7-9.9%). Funnel plots for the six outcomes with at least 10 trials showed no significant asymmetry (Egger p = 0.11-0.98) (Figure *5*). Trim-and-fill imputed two to four trials for ANB, U6 sagittal position, SN-MP, and U6 vertical position; adjusted estimates were consistent in direction with the primary results.

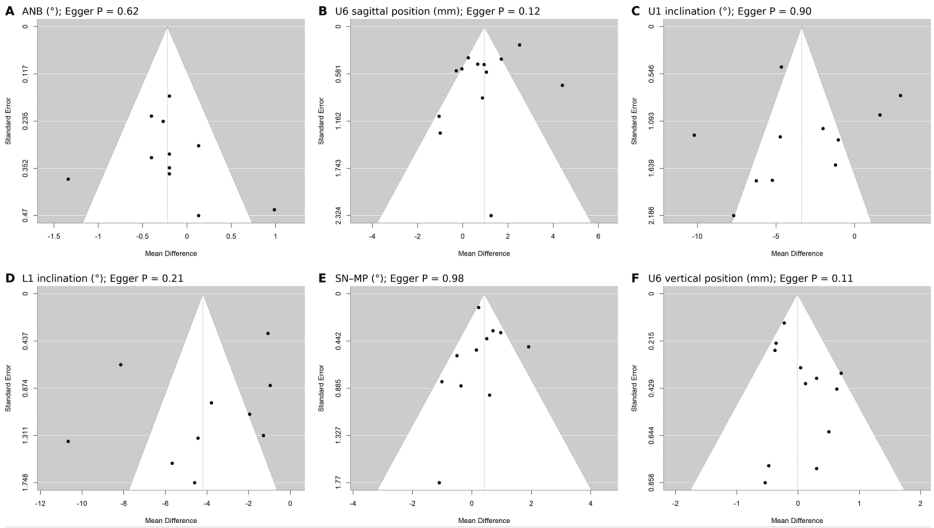


FIGURE 5: Funnel plots of trial mean differences against standard errors for outcomes informed by at least 10 trials, with pseudo-95% confidence regions (white) around the pooled estimate and Egger regression test p-values.

(A) ANB; (B) U6 sagittal position; (C) U1 inclination; (D) L1 inclination; (E) SN-MP; (F) U6 vertical position.

ANB, A point-nasion-B point angle; SN-MP, sella-nasion to mandibular plane angle

Discussion

This meta-analysis of 24 RCTs indicates that skeletal anchorage changes the way Class II malocclusion is corrected more than the amount of skeletal correction achieved. Relative to conventional anchorage, skeletal anchorage on average limited the dentoalveolar side effects that conventional mechanics produce (maxillary molar mesialization, maxillary and mandibular incisor proclination, and mandibular molar mesialization) and yielded a modest additional overjet reduction. For most of these outcomes, however, the prediction intervals included no effect, so the benefit should be expected on average rather than in every clinical setting. However, it did not increase mandibular advancement or ANB correction beyond a sub-degree restraint of SNA. Devices failed in approximately one in 12 placements, and active treatment was not prolonged. The certainty of this evidence was low to very low.

The largest and most robust average benefit was a reduction in mandibular incisor proclination of approximately 4°, which persisted in every sensitivity analysis. Lower incisor proclination is the principal mechanism by which fixed functional appliances reduce overjet and is a recognized threat to labial periodontal support and stability [3-5]. The pooled magnitude exceeds typical cephalometric measurement error and is comparable to the incisor proclination reported for conventional fixed functional appliances [3], suggesting that skeletal anchorage can neutralize a substantial share of this compensation. Its prediction interval (-11.50° to 3.11°), however, shows that the size of the benefit varies widely between settings and that it may be absent in some. Earlier syntheses limited to Forsus-type appliances reached similar conclusions [13,14,69]. Our subgroup analyses suggest that the effect may be larger with fixed functional appliances (approximately 5°) and with force delivered directly to symphyseal miniplates (approximately 9°) than with indirect miniscrew anchorage, which relies on ligature-tied mandibular teeth. These comparisons are between trials rather than within them. The miniplate estimate rests on two trials, and its CI included no effect, and they were among many subgroup tests; they should therefore be regarded as hypothesis-generating rather than as evidence of a dose-response relationship. If confirmed in head-to-head trials, direct skeletal loading would be particularly relevant for patients with thin symphyses or pre-existing incisor proclination.

In the maxilla, skeletal anchorage produced, on average, a molar position approximately 1 mm more distal and maxillary incisors approximately 3° less proclined. These effects arose from distalization and retraction trials, in which Nance buttons, transpalatal arches, and headgear allow measurable reciprocal incisor flaring or molar mesialization, and are consistent with earlier meta-analyses of intraoral distalizers and en masse retraction [9-12]. With fixed functional appliances, where the maxillary dentition is not the primary anchorage unit, the molar effect was negligible. The pronounced heterogeneity of the pooled molar estimate probably reflects, at least in part, clinically different anchorage demands, although heterogeneity persisted within distalization trials (I^2 = 82%) and the difference between mechanics was not confirmed by meta-regression (p = 0.10); its prediction interval crossing zero cautions that, in tooth-borne settings with low anchorage demand, the benefit may be absent.

The absence of a detectable gain in ANB, SNB, or effective mandibular length is perhaps the most important finding for clinical decision-making. A principal rationale for anchoring functional appliances to bone is to redirect the appliance force from the dentition to the mandible and thereby enhance its forward growth [13,15], yet pooled skeletal effects were small, centered near zero, and consistent with previous reviews of skeletally anchored fixed functional appliances and bimaxillary miniplates [13-17,70,71]. The comparisons with untreated controls confirm that skeletally anchored therapy corrects the Class II relationship, but chiefly through incisor retraction; skeletal estimates against controls were imprecise and highly heterogeneous. The small, homogeneous SNA reduction is biologically plausible, as skeletally anchored distalizers and functional appliances transmit a distal force to the maxilla without dissipation through the dentition, but at about 0.3° it is unlikely to be clinically meaningful. The slightly greater increase in SN-MP with miniplates, together with the absence of vertical molar control, suggests that bone-anchored functional mechanics do not protect against posterior rotation of the mandible [71,72]. The expectation that skeletal anchorage converts dental into skeletal correction is not supported by randomized evidence, and anchorage selection should be justified by the dentoalveolar objectives of treatment.

The pooled device failure rate of 8.3% is consistent with large observational syntheses of miniscrew failure [8] and was similar for miniscrews and miniplates, although miniplate data were sparse. Because failed devices were usually replaced without loss of treatment, the patient-level failure rate (approximately 2%) may be more informative for consent. Device-level pooling also treats devices in the same patient as independent; allowing for this clustering, up to counting each patient once, left the estimate essentially unchanged (7.7-8.2%) but widened its CI, so the precision of the device-level rate should not be overstated. The lower estimate under a binomial-normal model reflects the frequency of zero-event trials and illustrates the sensitivity of rare-event pooling to the model chosen [31]. Skeletal anchorage did not prolong active treatment overall; the longer phase with fixed functional appliances and shorter phase with distalizers are compatible with continued appliance activation until edge-to-edge incisor positions in the former and with more efficient molar movement in the latter. Patient acceptance, pain, and functional impairment did not differ in the only trial that measured them [55], but this evidence is too limited to exclude a burden from surgical placement.

The review was registered prospectively, restricted to RCTs, analyzed with methods that maintain nominal coverage when few heterogeneous trials are pooled [26-28], and reported prediction intervals and GRADE ratings for each primary outcome. The prespecified sensitivity analyses showed that the incisor and SNA effects were robust to estimator choice, SD imputation, risk of bias, and the influence of individual trials.

Limitations

Several limitations apply. First, blinding of participants and operators was impossible, most trials lacked a registered analysis plan, and three were at high risk of bias. Second, trials were small and geographically concentrated, with nearly half conducted in Egypt and several restricted to females, which limits generalizability. Third, the substantial heterogeneity of most dental outcomes reflects true clinical diversity in mechanics, devices, force systems, imaging modalities, and reference planes; we addressed this with mechanics-specific analyses and prediction intervals, but residual differences in cephalometric definitions may have attenuated pooled estimates. Fourth, four trials were available only as abstracts, and two Brazilian trials originated from the same registered protocol and may share participants [73]. Fifth, all outcomes were measured at the end of the active anchorage phase; no trial reported post-retention data, so the long-term stability of the dentoalveolar advantage, and whether reduced incisor compensation lowers relapse, remains unknown [5]. Sixth, the subgroup analyses were exploratory, involved multiple unadjusted tests, and compared trials rather than patients, and the device-level failure analysis could only approximate the clustering of devices within patients because patient-level device data were not reported. Finally, most comparisons included fewer than 400 participants, so imprecision contributed to downgrading for nearly every outcome.

Future trials should be registered with prespecified primary outcomes, use blinded three-dimensional superimposition on stable structures, report harmonized measures of mandibular incisor inclination and molar position, include patient-reported outcomes and costs, and follow patients beyond retention. Adequately powered head-to-head trials of direct versus indirect skeletal loading are needed to determine whether the larger dentoalveolar effect of miniplates justifies their greater surgical invasiveness.

Conclusions

Low- to very-low-certainty evidence from randomized trials indicates that, on average, skeletal anchorage improves dentoalveolar anchorage control during Class II correction, mainly by limiting mandibular and maxillary incisor proclination and molar mesialization, without increasing the skeletal sagittal correction or prolonging treatment, at the cost of an approximately 8% device failure rate. The size of this benefit varies between clinical settings and may be absent in some. Skeletal anchorage should therefore be selected for its dentoalveolar objectives rather than in expectation of enhanced mandibular growth.

Appendices

Appendix 1

Criterion	Inclusion	Exclusion
Population	Children, adolescents, or adults with Class II malocclusion diagnosed by recognized clinical or cephalometric criteria, irrespective of division or severity	Craniofacial syndromes, cleft lip and/or palate, or systemic conditions affecting bone metabolism or orthodontic tooth movement
Intervention	Orthodontic treatment using skeletal anchorage (miniscrews, mini-implants, microimplants, miniplates, or palatal plates), alone or combined with fixed appliances, functional appliances, distalizers, or Class II elastics	Treatment without skeletal anchorage in every arm; orthognathic surgery without skeletal anchorage devices; experimental devices not used clinically
Comparator	Conventional anchorage (headgear, transpalatal arch, Nance or splint anchorage, or the same appliance without skeletal anchorage), alternative protocols such as extraction, another skeletal anchorage system, or untreated Class II controls	No comparator group (single-arm studies)
Outcomes	Sagittal and vertical skeletal and dentoalveolar changes, skeletal anchorage device failure, treatment duration, adverse events, dropout, or patient-reported outcomes	No extractable data on any eligible outcome
Study design	Parallel-group or split-mouth randomized controlled trials, including conference abstracts with extractable outcome data	Non-randomized and observational studies, case reports and case series, reviews, editorials, animal studies, and in vitro studies
Language and publication date	No restrictions	None

TABLE 3: Eligibility criteria.

Appendix 2

Database or register	Search strategy	Search period
MEDLINE via PubMed	#1 "Malocclusion, Angle Class II"[MeSH] OR "Class II malocclusion"[tiab] OR "Class II division"[tiab] OR "skeletal Class II"[tiab]; #2 "Orthodontic Anchorage Procedures"[MeSH] OR miniscrew*[tiab] OR mini-implant*[tiab] OR microimplant*[tiab] OR miniplate*[tiab] OR "temporary anchorage device*"[tiab] OR "skeletal anchorage"[tiab]; #3 randomized controlled trial[pt] OR randomized[tiab] OR randomised[tiab] OR randomly[tiab]; #4 #1 AND #2 AND #3	Inception to September 2026
Cochrane Central Register of Controlled Trials (CENTRAL)	MeSH descriptor: [Malocclusion, Angle Class II] OR "Class II malocclusion" AND (MeSH descriptor: [Orthodontic Anchorage Procedures] OR miniscrew* OR mini-implant* OR microimplant* OR miniplate* OR "temporary anchorage device*" OR "skeletal anchorage")	Inception to September 2026
Embase	('malocclusion class II'/exp OR 'class II malocclusion':ti,ab) AND ('orthodontic anchorage'/exp OR miniscrew*:ti,ab OR 'mini implant*':ti,ab OR microimplant*:ti,ab OR miniplate*:ti,ab OR 'temporary anchorage device*':ti,ab OR 'skeletal anchorage':ti,ab) AND ('randomized controlled trial'/exp OR random*:ti,ab)	Inception to September 2026
Scopus	TITLE-ABS-KEY("Class II malocclusion" OR "Class II division") AND TITLE-ABS-KEY(miniscrew* OR "mini-implant*" OR microimplant* OR miniplate* OR "temporary anchorage device*" OR "skeletal anchorage") AND TITLE-ABS-KEY(random*)	Inception to September 2026
Google Scholar	"Class II" AND (miniscrew OR mini-implant OR miniplate OR "skeletal anchorage" OR "temporary anchorage device") AND randomized (first 200 records screened)	To September 2026
ClinicalTrials.gov	Condition: Class II malocclusion; Intervention: miniscrew OR mini-implant OR miniplate OR skeletal anchorage	To September 2026
WHO ICTRP	Class II malocclusion AND (miniscrew OR mini-implant OR miniplate OR skeletal anchorage)	To September 2026

TABLE 4: Search strategy.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

AI use statement: The authors have declared that no AI tools were used during the work or in the drafting of this article. The authors take full responsibility for the work. **Conflicts of interest:** In compliance with

the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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