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Umbrella review/meta-analysis

Effectiveness and efficiency of indirect bonding techniques: An umbrella review with meta-analysis of the pooled findings

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Transfer trays

Summary

Objectives > This umbrella review aimed to critically evaluate the available evidence regarding the accuracy, bond failure rate, working and chairside time, and oral hygiene associated with the indirect bonding of orthodontic brackets.
Material and methods > An electronic search was performed using the following databases: Cochrane Library, Scopus®, Web of Science™, EMBASE®, PubMed®, SciELO, and LILACS. The search was for systematic reviews published between January 1968 and January 2025. There were no restrictions on language or date of publication. The process of screening, study selection, data extraction, and methodological quality assessment using A Measurement Tool to Assess Systematic Reviews-2 (AMSTAR-2) was performed by two independent authors. The most reliable evidence was identified using the Jadad decision algorithm. Data were combined and analyzed using random-effects meta-analysis.
Results > Out of 66 studies eligible for assessment, 15 were selected for full-text assessment. Seven systematic reviews were included, five of which contained meta-analyses. According to the AMSTAR-2 tool, the included reviews varied in methodological quality from moderate to critically low, with four receiving the lowest rating, thus limiting the overall certainty of the available evidence. The meta-analysis of the pooled findings showed acceptable transfer accuracy for indirect bonding methods, with no significant difference compared to direct bonding. The bracket bond failure rate was also comparable in both techniques. Indirect bonding technique was

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associated with shorter chairside time but longer total working time. Finally, there is no reliable evidence in the current literature about oral hygiene and indirect bonding.

Conclusions > Based on the available evidence from the systematic reviews, within the limitations of the available evidence, direct and indirect bonding techniques did not significantly differ in bracket placement accuracy, bonding failure rate, and oral hygiene. Indirect bonding may require less chairside time but a longer overall working time than direct bonding.

Introduction

The advent of the straight wire technique in orthodontics has brought the need for accurate placement of brackets on the buccal surface of teeth along the facial axis of the clinical crown (FACC) [1]. It is important to place brackets carefully to avoid unwanted tooth movements like in/out, rotations, tipping, torque, and vertical changes [2,3]. Two common techniques are used in orthodontics for bracket placement. The most common and traditional method is direct bracket bonding, bonding individual brackets onto the surface of each tooth [4]. However, direct bonding is work-intensive concerning achieving optimal visibility, controlling oral humidity, comfort of patient and operator, and time of the procedure due to saliva contamination [5]. Practitioners may also make errors in bracket placement, such as vertical, horizontal, and rotational errors [6]. The indirect bonding concept was first introduced by Silverman and Cohen in 1972 [7,8]. It can be divided into two stages: laboratory and clinical. In the laboratory stage, after making a plaster cast of the patient's dental arch, an ideal bracket positioning is determined, and the brackets are bonded to study models. This can be done either manually on physical models or virtually on digital 3D models using specialized software. The choice between manual and virtual placement affects the workflow, precision, and potential for error [8]. In the clinical phase, they are directly applied onto the tooth surfaces, under the guidance of a custom transfer tray in a single visit [9]. Indirect bonding has many benefits compared with direct bonding in terms of increased accuracy, decreased patient discomfort, and decreased chairside time [10,11]. However, it also has some disadvantages, including more expense, and more complexity as it demands more skill and experience of the orthodontist. In general, indirect bonding is a reliable and effective technique for bracket placement and therefore recommended for patients who desire the most accurate and efficient treatment outcome [12]. It is also important to distinguish between conventional indirect bonding protocols performed manually on physical models, whether stone or 3D-printed, and fully digital workflows where bracket positioning is carried out virtually, followed by the fabrication of customized 3D-printed transfer trays [13]. These two approaches differ in terms of their workflow steps, potential for human error, and the technologies involved. Failure to distinguish between them could lead to biased interpretation of clinical outcomes in comparative studies [14].

Computer-aided design and computer-aided manufacturing (CAD/CAM) technology is another remarkable innovation that has changed the face of orthodontics and made it possible to achieve accurate position of brackets and prediction of treatment outcomes [15]. Digital indirect bonding software enables clinicians to closely examine individual teeth and brackets, enhancing precision [16]. Automated measurements and bracket comparisons promote symmetry in bonding. While digital workflows simplify placement, the clinician's expertise remains crucial [17,18]. Despite the technological precision offered by digital tools, the accuracy of bracket placement ultimately depends on the clinician's judgment in selecting ideal bracket positions, interpreting dental anatomy variations, and making case-specific decisions that technology alone cannot fully account for [19]. The previsualization feature is a significant advantage, harnessing computer algorithms to simulate the treatment's impact on the teeth's anatomy. This preview empowers customized appliance design, addressing individual anatomical variations in the vestibular surface [20,21]. By adjusting composite thickness and bracket slots, clinicians can refine the treatment plan [22,23].

Recently, there has been a notable surge in systematic reviews (SRs) that address the various techniques of indirect bonding. However, due to the vastness of this subject domain, decision-makers are facing a deluge of reviews presenting conflicting findings. Consequently, conducting a systematic review of published reviews (an umbrella review) emerges as a logical and fitting next step to synthesize the collective evidence and discern the most relevant conclusions from the diverse findings of multiple reviews.

The review question focuses on evaluating the effectiveness (accuracy of bracket positioning) and efficiency (chairside time, total working time, bond failure rate, and oral hygiene status) of different indirect bonding techniques.

Material and methods

Protocol and registration

This umbrella review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [24,25]. The protocol for this systematic review was prepared during the initial phase of review and registered in the International Prospective Register for

Systematic Reviews (PROSPERO) with the following number: CRD420251006375.

Eligibility and selection criteria

To identify relevant systematic reviews, the research question was formulated according to the following PICOS criteria [26]:

- type of participants (P): dental models and/or patients who received bonding techniques for the placement of orthodontic brackets;
- type of intervention (I): studies investigating the application of indirect bonding techniques for labial orthodontic appliances, either directly on patients' teeth or on dental models, including plaster casts or 3D-printed models;
- type of comparison (C): comparison with the direct bonding technique on patients' teeth and/or dental models (visually or with loupes/microscopes), with various indirect bonding techniques, or between the planned (ideal) position of orthodontic brackets versus the positions achieved post-transfer (actual);
- type of outcomes (O): accuracy of bracket positioning, chair-side time, total working time, bond failure rate, and oral hygiene status;
- study design: (S): only systematic reviews, with or without meta-analyses, were included in the study. Other review types were excluded.

Search strategy

A comprehensive electronic search of the following databases was conducted for this review from January 1968 to January 2025: Cochrane Library, Scopus®, Web of Science^{TM}, EMBASE®, PubMed®, SciELO, and LILACS. There were no restrictions on publication date, publication status, language, or age limit. Furthermore, relevant studies were identified through manual searches of the reference lists of the included articles. A variety of keywords were utilized for this search strategy. Details regarding the methodology used to identify relevant studies, including the search strategy and utilized keywords, are described in *table I*. Additional information on these keywords can be found in *supplementary table I*.

Table I
Electronic search strategy used in the current overview

Cochrane Library of SRs From January 1968 to January 2025 Title Abstract Keywords with no limits	#1 (Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") #2 ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") #3 ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") #4 ("systematic review" OR "meta-analysis") #5 #1 AND #2 AND #3 AND #4
Scopus From January 1968 to January 2025 Title Abstract Keywords with no limits	#1 TITLE-ABS-KEY (Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") #2 TITLE-ABS-KEY ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") #3 TITLE-ABS-KEY ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") #4 TITLE-ABS-KEY ("systematic review" OR "meta-analysis") #5 #1 AND #2 AND #3 AND #4
Web of Science All Data Bases TS = topics From January 1968 to January 2025 with no limits	#1 TS = (Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") AND #2 TS = ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") AND #3 TS = ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") AND #4 TS= ("systematic review" OR "meta-analysis")

Table I **(Continued).**

EMBASE From January 1968 to January 2025	#1 (Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") #2 ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") #3 ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") #4 ("systematic review" OR "meta-analysis") #5 #1 AND #2 AND #3 AND #4
PubMed All fields From January 1968 to January 2025 with no limits	#1 (Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") #2 ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") #3 ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") #4 ("systematic review" OR "meta-analysis") #5 #1 AND #2 AND #3 AND #4
SciELO From January 1968 to January 2025 with no limits	(Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") AND ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") AND ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") AND ("systematic review" OR "meta-analysis")
LILACS From January 1968 to January 2025 with no limits	(Bracket* OR orthodontic* OR "bracket positioning" OR "bracket placement" OR "ideal bracket placement" OR "bracket application" OR "bracket bonding") AND ("Indirect bonding" OR "digital indirect bonding" OR "indirect adhesion" OR "3D fabricated transfer trays" OR "3D-based bracket positioning" OR "3D fabricated transfer jigs" OR "3D customized transfer trays" OR "3D-printed customized transfer devices" OR "Indirect bracket positioning" OR "3D printed transfer trays" OR "CAD/CAM transfer trays") AND ("Accuracy" OR "transfer accuracy" OR "transfer precision" OR "chairside time" OR "working time" OR "labor time" OR "bond failure" OR "oral hygiene status" OR "adverse effects") AND ("systematic review" OR "meta-analysis")

Study selection and data extraction

Study selection was done independently by two reviewers (ZMA and MYH) based on the established eligibility criteria. A preliminary screening was performed based on the titles and abstracts of the identified articles. Then, the full-text articles of the remaining studies were screened for further review. Articles that did not meet all the eligibility criteria were excluded. Finally, data relevant to this review were extracted from each included study, such as authors, number of primary studies, study setting, participants, interventions, outcomes, study design, quality of primary studies, and main findings. Divergent opinions between the two reviewers were meticulously addressed through a collaborative discussion process until a unified consensus was achieved.

Quality assessment of the selected reviews

The methodological quality for the included systematic reviews was evaluated independently by two reviewers using the Assessment of Multiple Systematic Reviews-2 (AMSTAR-2) tool [27]. The AMSTAR-2 is the 16-item checklist for assessing the completeness of a systematic review domain, with seven domains categorized as critical domains and nine domains classified as non-critical domains.

The following seven key domains were assessed:

- whether the review followed a pre-registered protocol;
- the comprehensiveness and transparency of the search strategy;
- adequateness of justification for individual studies exclusion;
- the evaluation of potential biases among the included studies;
- the adequacy of statistical methods used;
- the integration of bias considerations in interpreting results;
- publication bias. Final ratings could be assigned: high if no or only one non-critical flaw was identified, moderate if more than one non-critical flaw was detected, low if one critical flaw with/without one non-critical weakness was identified, or

critically low if one critical weakness with/without more than one non-critical flaw was found.

Choice of the best body of evidence

When multiple systematic reviews with conflicting results were identified, the Jadad decision algorithm was employed to identify the systematic review that offered the most compelling and best body of evidence based on the available studies [28,29]. The Jadad decision algorithm serves as an ancillary decision-making tool to assist decision-makers in interpreting and choosing between discordant systematic reviews [28]. It consists of a series of reasoning steps (involving questions about the methodological aspects of the studies) employed when two or more systematic reviews reach divergent conclusions about the same exposure. This decision (selecting the study or studies with the most rigorous methodology, and consequently, the strongest evidence) is guided by discrepancies in the study question, trials included, type of study method employed, assessment quality, criteria for selecting primary studies, data extraction methods, data consolidation approaches, statistical analysis techniques, search strategies, and study selection processes.

Assessment of overlap

To assess the degree of overlap among the included systematic reviews, all primary studies from each review were extracted and entered into an overlap matrix. The corrected covered area (CCA) was then calculated following the method proposed by Pieper et al. [30] using the formula:

$$CCA = \frac{N - r}{r \times (c - 1)}$$

where N is the total number of occurrences of primary studies, r is the number of unique primary studies, and c is the number of systematic reviews.

The CCA provides a quantitative measure of overlap, with values categorized as slight (0–5%), moderate (6–10%), high (11–15%), and very high (> 15%). This process allowed us to evaluate the extent to which primary studies were repeatedly included across reviews, which could potentially impact the overall conclusions of the umbrella review.

Data synthesis

Meta-analysis was conducted for the following variables:

- bracket transfer accuracy;
- bond failure rate;
- chairside time and total working time.

Primary study data from the systematic reviews were pooled. One-arm data was pooled using Comprehensive Meta-Analysis software (Version 4; Biostat Inc., New Jersey, United States), and two-arm data (comparing bonding techniques) were pooled using Review Manager software (Version 5.4.1; the Nordic Cochrane Centre, Cochrane Collaboration, Copenhagen, Denmark). The random effects model and mean differences (MD) with associated 95% confidence intervals were applied to analyze continuous data. For dichotomous data, the risk ratio (RR) and 95% confidence interval (95% CI) were calculated for each study. Statistical heterogeneity between the studies was assessed using the I^2 index. The statistical significance of the hypothesis test was set at $P < 0.05$. Publication bias was assessed through visual inspection of funnel plots for outcomes reported in ten or more trials.

Results

Literature search flow and the retrieved reviews

A total of 66 unique citations were identified from electronic and manual searches. Upon removing duplicates, 27 citations were screened based on their titles and abstracts. Ultimately, 15 full-text reviews were assessed, and seven systematic reviews were eligible for inclusion in the overview. Those reviews not included in the full-text assessment are listed in *supplementary table II* with reasons for exclusion.

Figure 1 shows a flow diagram of the processes used to facilitate review identification and selection.

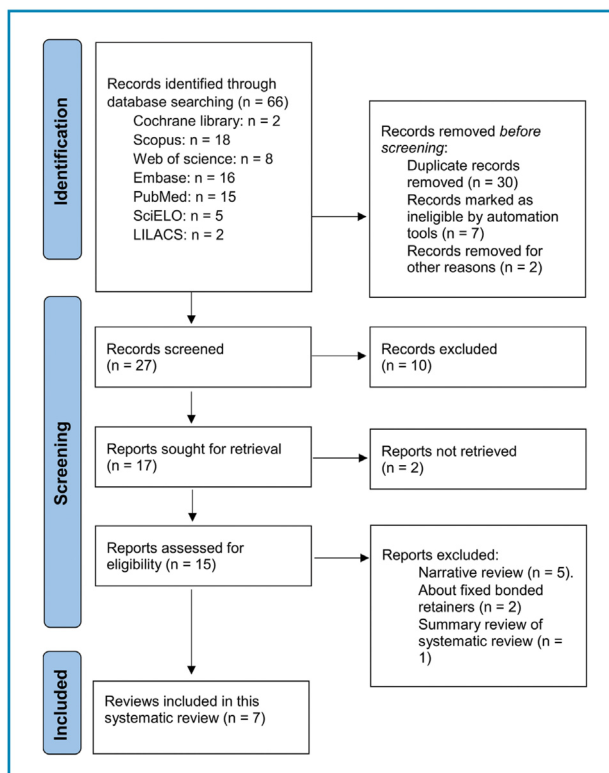

FIGURE 1

PRISMA flow diagram of the included reviews

Characteristics of the included reviews

All systematic reviews considered in this analysis were published recently, between 2019 and 2023. Four of the included reviews were conducted in Italy [31–34], with one each in China [35], Germany [36], and Syria [37]. Moreover, five systematic reviews included meta-analyses as a part of their design. The number of papers included in the review ranged from 7 [37] to 16 [36].

Only one review focused solely on randomized controlled trials (RCTs) [35], while the remaining reviews included a variety of study designs, such as cohort, case-control and laboratory studies [31–34,36,37]. This variability in study designs among the included reviews may impact the strength and generalizability of the pooled findings presented in this overview.

The accuracy of orthodontic bracket transfer in indirect bonding techniques was assessed in 6 reviews [31–33,35–37]. These reviews discussed different types of transfer trays, including 3D-printed transfer trays in 3 reviews [31,32,37], and vacuum-formed or silicone transfer trays in 3 reviews [33,35,36]. Another group of three reviews evaluated the bond failure rate associated with indirect bonding techniques [34]. Work time and chairside time required during the application of this technique were evaluated in two reviews [33,35]. Meanwhile, oral hygiene status [35], number of appointments [34], and treatment duration [34] were evaluated in one review.

The characteristics of the included reviews are summarized in *table II*. Both reviewers reached a perfect consensus throughout the data extraction process.

Table II
Characteristics of included systematic

Author, year (country) Study design	No. of studies (type of studies)	Interventions (no. of studies)	Comparison	Outcomes	Quality of primary studies	Conclusions
Albertini et al., 2021 (Italy) [34] SR	12 (6 RCTs, 2 cohort, 4 case-control)	Digital IBT (2) Traditional IBT (8)	Direct bonding (9) Conventional IBT (1)	Treatment time Number of appointments Number of detachments	Not addressed	IBT typically requires fewer appointments and treatment time. This time was further reduced with computer-aided IBT and setup. However, digital IBT has a longer total work time than direct. Bonding technique does not affect bracket detachments
Bakdach and Hadad, 2022 (Syria) [37] SR + MA	7 (1 RCT, 1 cohort, 5 laboratory)	Labial brackets were transferred to the patient's teeth by 3D printed trays (2) Labial brackets were transferred to dental casts by 3D-printed trays (3) Labial brackets were transferred to 3D-printed models by 3D-printed trays (2)	Labial brackets were transferred by VF trays (3) Labial brackets were transferred to the patient's teeth by PVS transfer tray (2) Labial brackets were transferred to dental casts (with 0.5 mm of grinding) by 3D-printed trays (1)	The transfer error for linear and angular variables	Low risk (for clinical studies)	3D-printed trays have an acceptable accuracy rate with a maximum linear transfer error in the buccolingual direction and a maximum angular transfer error in the torque

Table II **(Continued).**

Author, year (country) Study design	No. of studies (type of studies)	Interventions (no. of studies)	Comparison	Outcomes	Quality of primary studies	Conclusions
Campobasso et al., 2023 (Italy) [31] SR + MA	15 (1 RCT, 1 cohort, 1 prospective, 12 laboratory)	3D-printed tray	IBT with another 3D-printed tray (5) Conventional IBT with: – PVS tray (3) – Double-layer tray (3) – VF trays (2)	Accuracy of orthodontic bracket transfer, in terms of: – Linear (mesio-distal, bucco-lingual, vertical measurements) – Angular (angulation, rotation, torque measurements)	Not addressed	3D-printed devices are accurate for IBT (linear and angular, in vivo and in vitro). In vitro, the highest errors were bucco-lingual (linear) and torque (angular). In vivo, the worst inaccuracies with 3D-printed trays were bucco-lingual (incisors) and torque/tip (premolars), but mostly within clinical limits (except bucco-lingual)
Li et al., 2019 (China) [35] SR + MA	8 (RCTs)	IBT with: – VF trays (4) – PVS tray (2) – Double-layer tray (2)	Direct bonding	Bracket placement accuracy Working time Bond failure rate Oral hygiene status	Unclear risk (all studies)	Direct and IBT showed no difference in accuracy, oral hygiene status, or bond failure, but direct bonding may be faster overall (less total time)
Palone et al., 2023 (Italy) [32] SR + MA	13 (1 RCT, 3 cohort, 9 laboratory)	IBT with 3D-printed trays	IBT with: – PVS tray (3) – VF tray (3) – CAD/CAM transfer tray (2) – Two-layered silicone (1)	Linear (mesiodistal, vertical, and buccolingual) and angular (angulation/tip, inclination/torque, and rotation) positioning errors Difference in accuracy between CAD/CAM transfer trays made of hard versus soft resins	Low risk (for clinical studies)	CAD/CAM trays are precise, but vertical errors are highest, and inclination is least reliable. PVS trays are more precise than CAD/CAM for vertical and inclination; other measurements are comparable. Soft resin CAD/CAM trays are generally more accurate than rigid, except for vertical position (rigid better). However, rotation accuracy is the same for both
Patano et al., 2023 (Italy) [33] SR	11 (5 RCTs, 1 cohort, 1 cross-sectional, 4 laboratory)	Conventional IBT (7) Digital IBT (1) Virtual IBT (3)	Direct bonding	Accuracy of bracket positioning Chairside time Bonding failure	Not addressed	IBT has a more accurate bracket placement, similar time and failures. Digital bracket placement is convenient, but crowding can reduce precision
Sabbagh et al., 2022 (Germany) [36] SR + MA	16 (1 RCT, 3 cohort, 12 laboratory)	IBT with: – CAD/CAM transfer trays (9) – PVS trays (2) – VF trays (4) – Double-layer tray (1)	Comparison between the planned position of the orthodontic brackets with the positions achieved post-transfer (8) IBT with: – CAD/CAM transfer trays (2) – PVS trays (4) – VF trays (2)	Accuracy of bracket positioning	Unclear risk (3) High risk (13)	IBT accurately reflects planned bracket positions. Silicone and 3D-printed trays are more accurate than VF trays

SR: systematic review; MA: meta-analysis; RCT: randomized clinical trials; IBT: indirect bonding technique; PVS: polyvinyl siloxane; VF: vacuum-formed.

Quality of the evidence

The methodological quality of the included systematic reviews, as assessed using the AMSTAR-2 checklist, demonstrated variable methodological qualities ranging from critically low to moderate-quality reviews. In other words, there were some methodological shortcomings in the reviews. Two reviews were considered moderate-quality [32,37], one as low [36], and four as critically low [31,33–35]. The results of the AMSTAR-2 assessments for each review are shown in *table III*. Concerning the 7 critical items of the AMSTAR-2 tool, most included reviews did not use an adequate tool to evaluate the risk of bias in each included study (42.85% of the included reviews), and a lack of consideration for these biases when discussing and interpreting the results (42.85%). Nevertheless, most reviews pre-registered their study protocols (85.71%), provided comprehensive descriptions of their literature search strategies (85.71%), and meticulously documented a list of excluded studies along with justifications for their exclusion (71.42%). The rationale for each evaluation is comprehensively elucidated in *supplementary table III*. Despite the relatively low methodological quality of several included reviews, they were retained in this umbrella review to provide a comprehensive synthesis of the available evidence on the accuracy and performance of indirect bonding techniques. Excluding these reviews would have substantially reduced the breadth of the overview and potentially introduced selection bias. Moreover, by systematically assessing the methodological rigor using the AMSTAR-2 tool, the strengths and limitations of each included review were transparently documented, allowing readers to interpret the pooled findings considering these methodological limitations. Similar approaches have been adopted in previous umbrella reviews within orthodontics and other dental fields to ensure a balanced and inclusive appraisal of the current evidence base.

Table III

Methodological quality assessment based on the AMSTAR 2 items

AMSTAR 2 domains	Albertini et al. 2021 [34]	Bakdach and Hadad 2022 [37]	Campobasso et al. 2023 [31]	Li et al. 2019 [35]	Palone et al. 2023 [32]	Patano et al. 2023 [33]	Sabbagh et al. 2022 [36]
1. Did the research questions and inclusion criteria for the review include the components of PICO?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?	No	Partial yes	Yes	Partial yes	Yes	Yes	Yes
3. Did the review authors explain their selection of the study designs for inclusion in the review?	No	No	No	No	No	No	No
4. Did the review authors use a comprehensive literature search strategy?	No	Partial yes	Partial yes	Yes	Yes	Partial yes	Partial yes
5. Did the review authors perform study selection in duplicate?	No	Yes	Yes	Yes	Yes	Yes	Yes
6. Did the review authors perform data extraction in duplicate?	No	Yes	Yes	Yes	Yes	No	Yes
7. Did the review authors provide a list of excluded studies and justify the exclusions?	No	Yes	Yes	Yes	Yes	No	Yes
8. Did the review authors describe the included studies in adequate detail?	Partial yes	Yes	Yes	Yes	Yes	Yes	Partial yes
9. Did the review authors use a satisfactory technique for assessing the risk of bias in individual studies that were included in the review?	No	RCTs: yes Non-RCTs: yes	No	Yes	RCTs: yes Non-RCTs: yes	No	RCTs: yes Non-RCTs: no
10. Did the review authors report on the sources of funding for the studies included in the review?	No	No	No	No	No	No	No
11. If meta-analysis was performed, did the review authors use appropriate methods for statistical combination of results?	–	Yes	Yes	Yes	Yes	–	Yes

Table III **(Continued).**

AMSTAR 2 domains	Albertini et al. 2021 [34]	Bakdach and Hadad 2022 [37]	Campobasso et al. 2023 [31]	Li et al. 2019 [35]	Palone et al. 2023 [32]	Patano et al. 2023 [33]	Sabbagh et al. 2022 [36]
12. If meta-analysis was performed, did the review authors assess the potential impact of risk of bias in individual studies on the results of the meta-analysis or other evidence synthesis?	–	No	No	Yes	Yes	–	No
13. Did the review authors account for risk of bias in individual studies when interpreting/discussing the results of the review?	No	Yes	No	No	Yes	No	Yes
14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	No	No	Yes	No	Yes	No	No
15. If they performed quantitative synthesis, did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	–	Yes	No	No	Yes	–	Yes
16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quality results	Critically low	Moderate	Critically low	Critically low	Moderate	Critically low	Low

RCT: randomized clinical trial; non-RCT: non-randomized clinical trial.

Effects of interventions

The raw data from the primary studies were statistically combined to evaluate the main outcomes (1: bracket placement accuracy, 2: bond failure rate, 3: total working time and chairside time, and 4: oral hygiene status), using a random effects meta-analysis.

Bracket placement accuracy

Results regarding the transfer accuracy of indirect bonding trays were extracted from six systematic reviews: Bakdach and Hadad 2022, Palone et al., 2023, Campobasso et al., 2023, Li et al., 2019, Sabbagh et al., 2022, and Patano et al., 2023 [31–33,35,36,38].

Among the six reviews that evaluated bracket placement accuracy using indirect bonding techniques, three reviews addressed the same question with a substantial overlap of included trials [31,32,37], while the remaining three studies explored the same question but differed in their recruited trials and selection criteria [33,35,36]. In this instance, the JADAD algorithm suggests selecting the best available review based on its publication recency, the methodological quality of its primary studies, language limitations, and individual patient data analysis. Consequently, Palone et al., 2023 [32] was chosen as the optimal body of evidence (*figure 2*). The detailed steps of the JADAD decision algorithm, from initiation to the final constructive decision, are presented in *supplementary table IV*.

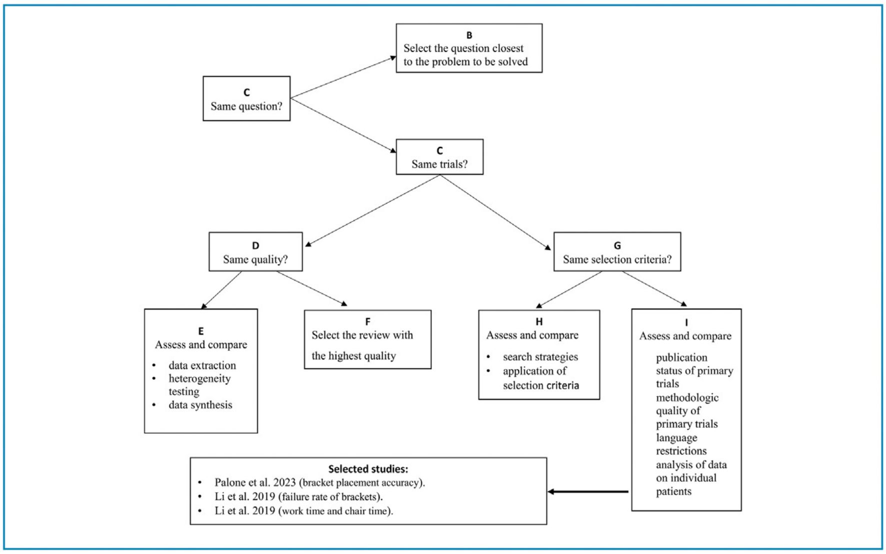

FIGURE 2

Flowchart of JADAD decision algorithm for selecting the best body of evidence

Bracket placement accuracy between direct and indirect bonding techniques

Using data from three studies [39–41], a quantitative analysis was performed to evaluate the linear (mesiodistal, vertical) and angular (angulation) differences between direct and indirect bracket bonding techniques.

There were no differences between direct and indirect bonding techniques in the accuracy of vertical dimension (MD = −0.04; 95% CI: −0.10, 0.02; $P < 0.001$). However, the heterogeneity was high ($\chi^2 = 10.97$, $P = 0.004$; $I^2 = 82\%$). Therefore, a leave-one-out sensitivity analysis was performed with the exclusion of one study. The heterogeneity became very low ($\chi^2 = 0.00$, $P = 1.0$; $I^2 = 0\%$); resulting in higher vertical positional accuracy in the indirect bonding group (MD = −0.04; 95% CI: −0.08, −0.00; $P = 0.05$; *figure 3*).

Regarding the mesiodistal dimension, there were no differences between direct and indirect bonding techniques (MD = 0.01; 95% CI: −0.04, 0.06; $P = 0.81$). However, the heterogeneity was high ($\chi^2 = 14.57$, $P = 0.0007$; $I^2 = 86\%$). Therefore, a leave-one-out sensitivity analysis was performed with the exclusion of one study. The heterogeneity became very low ($\chi^2 = 0.81$, $P = 0.37$; $I^2 = 0\%$); however, the difference remained nonsignificant between both groups (MD = −0.02; 95% CI: −0.04, −0.00; $P = 0.10$; *figure 3*).

Finally, the pooled estimate of the mean transfer error showed that indirect bonding has a better angulation accuracy

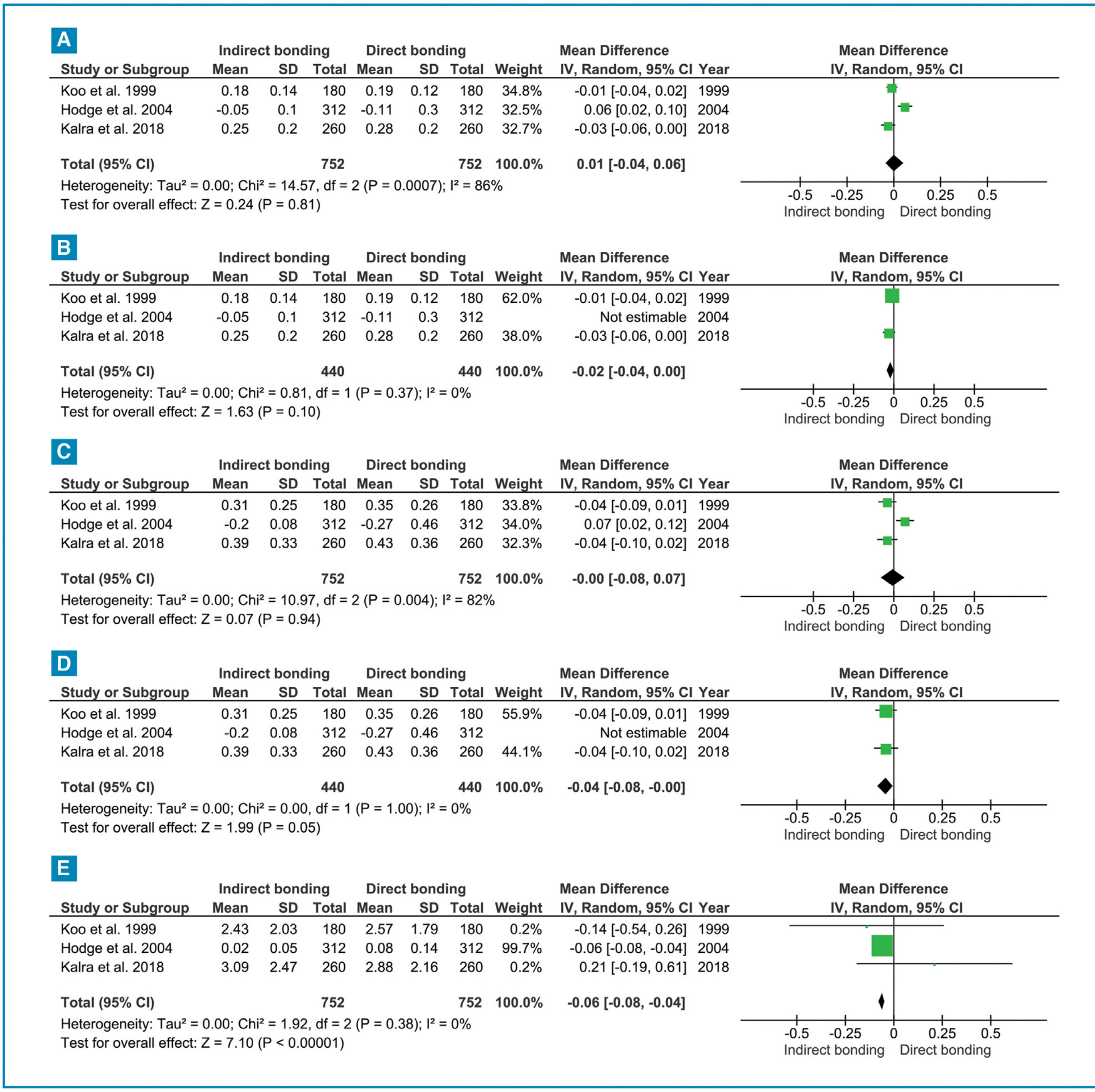

FIGURE 3

Forest plots of the transfer accuracy comparison between direct and indirect bonding

A. Mesiodistal error "millimeter" (without sensitivity analysis). B. Mesiodistal error "millimeter" (with sensitivity analysis). C. Vertical error "millimeter" (without sensitivity analysis). D. Vertical error "millimeter" (with sensitivity analysis). E. Angulation error "degrees".

(MD = −0.06; 95% CI: −0.08, −0.04; $P < 0.001$; *figure 3*) with low heterogeneity ($\chi^2 = 1.92$, $P = 0.38$; $I^2 = 0\%$).

Transfer accuracy of brackets using indirect bonding trays

Quantitative analysis was limited to 14 studies [18,23,38–40,42–50] because the remaining studies failed to provide sufficient data, particularly the mean transfer error of the used brackets. Linear (mesiodistal, vertical, buccolingual) and angular (angulation, torque, rotation) deviations between transferred and actual bracket positions were evaluated in most studies; two studies restricted their analysis to mesiodistal, vertical, and angulation measurements.

The pooled estimate of the mean transfer error was 0.08 mm in the mesiodistal direction (95% CI: 0.06, 0.09) with high heterogeneity ($I^2 = 99.49\%$; *figure 4*). In the buccolingual direction, the

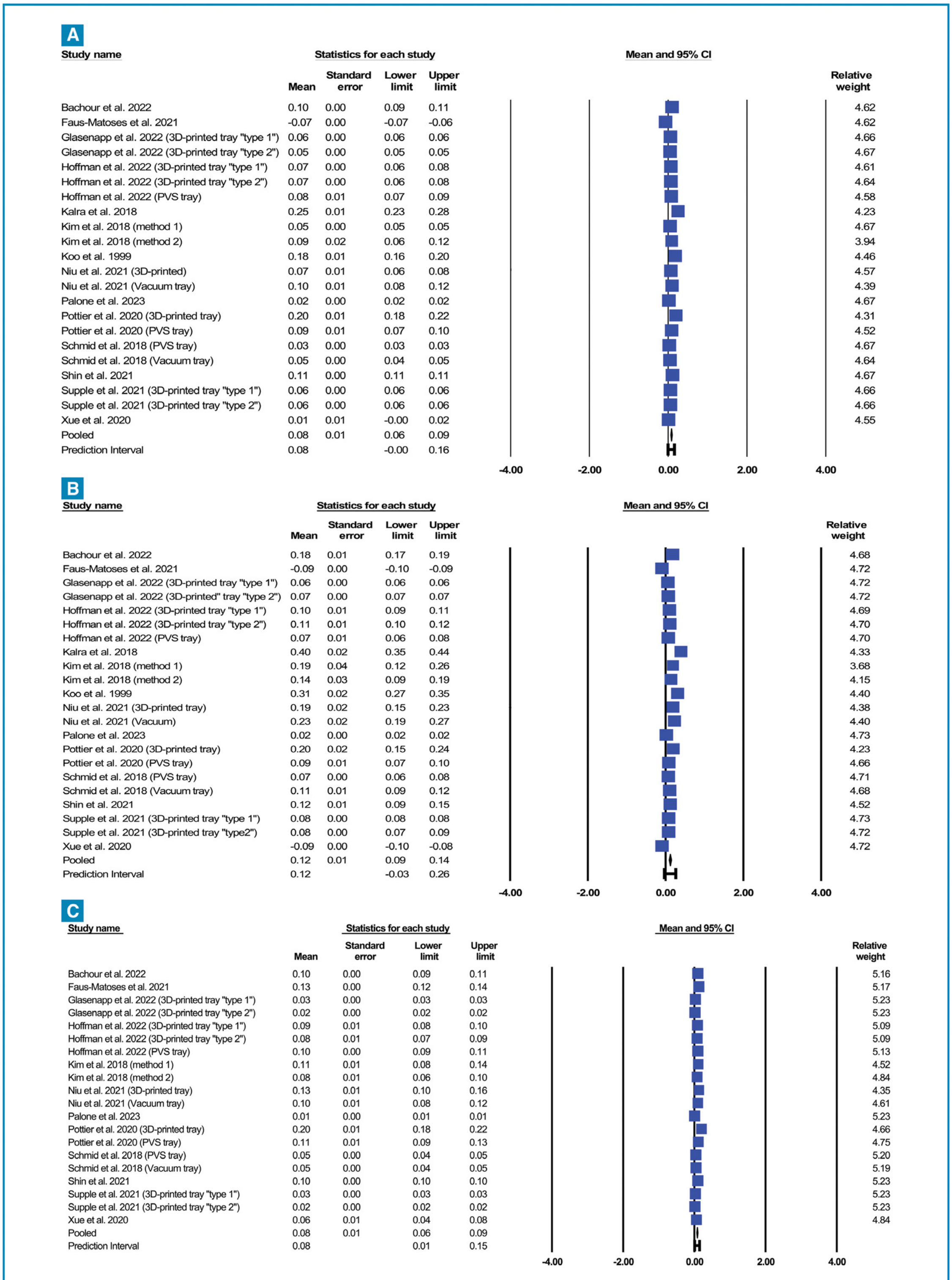

FIGURE 4

Forest plots of mean transfer errors for linear dimensions "millimeter"

A. Mesiodistal errors. B. Vertical errors. C. Buccolingual errors.

pooled estimate showed an error of 0.08 mm; 95% CI (−0.06, 0.09) with high heterogeneity (I^2 = 99.68%; *figure 4*). Finally, the pooled estimate of the vertical direction error was 0.12 mm; 95% CI (0.09, 0.14) with high heterogeneity (I^2 = 99.71%; *figure 4*).

In terms of angular dimensions, the pooled estimate showed an angulation error of 1 degree (95% CI: 0.81, 1.20) along with a high level of heterogeneity (I^2 = 99.47%; *figure 4*). A rotation error of 0.76 degrees (95% CI: 0.54, 0.97) with high heterogeneity (I^2 = 99.61%; *figure 4*) was observed. Finally, the pooled torque estimate had an error of 1.10 degrees (95% CI: 0.86, 1.33). Heterogeneity was high (I^2 = 99.57%; *figure 5*).

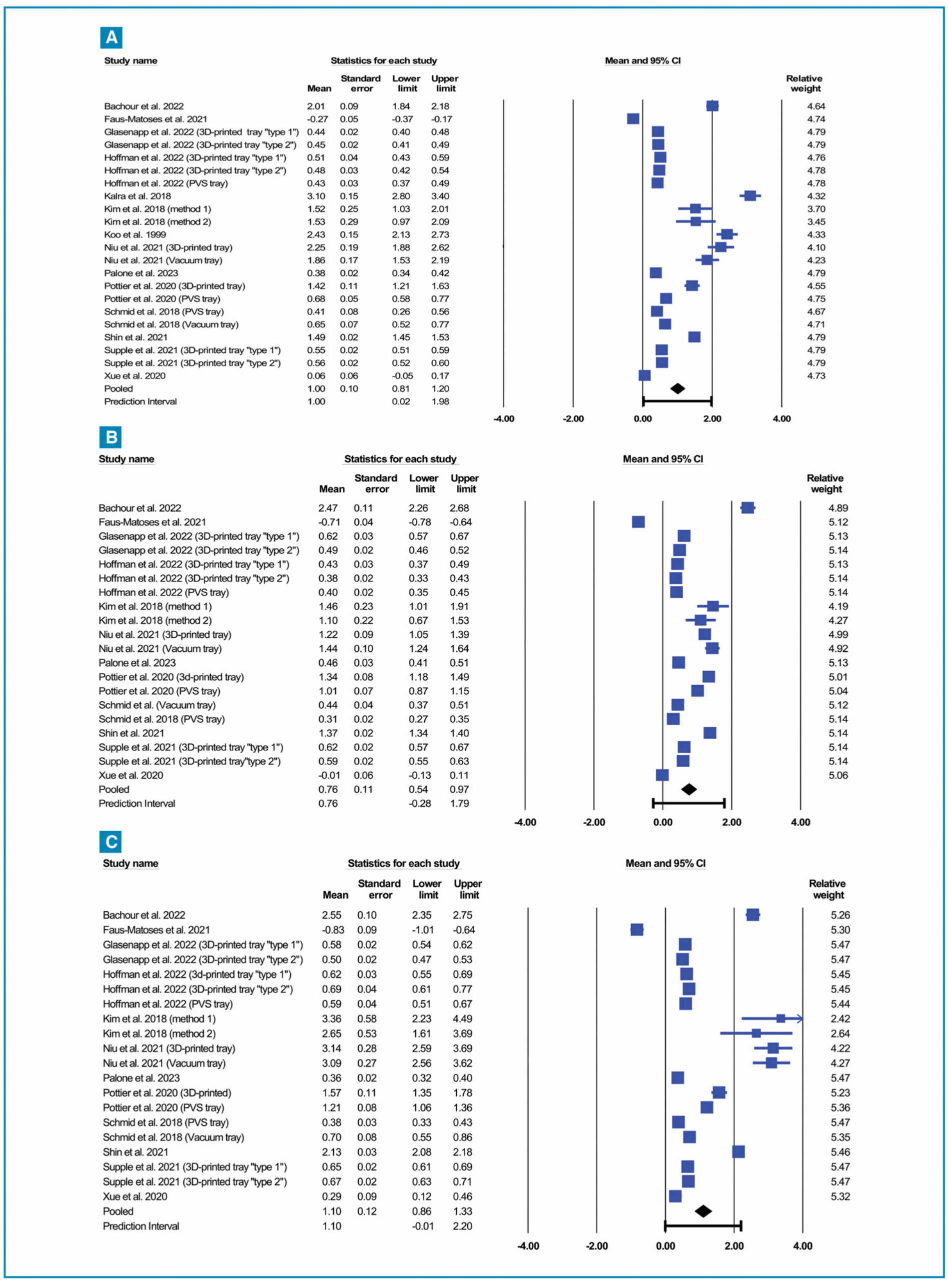

FIGURE 5

Forest plots of mean transfer errors for angular dimensions "degrees"

A. Angulation errors. B. Rotation errors. C. Torque errors.

Comparison of transfer accuracy between different types of indirect bonding trays

Heterogeneity among the studies included in the systematic reviews limited the scope of comparison between 3D printed and vacuum-formed trays. The quantitative analysis involved data from two studies [46,49].

The pooled estimate of the mean placement error revealed that 3D-printed trays resulted in significantly smaller errors in the vertical (MD = −0.06; 95% CI: −0.10, −0.04; P = 0.0009; I^2 = 34%; *figure 6*) and mesiodistal (MD = −0.03; 95% CI: −0.05, −0.01; P = 0.0007; I^2 = 0%; *figure 6*) directions. Conversely, vacuum transfer trays demonstrated a statistically significant advantage in buccolingual placement (MD = 0.02; 95% CI: 0.00, 0.04; P = 0.02; I^2 = 0%; *figure 6*). In contrast, no differences were found between both trays in the accuracy of angulation (MD = −0.04; 95% CI: −0.87, 0.79; P = 0.92; I^2 = 83%; *figure 7*), rotation (MD = −0.21; 95% CI: −0.43, 0.01; P = 0.06; I^2 = 0%%; *figure 7*), and torque (MD = −0.02; 95% CI: −0.47, 0.42; P = 0.92; I^2 = 0%; *figure 7*).

Among the 3D-printed trays, different printing technologies were employed across the included studies, primarily stereolithography (SLA) and digital light processing (DLP). These technologies differ in their accuracy, layer resolution, and printing speed. Moreover, variations in tray design and resin material characteristics may also influence the outcomes. An additional source of heterogeneity relates to the extent of the bonding tray. Some studies employed trays extending to the second molars, while others included only anterior teeth and premolars. It is worth noting that conventional silicone trays are still considered the gold standard for bracket transfer due to their predictable accuracy and long-established clinical reliability.

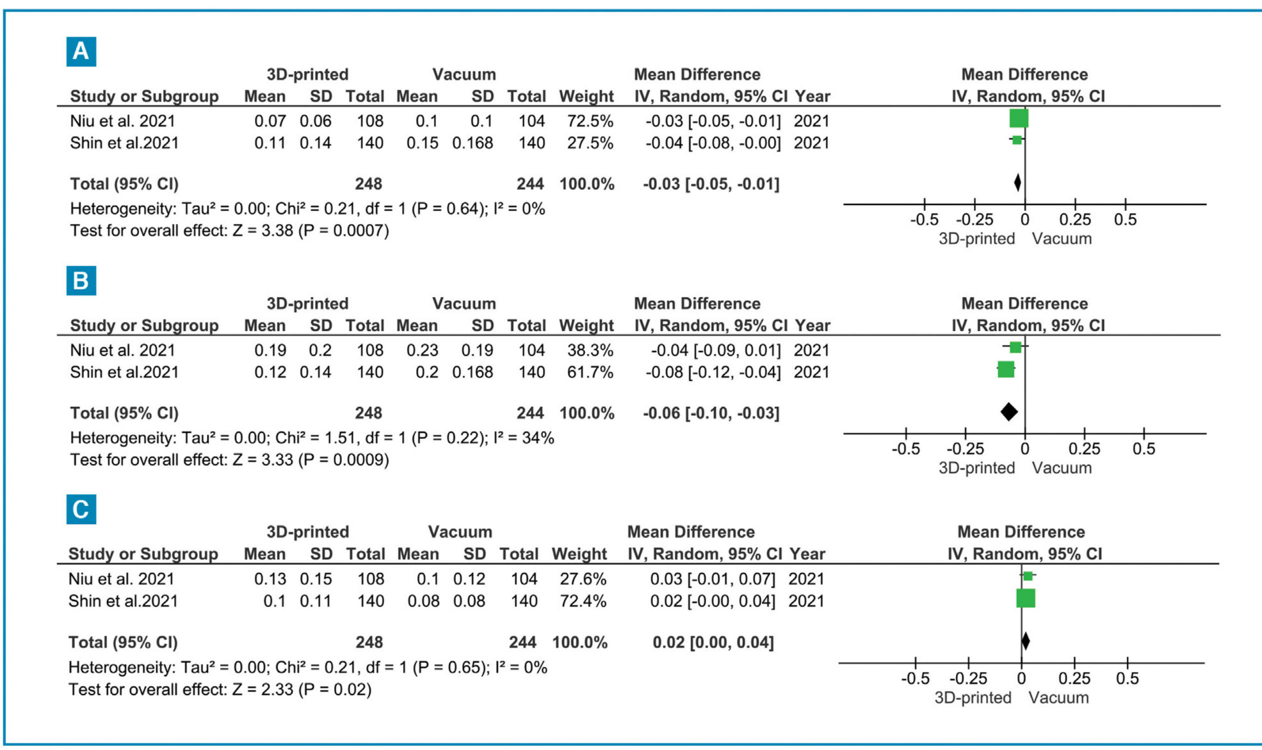

FIGURE 6

Forest plots of transfer accuracy comparison between vacuum-formed and 3D-printed transfer trays for linear dimensions "millimeter"

A. Mesiodistal. B. Vertical. C. Buccolingual.

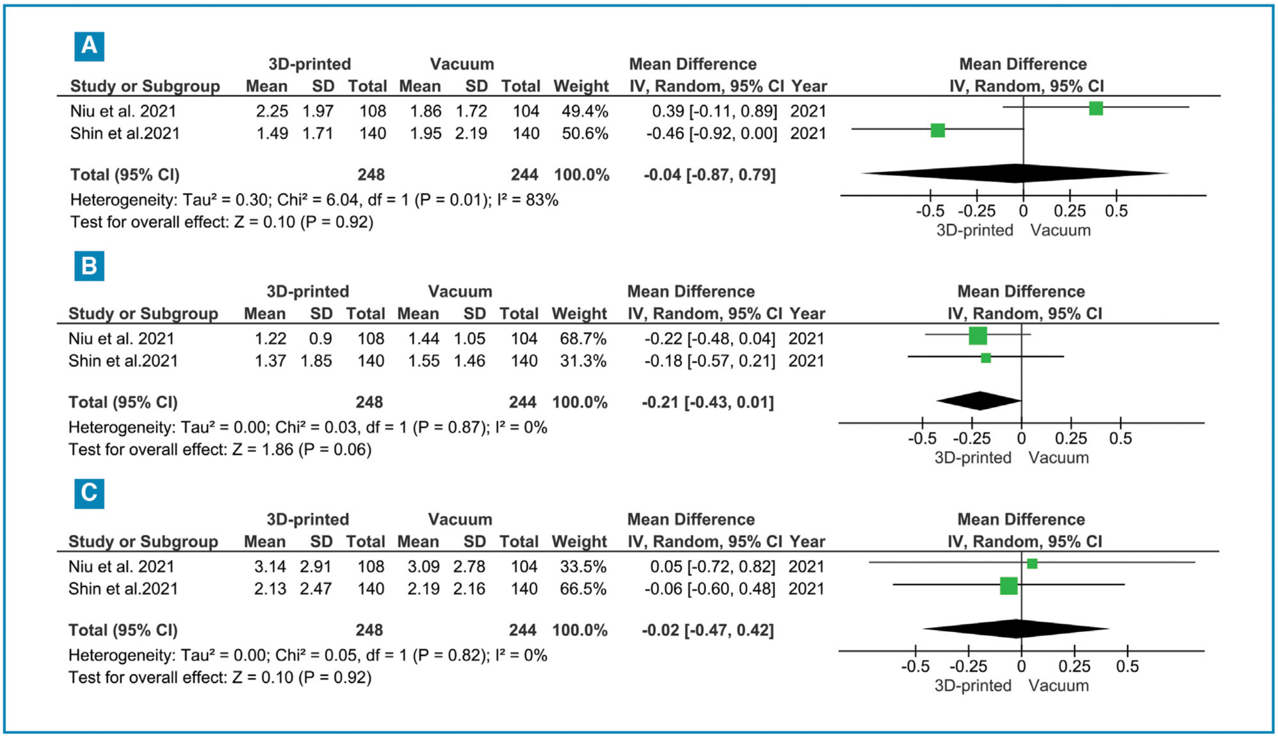

FIGURE 7

Forest plots of transfer accuracy comparison between vacuum-formed and 3D-printed transfer trays for angular dimensions "degrees"

A. Angulation error. B. Rotation error. Torque error.

Bond failure rate

This outcome was investigated by three reviews: Li et al., 2019, Albertini et al., 2021 and Patano et al., 2023 [33–35].

These reviews addressed the same question but included different trials and employed varying selection criteria [33–35]. Therefore, the best available review was selected according to the JADAD algorithm based on its publication recency, the methodological quality of its primary studies, language limitations, and individual patient data analysis. Consequently, Li et al., 2019 [35] was chosen (*figure 4*). The detailed steps of the applied Jadad decision algorithm, from initiation to the final decision, are provided in *supplementary table V*.

Seven studies compared the bond failure rate of direct and indirect bonding [10,51–56]. Meta-analysis was performed. No difference in bond failure rate was found between the direct and indirect bonding (RR = 1.05; 95% CI = 0.65–1.68; P = 0.85; *figure 8*). In these studies, the debonding rate was assessed after the initial bonding appointment with follow-up periods ranging from 3 to 6 months. However, the heterogeneity was high (χ^2 = 23.30, P = 0.0007; I^2 = 74%). Therefore, a sensitivity analysis was performed with the exclusion of two studies. The heterogeneity became very low (χ^2 = 5.13, P = 0.27; I^2 = 22%); however, the difference remained nonsignificant between both groups (RR = 1.13; 95% CI: 0.78–1.64; P = 0.50; *figure 8*).

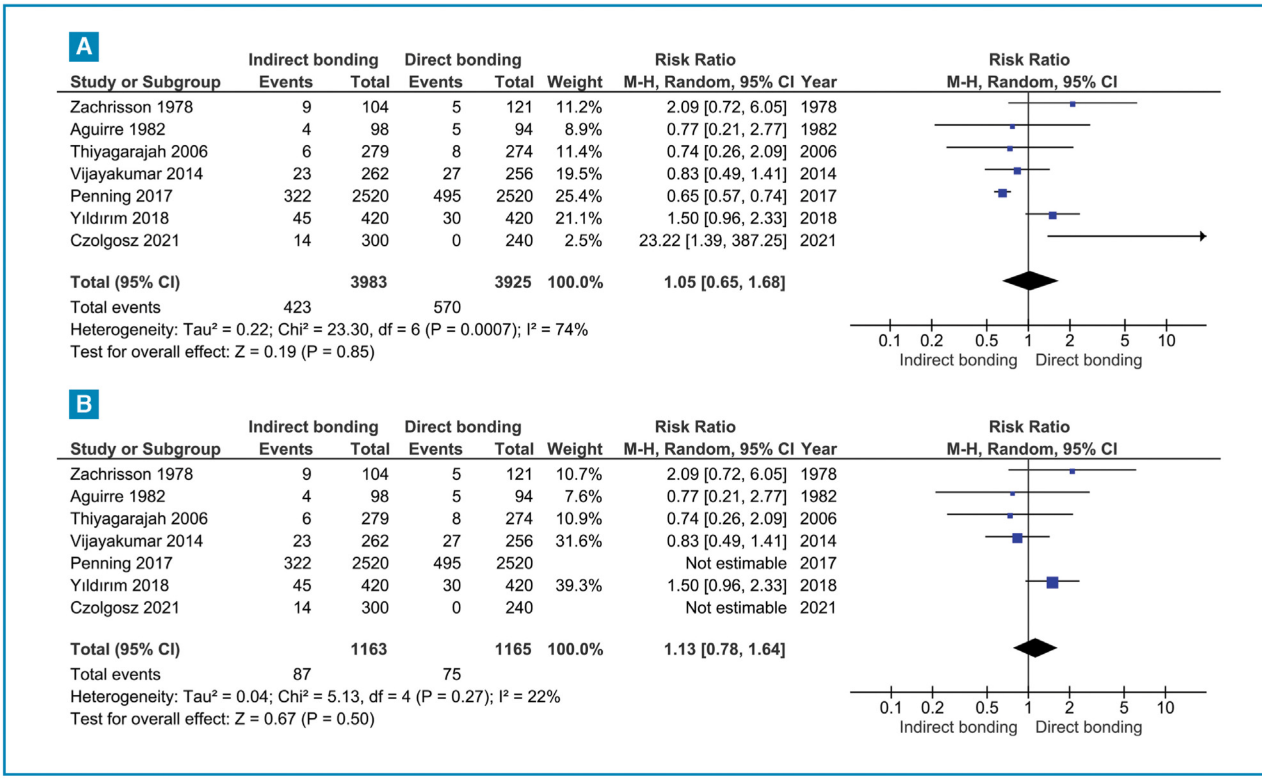

FIGURE 8

Forest plot for the bond-failure rate (%) between direct and indirect bonding

A. Without sensitivity analysis. B. With sensitivity analysis.

Chairside time and total working time

An appraisal of this outcome can be found in two systematic reviews: Li et al., 2019, and Patano et al., 2023 [33,35]. Although reviews addressed the same research question, there were differences in trial selection and inclusion criteria for the included studies [33,35]. Using the Jadad decision algorithm, we evaluated the publication date, quality of study, language of publication, and analysis of data of patients to determine the most relevant review. This resulted in the selection of Li et al., 2019 [35] (*figure 4*), and the detailed steps of the algorithm are summarized in *supplementary table VI*.

Chairside time

The analysis of four studies [10,31,52,56] revealed a significant reduction in chairside time with indirect bonding by an average of 14.22 minutes (MD = −14.22; 95% CI: −21.65, −6.79; $P = 0.0002$; *figure 9*), but the very high level of heterogeneity ($\chi^2 = 310.06$, $P < 0.00001$; $I^2 = 99\%$) raises concerns about the reliability of this result.

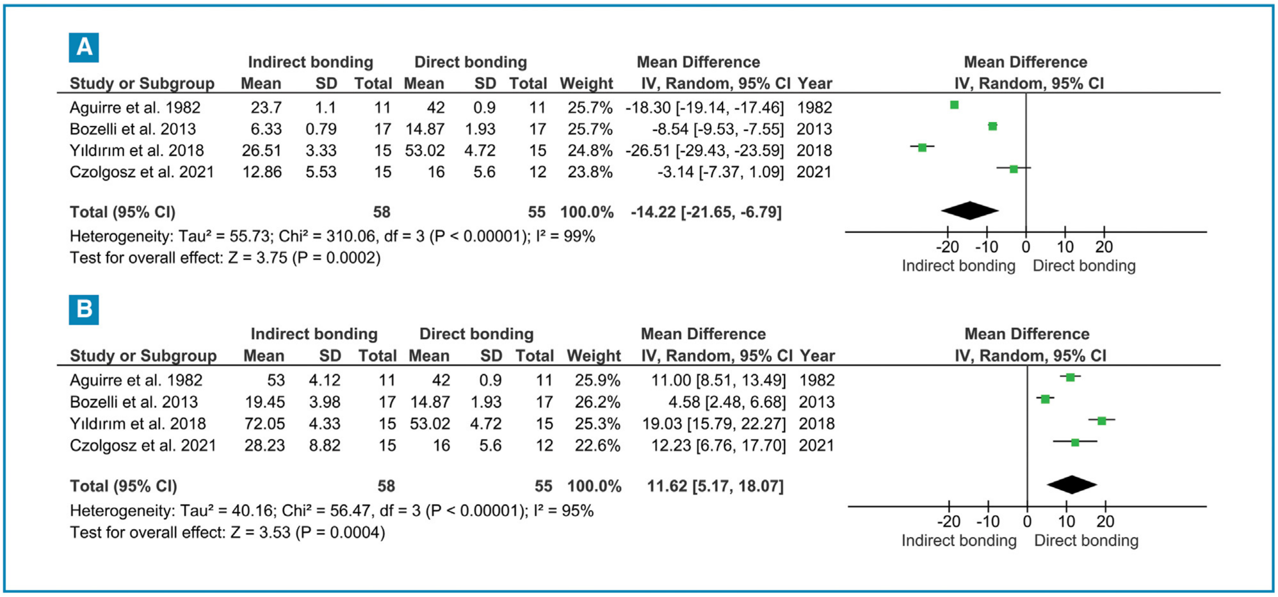

FIGURE 9

Forest plots of the chairside time "minutes" (A), and total working time "minutes" (B) comparison between direct and indirect bonding

Total working time

Four studies [4,10,52,56] showed that direct bonding significantly reduced total working time compared to indirect bonding by an average of 11.62 minutes (MD = 11.62; 95% CI: 5.17, 18.07; $P = 0.0004$; *figure 9*). However, the heterogeneity was very high ($\chi^2 = 56.47$, $P < 0.00001$; $I^2 = 95\%$).

Oral hygiene status

One systematic review (Li et al., 2019), including three RCTs from 1978 to 2018, analyzed oral hygiene differences regarding direct vs. indirect bonding [35]. There were no significant differences between the two bonding methods in terms of plaque accumulation around brackets, white spot lesion development, and gingival health as per two studies included. A study reported that indirect bonding led to lower plaque accumulation in the first four months after bracket placement and delayed white spot lesion development. However, no significant differences between groups were observed when assessing whole-mouth plaque accumulation. A meta-analysis of oral hygiene outcomes was not possible due to the wide range of methodological differences and the high degree of heterogeneity between studies.

Overlap analysis

The overlap matrix demonstrated a corrected covered area (CCA) of 10.7%, indicating a moderate overlap among the included systematic reviews. This suggests that while some primary studies were shared between reviews, the degree of redundancy remained within an acceptable range for interpretation of the pooled evidence which is expected in umbrella reviews covering specialized clinical topics such as indirect bonding techniques in orthodontics (*supplementary file VII*).

Publication bias

Publication bias was assessed for the outcome transfer accuracy of brackets using indirect bonding trays, considering its different measurement types. Funnel plots were generated separately for linear positional accuracy measurements (vertical, mesiodistal, buccolingual) and angular measurements (torque, rotation, angulation) when at least 10 studies were available in the corresponding meta-analysis. The funnel plots illustrating the effect estimates versus standard errors for the outcomes are displayed in *figures 10 and 11*. *Figure 10* showed no potential publication bias, while *figure 11* indicated a potential risk of publication bias.

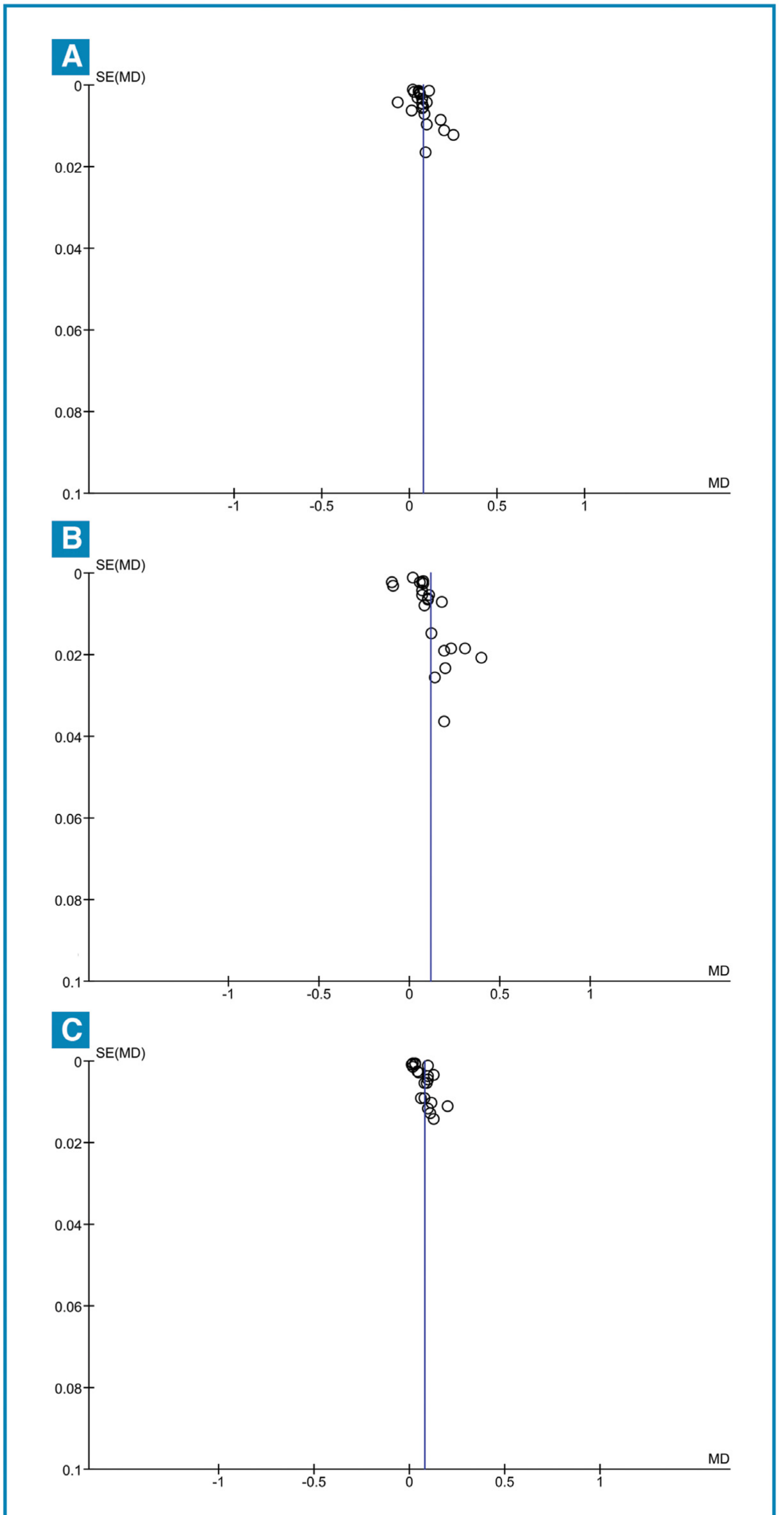

FIGURE 10

Funnel plots for linear positional accuracy measurements of indirect bonding

A. Mesiodistal. B. Vertical. C. Buccolingual.

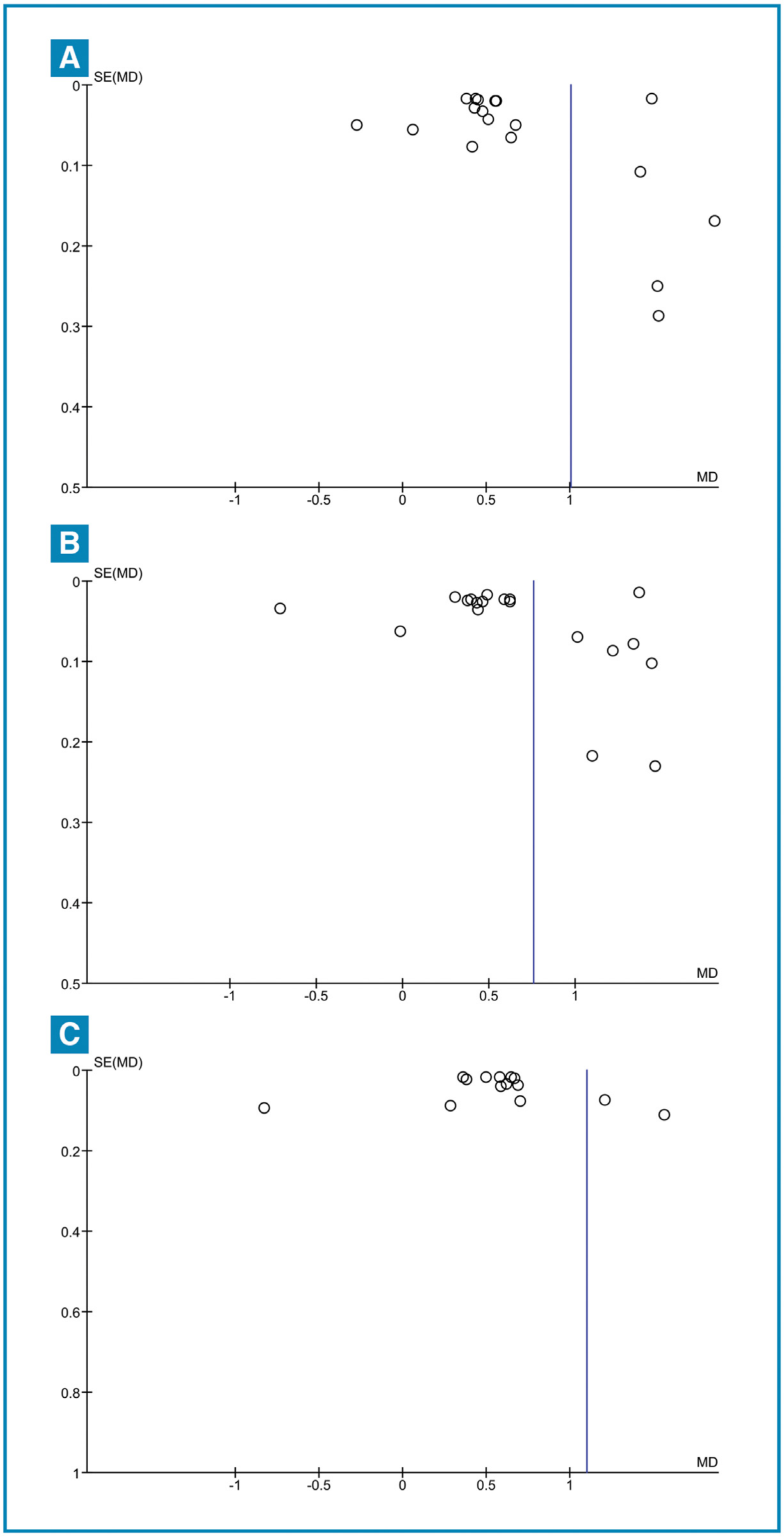

FIGURE 11

Funnel plot for angular accuracy measurements of indirect bonding

A. Angulation. B. Rotation. C. Torque.

Discussion

To the best of our knowledge, this overview represents the first comprehensive evaluation and analysis of findings from seven systematic reviews investigating the effectiveness (i.e., bracket placement accuracy) and efficiency (i.e., bond failure rate, total working time, chairside time, and oral hygiene) of indirect bonding techniques. Indirect bonding, by utilizing various transfer trays, can achieve high precision and repeatability in bracket positioning, with accuracy comparable to that of conventional direct bonding, which relies on manual bracket placement without trays. The total working time was higher with indirect bonding, but chairside time decreased considerably, and there were no significant differences between the two groups regarding bond failure rates or oral hygiene.

Bracket placement accuracy

Indirect bonding is regarded as a technique for precisely positioning brackets owing to the benefits of clear visibility and sufficient working time, particularly when attaching brackets to molars and premolars [12,57]. However, we acknowledge that heterogeneity in tooth inclusion across the primary studies within the systematic reviews – for example, the exclusion of second molars in some studies, such as Süpple et al. in Sabbagh's systematic review, represents a potential limitation to the generalizability of our findings regarding molars and premolars [50]. The only review by Li et al. compared the precision of bracket positioning through direct versus indirect bonding methods [35]. Contrary to expectations, this overview's key finding showed that the precision of bracket positioning did not significantly vary between direct and indirect bonding methods, except for a slight and clinically trivial decrease in angulation transfer error noted in indirect bonding. In indirect bonding, the absence of variation may result from possible inaccuracies when transferring brackets from the model to the patient's teeth. Factors such as varying thickness of bonding material, obstructions from soft tissues, operational mistakes, and contamination can compromise the precision of bracket transfer during indirect bonding [13].

Six systematic reviews analyzed the precision of bonding placement by comparing the intended position with the result following bracket transfer and bonding [31–33,35–37]. Nonetheless, they incorporated different types of studies, covering both clinical and laboratory investigations. The meta-analysis of 13 primary studies drawn from the included reviews revealed an overall bracket transfer precision for the indirect bonding of 0.08 mm, 0.08 mm, and 0.12 mm linear deviations in the mesiodistal, buccolingual, and vertical directions, respectively. The measurements for angular deviations were 1 degree, 0.76 degrees, and 1.10 degrees, respectively, corresponding to angulation, rotation, and torque inaccuracies. It is noteworthy that across all indirect bonding tray manufacturing methods and materials, angular transfer errors consistently demonstrated higher pooled estimates compared to linear measurements. This could be attributed to the compounded effect of minor positional inaccuracies across multiple planes during the transfer process, along with inherent difficulties in precisely controlling bracket orientation in three dimensions within transfer trays. Despite this, the reported angular deviations remain within clinically acceptable ranges, as per the standards of the American Board of Orthodontics [58]. Due to the lack of evidence-based thresholds for clinically acceptable deviations in existing literature, many studies cite the American Board of Orthodontics professional standards of 0.5 mm for linear deviations and 2 degrees for angular deviations [13,58,59]. However, these thresholds inherently pertain to deviations in dental positioning. Since full slot engagement with the straight-wire technique cannot be attained, surpassing these limits does not automatically imply associated dental misalignment [60]. Furthermore, differences in the thickness of the bonding material and insufficient fitting of the brackets into the indirect bonding trays may also play a role in this [18,61]. Because of these aspects and due to the limitations of current standards, such variability in the accuracy of the indirect bonding technique is still acceptable for clinical practice.

When comparing transfer trays used for indirect bonding, 3D-printed trays exhibited greater accuracy than vacuum-formed trays in both mesiodistal and vertical dimensions. The production of vacuum-formed trays can lead to vertical discrepancies and contouring problems [46]. However, it is worth noting that vacuum-formed trays demonstrated a statistically significant advantage in buccolingual bracket placement accuracy. This might be attributed to the flexibility and intimate fit of vacuum-formed trays over the buccal and lingual surfaces, which can enhance positional control in this specific dimension, despite their limitations in other planes of space.

It is also important to consider that the methodological heterogeneity among included studies in measuring transfer accuracy could have influenced the reported outcomes. Differences such as full-arch versus single-tooth superimposition, manual versus automated assessments, and optical versus physical measurements can substantially affect the accuracy readings and the comparability between studies. For instance, full-arch superimposition may distribute errors across multiple teeth, potentially masking minor deviations, whereas single-tooth analysis offers a more precise but isolated error evaluation. Similarly, automated digital measurements tend to yield more consistent and reproducible results than manual assessments. These methodological variations should be acknowledged when interpreting the pooled estimates reported in this overview.

Moreover, different 3D printing techniques, tray materials, and tray designs have been shown to influence the accuracy of bracket transfer in indirect bonding. Hoffman et al. [44] evaluated the accuracy of transfer trays fabricated using two types of 3D-printable resins (Dreve vs. NextDent) and reported superior accuracy with the Dreve resin. They concluded that selecting an appropriate 3D-printing material with optimal rigid-flexible characteristics can reduce transfer errors. In terms of tray design, recent studies have investigated the use of guide-type 3D-printed trays, such as those described by Glasenapp et al. and Xue et al. [18,43], which incorporate integrated guiding slots or cutouts around each bracket. These designs improve bracket stability during transfer and enhance positional accuracy. When compared to silicone indirect bonding trays, which have traditionally been regarded as the gold standard due to their flexibility, adaptability, and proven clinical performance, 3D-printed trays, especially with optimized materials and guide designs, offer comparable or even superior accuracy while providing additional benefits such as digital workflow integration and reproducibility [47,62]. However, further in-vivo investigations are necessary to confirm these advantages in clinical settings.

Bond failure rate

The detachment of orthodontic brackets disrupts the planned treatment resulting in prolonged treatment and lowering of its outcome. This problem requires unplanned patient appointments, leading to higher expenses and reduced efficiency [63]. Three systematic reviews have evaluated the bond failure rate of brackets for direct vs indirect bonding [33–35]. The results of the meta-analysis showed that neither direct nor indirect bonding significantly reduced the frequency of bond failure of brackets. This result aligns with a contributing in-vivo study [64], reporting similar brackets survival rates for indirect (98.3%) and direct (98.6%) bonding and demonstrating no difference between the two bonding techniques. Applying indirect bonding trays with consistent and steady pressure on several teeth can be challenging, leading to excessive adhesive and diminished bond strength [65]. This also helps to better isolate moisture, particularly in the posterior of the dental arch, which may improve bond failure rates [66,67]. The advantage of direct bonding is that the working area is visible and the bite can be immediately evaluated [67].

The concern regarding increased plaque accumulation and early bond failures with indirect bonding is biologically plausible, primarily due to the potential for excess adhesive flash around brackets and the mechanical stress associated with tray removal immediately after light curing. Several studies have reported that improper removal of adhesive flash can predispose to plaque accumulation and white spot lesions [13,61]. Moreover, the act of removing the transfer tray while the adhesive is still in its early polymerization phase may affect bond integrity, increasing the risk of early bracket failure [39,47]. Nevertheless, the present umbrella review found no statistically significant differences between indirect and direct bonding in terms of oral hygiene outcomes and bond failure rates. This could be attributed to the fact that most included studies were conducted in controlled clinical settings with standardized adhesive removal protocols and operator expertise, minimizing the biological risks typically associated with indirect bonding. Given these considerations, clinicians should remain vigilant about thorough adhesive flash removal and tray management techniques when using indirect bonding, as these factors may influence long-term outcomes despite the aggregated findings of the current review.

Chairside time and total working time

Minimizing the chairside time required for orthodontic bracket bonding can reduce patient discomfort and increase the efficiency of the clinician in treating a larger number of patients [10]. Meta-analysis of pooled results from two systematic reviews [33,35] indicated that indirect bonding requires a longer total working time for the bonding procedure compared to direct bonding but less chairside time in the clinical phase. Indirect bonding saves chairside time since several brackets can be bonded concurrently [68], but it requires significant time for the laboratory phase. Notably, Czolgosz et al. emphasized that while indirect bonding increases laboratory workload and costs, the reduction in chairside time and improved clinical efficiency may justify this trade-off, particularly in busy clinical settings [56]. This aligns with the latest clinical research demonstrating a significant decrease in chairside time associated with indirect bonding procedures [69].

It is well established in the orthodontic literature that indirect bonding reduces chairside time while increasing total working time due to the need for laboratory preparation. This finding has been consistently reported since the early adoption of the technique [51,52]. The present overview reaffirms this time efficiency pattern across a broader and more contemporary evidence base, including studies utilizing digitally designed and 3D-printed transfer trays. By synthesizing data from both conventional and digital protocols, this review provides updated insights into whether recent technological advancements have significantly altered the balance between chairside and total working times. Our findings suggest that, despite improved tray fabrication methods, the overall time distribution remains similar, reinforcing the enduring nature of this trade-off in clinical practice.

Oral hygiene status

Orthodontists face a major challenge in preventing inadequate oral hygiene and enamel demineralization during treatment. This overview considered the impact of bonding techniques on the condition of oral hygiene. During the initial four months of treatment, a study cited within the review by Li et al. [35] noted a greater incidence of biofilm formation and white spot lesions in individuals who underwent bonding directly than in those who underwent bonding indirectly [68]. This is consistent with a recent study, perhaps due to the more leftover adhesive in the indirect bonding method, which results in more plaque accumulation [70]. These observations highlight the importance of effective adhesive clean-up and strict oral hygiene instructions irrespective of the bonding technique used.

Limitations

While the current umbrella review suggests favorable efficacy and efficiency outcomes for indirect bonding techniques, several conceptual and methodological limitations should be acknowledged when interpreting these findings.

First, a substantial proportion of the primary studies included within the source systematic reviews were in-vitro investigations conducted on dental casts. This may limit the clinical applicability of the results, as bonding in the oral environment involves additional challenges related to moisture control, access, and patient variability. Second, although the review aimed to comprehensively synthesize existing evidence, the number of primary studies contributing to quantitative analyses remained limited due to the restricted availability of data and considerable heterogeneity among the included reviews. Another important limitation pertains to the methodological quality of the source systematic reviews. Four out of the seven included reviews were rated as "critically low'' according to the AMSTAR-2 tool, which compromises the overall certainty of the evidence. While formal grading frameworks such as GRADE were not applied, given the predominance of in-vitro data and the limited suitability of such tools in this context, findings should nonetheless be interpreted with caution. Additionally, an overlap analysis revealed a moderate degree of redundancy among the included systematic reviews, with a Corrected Covered Area (CCA) of 10.7%. Although this level of overlap is considered acceptable for umbrella reviews, it may still introduce a degree of redundancy that could influence the precision of pooled estimates. Furthermore, substantial statistical heterogeneity was observed in several outcomes, notably chairside time and total working time. Despite attempts to perform subgroup analyses based on tray type and study setting, the small number of available studies per subgroup and the overlap between reviews limited the feasibility of further exploratory analyses such as meta-regression. As a result, a narrative synthesis approach was adopted in cases where heterogeneity remained unresolved. Lastly, while publication bias was assessed through funnel plots for outcomes with sufficient data ($\geq$10 studies), many outcomes did not meet this threshold, limiting the ability to detect potential publication bias across all findings.

Taken together, these limitations underscore the need for high-quality, well-designed randomized clinical trials investigating both conventional and digital indirect bonding protocols in diverse clinical settings to provide more definitive evidence.

Conclusion

The current body of evidence from systematic reviews indicates that indirect bonding techniques, encompassing both conventional and increasingly prevalent digital approaches, demonstrate acceptable transfer accuracy based on the American Board of Orthodontics Objective Grading System (ABO OGS). They exhibit no significant clinical differences compared to direct bonding in terms of treatment outcomes. Bond failure rates and oral hygiene status were comparable across both techniques. While indirect bonding consistently reduces chairside time, it often requires an extended total working time due to laboratory procedures. Future research and clinical considerations should further differentiate outcomes and efficiencies between conventional and digital indirect bonding, given the rapid advancements in digital workflows.

Ethical approval : Not applicable.

Data availability : The datasets used and/or analyzed during this review are available from the corresponding author upon reasonable request.

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Authors' contributions : ZMA spearheaded the literature review, including database searches, paper selection, data extraction, and initial manuscript draft. MYH developed the idea of the review, helped in paper selection and data extraction, directed the data analysis, and critically revised the manuscript. MKA, STJ, and SJ were involved in developing the idea of this review, helped in data analysis and results' interpretation, and participated in the writing of the first drafts of this manuscript. All authors reviewed and approved the final version of the manuscript.

Disclosure of interest : The authors declare that they have no competing interest.

Acknowledgments: Not applicable.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ortho.2025.101036.

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