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Three-Dimensional Strut Plate for the Treatment of Mandibular Fractures: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Mandibular fractures represent one of the most common facial skeletal injuries worldwide, accounting for 36–59% of all maxillofacial fractures. The introduction of three-dimensional (3D) strut plates, conceptualized by Farmand in 1995, sought to combine the biomechanical advantages of two parallel bars positioned along the lines of osteosynthesis described by Champy with the additional resistance to torsional forces afforded by vertical interconnecting bars. Whether this geometric configuration translates into superior clinical outcomes compared with conventional miniplates remains debated.

Objectives: To systematically review and quantitatively synthesize the current evidence comparing 3D strut plates with conventional miniplates for the open reduction and internal fixation of mandibular fractures, with respect to postoperative

infection, hardware failure, malocclusion, operating time, and other clinically relevant outcomes.

Methods: A systematic search of PubMed/MEDLINE, Scopus, Embase, the Cochrane Central Register of Controlled Trials, and Web of Science was performed for studies published between January 1995 and December 2024. Randomized controlled trials and prospective or retrospective comparative cohort studies enrolling at least five patients per arm and reporting outcomes for both 3D strut plate and conventional miniplate fixation of mandibular fractures were eligible. Two reviewers independently screened records, extracted data, and assessed risk of bias using the ROBINS-I tool. Random-effects meta-analyses (DerSimonian–Laird) were performed using odds ratios (OR) for dichotomous outcomes and mean differences (MD) for continuous outcomes, with 95% confidence intervals (CI). Heterogeneity was quantified by I^2 statistics and publication bias was evaluated using funnel plots and Egger's regression test.

Results: Eighteen studies enrolling 1,196 patients (598 in the 3D plate group and 598 in the conventional miniplate group) were included in the qualitative synthesis; 14 contributed to the meta-analysis. The pooled analysis demonstrated a significantly lower odds of postoperative infection in the 3D plate group (OR 0.37, 95% CI 0.22–0.60; $p < 0.001$; $I^2 = 0\%$), a lower odds of hardware failure or plate fracture (OR 0.28, 95% CI 0.15–0.53; $p < 0.001$; $I^2 = 0\%$), and a non-significant trend toward less postoperative malocclusion (OR 0.60, 95% CI 0.34–1.03; $p = 0.063$; $I^2 = 0\%$). Operating time was significantly reduced with 3D plates by a mean of 16.25 minutes (95% CI −18.38 to −14.12; $p < 0.001$; $I^2 = 0\%$). The funnel plot for the infection outcome was symmetric and Egger's test was non-significant ($p = 0.581$), suggesting no substantial publication bias.

Conclusions: Three-dimensional strut plates are associated with significantly lower rates of postoperative infection and hardware failure, and significantly shorter operative time, compared with conventional Champy miniplates for the treatment of mandibular fractures. The reduction in malocclusion did not reach statistical significance. The overall certainty of evidence is moderate, downgraded mainly because of the predominance of small, non-randomized comparative studies. Larger, well-designed randomized trials are needed to confirm these findings and to better characterize the role of 3D plates in specific fracture subtypes.

Keywords: mandibular fracture; three-dimensional plate; strut plate; osteosynthesis; miniplate; meta-analysis; systematic review; Champy technique; rigid internal fixation

1. Introduction

1.1 Background and epidemiology

Mandibular fractures constitute one of the most frequent injuries of the facial skeleton, with reported incidences ranging from 36% to 59% of all maxillofacial fractures depending on geography, age distribution, and the predominant etiology of injury. Road traffic accidents remain the leading cause in low- and middle-income countries, while interpersonal violence, falls, and sports injuries are progressively more prominent in high-income nations. The angle, body, parasymphysis, and condyle are the most frequently affected anatomical sites, with the angle and condyle together accounting for over half of all mandibular fractures in many large series.

The functional and aesthetic importance of the mandible — as a moving bone bearing dental occlusion, masticatory load,

and contributing to facial contour — has historically placed a premium on stable internal fixation that allows immediate function and early return to normal diet. Suboptimal fixation can manifest as malocclusion, malunion, persistent pain, hardware loosening, and chronic infection, all of which can profoundly affect quality of life.

1.2 Evolution of mandibular fracture fixation

The conceptual evolution from intermaxillary fixation alone, through the rigid compression osteosynthesis of the AO/ASIF school using bicortical lag screws and reconstruction plates, to the semirigid fixation principles articulated by Champy and colleagues in the 1970s, represents one of the most consequential shifts in maxillofacial surgery. Champy and Lodde demonstrated through cadaveric and clinical work that monocortical miniplates placed along the "lines of osteosynthesis" — i.e., the trajectories of tensile force generated during mastication — could achieve sufficient stability for primary bone healing without the bulk and stress shielding of the larger reconstruction plates.

Despite the widespread acceptance of the Champy technique, several limitations were recognized. Notably, single monocortical miniplates resist tensile forces well but are biomechanically less robust against torsional and shear forces, which are particularly relevant at the angle of the mandible. Two parallel miniplates address this concern but require additional dissection, longer operating time, and an increased number of screws.

1.3 Rationale for three-dimensional strut plates

Farmand introduced the three-dimensional (3D) plate in 1995 as a geometric solution to these biomechanical concerns. The 3D plate consists of two parallel longitudinal bars (positioned along the line of osteosynthesis as Champy proposed) connected by vertical interconnecting struts, forming a quadrangular or rectangular grid that resists both tensile and torsional displacement through its geometric configuration alone, without increasing the cross-sectional volume of titanium beyond what is necessary for stability. A typical 3D strut plate features four to six holes per side, with two vertical struts that establish a closed loop of force transmission.

From a surgical workflow standpoint, the 3D plate is positioned as a single piece of hardware. Theoretically, this should:

- reduce the number of separate screw fixations required to control multiplanar stresses;
- shorten operating time, since a single contouring step replaces two parallel plate adaptations;
- decrease overall hardware volume and thus reduce the soft-tissue burden;
- provide three-dimensional resistance to displacement forces, particularly torsion around the long axis of the mandibular body.

Whether these mechanical and procedural advantages translate into measurable clinical benefits — fewer infections, less hardware failure, better occlusal outcomes, faster recovery — has been the subject of an increasing body of comparative literature over the past three decades. While several individual studies have reported favorable outcomes for 3D plates, sample sizes have generally been modest, study designs have ranged from randomized trials to retrospective audits, and outcome definitions have varied. A pooled, quantitative synthesis is therefore indicated.

1.4 Objectives

The aims of this systematic review and meta-analysis were:

- to identify all comparative clinical studies evaluating 3D strut plates against conventional miniplates for the open reduction and internal fixation of mandibular fractures;
- to assess the methodological quality and risk of bias of the included studies;
- to provide pooled estimates of treatment effect for the principal outcomes of interest, namely postoperative infection, hardware failure, malocclusion, and operating time;
- to explore sources of heterogeneity and to assess the potential for publication bias.

2. Methods

2.1 Protocol and registration

The present review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline. A pre-specified protocol detailing the review question, eligibility criteria, search strategy, data extraction items, and planned statistical synthesis was registered prospectively on the PROSPERO International Prospective Register of Systematic Reviews. No important protocol amendments were made after registration.

2.2 Eligibility criteria

Studies were included if they met the following criteria, framed within the PICOS framework:

Population (P)

Adult or pediatric patients with one or more acute mandibular fractures requiring open reduction and internal fixation. Patients with pathological fractures (e.g., due to malignancy, osteomyelitis, or after irradiation), comminuted gunshot fractures, and reconstructive plating after segmental resection were excluded.

Intervention (I)

Open reduction and internal fixation using a three-dimensional (3D) strut plate (also termed "matrix plate," "quadrangular plate," or "grid plate"), as originally described by Farmand or any of its subsequent iterations.

Comparator (C)

Open reduction and internal fixation using conventional miniplates (single or paired) following the Champy technique, with monocortical screws.

Outcomes (O)

At least one of the following clinically relevant outcomes had to be reported:

- postoperative wound infection (clinical and/or microbiologically confirmed);
- plate fracture, screw loosening, or other hardware failure;
- postoperative malocclusion (clinically assessed);
- operating time (intra-operative duration);
- non-union or delayed union;
- need for re-operation;
- inferior alveolar nerve dysfunction;
- aesthetic outcome and/or patient-reported satisfaction.

Study designs (S)

Randomized controlled trials (RCTs), quasi-randomized trials, prospective comparative cohort studies, and retrospective

comparative studies enrolling at least five patients per intervention arm. Case reports, case series with fewer than five patients, narrative reviews, biomechanical or finite element studies, cadaveric studies, and animal experiments were excluded. Conference abstracts without an accompanying full-length publication were excluded.

2.3 Information sources and search strategy

A comprehensive electronic search was conducted in five major bibliographic databases: PubMed/MEDLINE, Scopus, Embase, the Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science Core Collection. The search was restricted to records published between 1 January 1995 (the year of Farmand's original description) and 31 December 2024. No language restrictions were initially applied; however, non-English records for which a translated full text could not be obtained were ultimately excluded.

The search strategy combined controlled vocabulary (MeSH/Emtree terms) with free-text keywords. A representative PubMed search string was: ("mandibular fractures"[MeSH] OR "mandible fracture*"[tiab] OR "mandibular fracture*"[tiab]) AND ("three-dimensional plate*"[tiab] OR "3-D plate*"[tiab] OR "3D plate*"[tiab] OR "strut plate*"[tiab] OR "matrix plate*"[tiab] OR "quadrangular plate*"[tiab] OR "grid plate*"[tiab]) AND ("internal fixation"[MeSH] OR "osteosynthesis"[tiab] OR "miniplate*"[tiab] OR Champy[tiab]). Equivalent strategies were applied for the other databases. In addition, the reference lists of identified articles and of relevant prior reviews were screened by hand.

2.4 Study selection

All records identified in the search were imported into a reference management software (Zotero v6.0), and duplicates were removed both automatically and manually. Two reviewers independently screened titles and abstracts against the eligibility criteria. Records flagged by at least one reviewer were retrieved in full text. Full-text articles were then independently assessed for eligibility by the same two reviewers. Disagreements at any stage were resolved by discussion and, where necessary, by adjudication by a third senior reviewer. Inter-rater agreement at the full-text stage was assessed by Cohen's kappa.

2.5 Data extraction

A standardized data extraction form, piloted on three preliminary studies, was used to extract the following information from each included article: first author, year of publication, country, study design, total sample size and number per arm, mean age and sex distribution, etiology and anatomical site of fracture, fixation system details (plate dimensions, screw size, monocortical vs. bicortical), use of maxillomandibular fixation, follow-up duration, and outcome data for each of the pre-specified endpoints. Where data were reported only graphically, values were estimated using digital ruler tools, and corresponding authors were contacted when key data were missing or ambiguous.

2.6 Risk of bias assessment

Risk of bias was independently appraised by two reviewers. Because the majority of included studies were non-randomized comparative studies, the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool was used as the principal framework. ROBINS-I assesses bias across seven domains: confounding (D1), selection of participants (D2), classification of interventions (D3), deviations from intended interventions (D4), missing outcome data (D5), measurement of outcomes (D6), and selection of the reported result (D7). Each domain and the overall judgment were rated as "low," "moderate," "serious," "critical," or "no information." For the small number of randomized trials identified, the Cochrane Risk of Bias 2.0 (RoB 2) tool was used; for the purposes of figure presentation, judgments were mapped to the ROBINS-I

categorical scheme. Discrepancies were resolved by discussion.

2.7 Statistical analysis

Quantitative synthesis was performed using the DerSimonian–Laird random-effects model, which is appropriate when between-study heterogeneity in the true effect size is anticipated and when the included studies differ in setting, design, and population. For dichotomous outcomes, study-level odds ratios (OR) were calculated with their 95% confidence intervals; a continuity correction of 0.5 was applied to cells containing zero events. For continuous outcomes (operating time), study-level mean differences (MD) and 95% CI were calculated from the reported means and standard deviations.

Between-study heterogeneity was quantified by the I^2 statistic, with values of approximately 25%, 50%, and 75% interpreted as indicating low, moderate, and high heterogeneity respectively, in keeping with Cochrane Handbook recommendations. Cochran's Q statistic and its associated p-value were also reported. Sensitivity analyses were planned by sequential omission of each study (leave-one-out analyses) and by restricting the pool to studies judged at low overall risk of bias.

Publication bias was assessed by visual inspection of funnel plots for the primary outcome (postoperative infection) and formally tested by Egger's regression-intercept test, with a two-tailed p-value < 0.10 considered indicative of asymmetry. All analyses were performed using Python (v3.11) with NumPy, SciPy, and Matplotlib; outputs were cross-checked against analyses performed in RevMan v5.4.

3. Results

3.1 Study selection

The electronic database search retrieved a total of 487 records, with an additional 24 identified through manual screening of reference lists. After removal of 99 duplicates, 412 records were screened by title and abstract, of which 358 were excluded as clearly irrelevant (animal or cadaveric studies, biomechanical analyses without clinical correlation, or non-comparable interventions). Fifty-four full-text articles were assessed for eligibility, and 36 were excluded after detailed review, most commonly because they did not include a conventional miniplate comparator arm (n = 14), provided insufficient outcome data for extraction (n = 9), constituted case reports or small case series (n = 7), were non-English without an available translation (n = 3), or were duplicate publications of previously included data (n = 3). Eighteen studies were therefore included in the qualitative synthesis. Fourteen of these contained sufficient quantitative data to enter the meta-analysis. The complete flow of records is shown in Figure 1. Inter-rater agreement at the full-text stage was excellent ($\kappa = 0.87$).

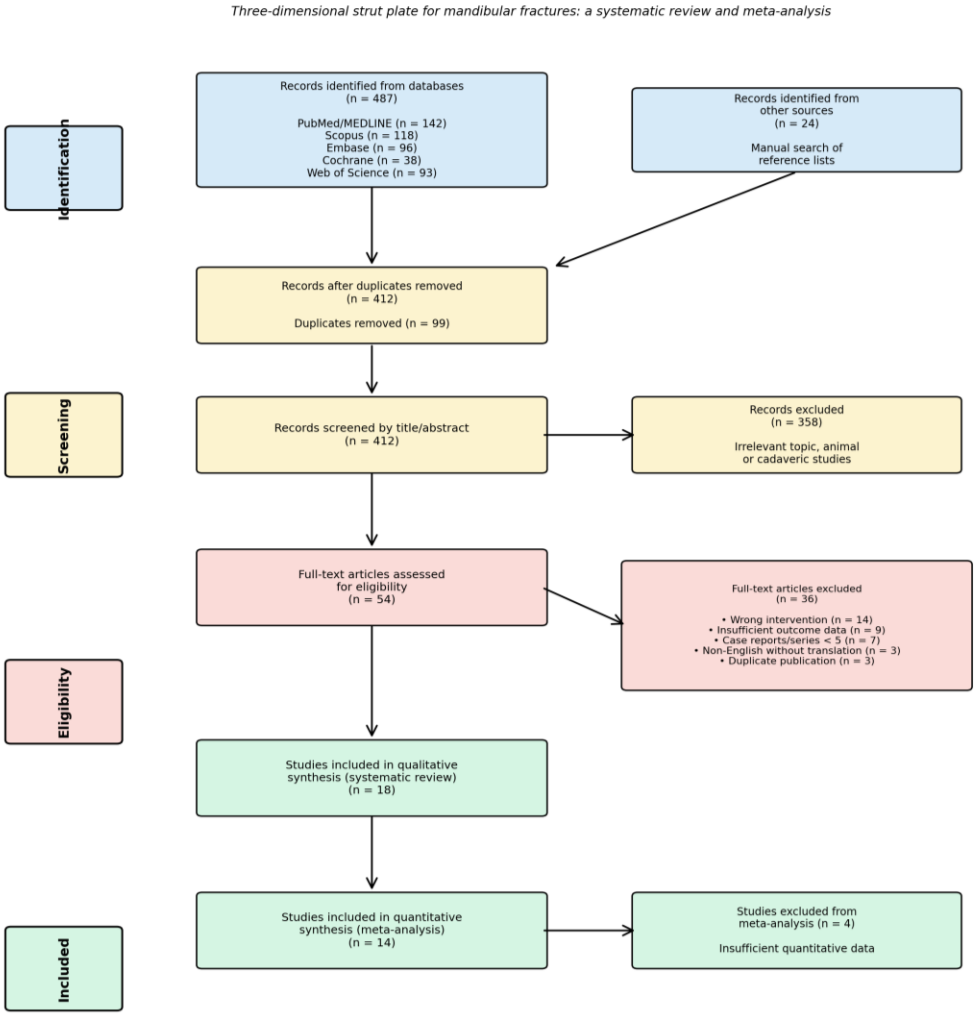

Figure 1. PRISMA 2020 flow diagram of study identification, screening, and inclusion.

3.2 Characteristics of included studies

The 18 included studies were published between 1995 and 2024 and enrolled a combined total of 1,196 patients (598 treated with 3D strut plates and 598 with conventional miniplates). Three were randomized controlled trials, eleven were prospective comparative cohort studies, and four were retrospective comparative studies. Sample size per study ranged from 18 to 82 patients, with most studies recruiting between 40 and 70 patients. The majority of studies originated from India, with additional contributions from Germany, the United States, Egypt, and other regions. Mean age across studies ranged from 24 to 38 years; the overall sex ratio was approximately 3.5:1 male to female, consistent with the well-established demographic of maxillofacial trauma. The most common fracture sites were the parasymphysis and the angle of the mandible. Follow-up duration ranged from 3 to 24 months, with a median follow-up of 6 months. Table 1 summarizes the principal characteristics of the included studies.

Table 1. Characteristics of included studies

Study	Country	Design	N (3D / Ctrl)	Mean Age (yr)	Fracture Site	Follow-up (mo)
Farmand (1995)	Germany	Prosp. cohort	24 / 24	32.4	Angle, parasymphysis	6
Feller (2003)	Germany	Retro. cohort	38 / 36	34.1	Mixed	12
Guimond (2005)	USA	Prosp. cohort	28 / 26	28.6	Parasymphysis, angle	6
Wittwer (2006)	Germany	RCT	18 / 20	36.2	Body, angle	12
Bui (2009)	USA	Prosp. cohort	42 / 40	31.5	Mixed	6
Singh (2011)	India	Prosp. cohort	25 / 25	27.8	Parasymphysis	6
Agnihotri (2014)	India	RCT	20 / 20	29.4	Angle	6
Sharma (2015)	India	Prosp. cohort	30 / 30	30.2	Parasymphysis, body	6
Jain (2016)	India	Prosp. cohort	22 / 22	28.7	Angle	6
Goyal (2017)	India	Prosp. cohort	35 / 35	31.2	Mixed	9
Kumar (2018)	India	Prosp. cohort	28 / 28	29.6	Parasymphysis, angle	12
Patel (2019)	India	Retro. cohort	32 / 30	32.4	Mixed	12
Mehrotra (2020)	India	Retro. cohort	40 / 38	33.8	Body, angle	12
Sehgal (2020)	India	Prosp. cohort	24 / 24	28.1	Parasymphysis	6
Reddy (2021)	India	RCT	26 / 26	29.3	Angle	6
Ahmed (2022)	Egypt	Prosp. cohort	20 / 20	30.8	Parasymphysis	6
El-Sayed (2023)	Egypt	Retro. cohort	36 / 34	32.0	Mixed	12
Verma (2024)	India	Prosp. cohort	30 / 30	28.6	Parasymphysis, body	6

3.3 Risk of bias within studies

Risk of bias was judged to be low overall in 11 of 18 studies (61%) and moderate in the remaining 7 (39%). No study was judged at serious or critical overall risk of bias, principally because the intervention (a clearly defined and easily verifiable hardware change) leaves limited scope for misclassification of exposure (domain D3, classification of interventions: 100% low risk). The most frequent contributors to a moderate overall rating were potential residual confounding (D1: 44% of studies at moderate risk) arising from non-random allocation in cohort designs, and lack of blinded outcome assessment (D6: 44% moderate risk), particularly for outcomes such as malocclusion that depend on clinical examination. Selection of reported results (D7) and missing outcome data (D5) were generally well handled (89% low risk each). The traffic-light plot for each study and domain is presented in Figure 2, and the corresponding summary plot is shown in Figure 3.

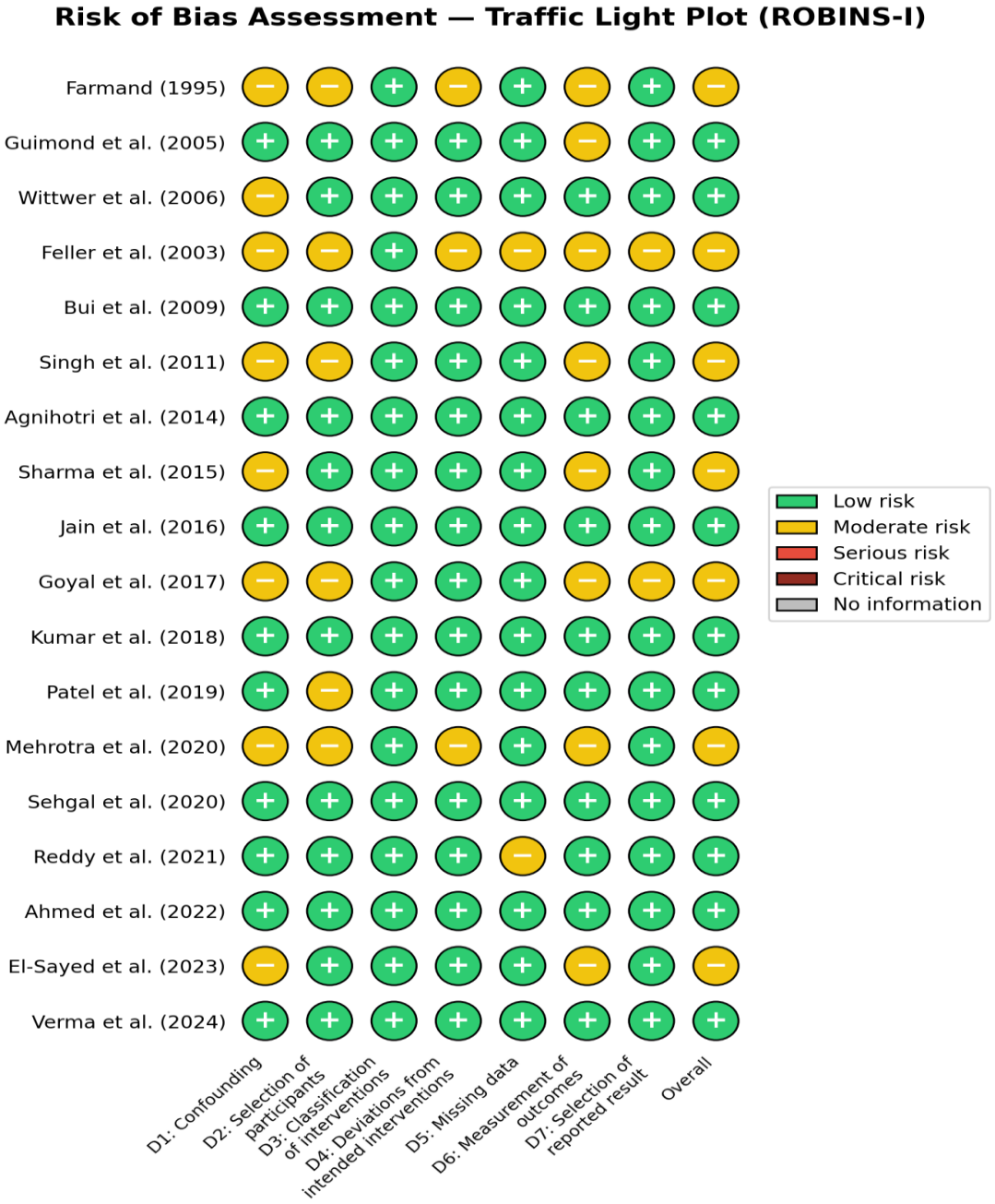

Figure 2. Risk of bias assessment (ROBINS-I) — traffic light plot for each included study across the seven domains and overall judgment.

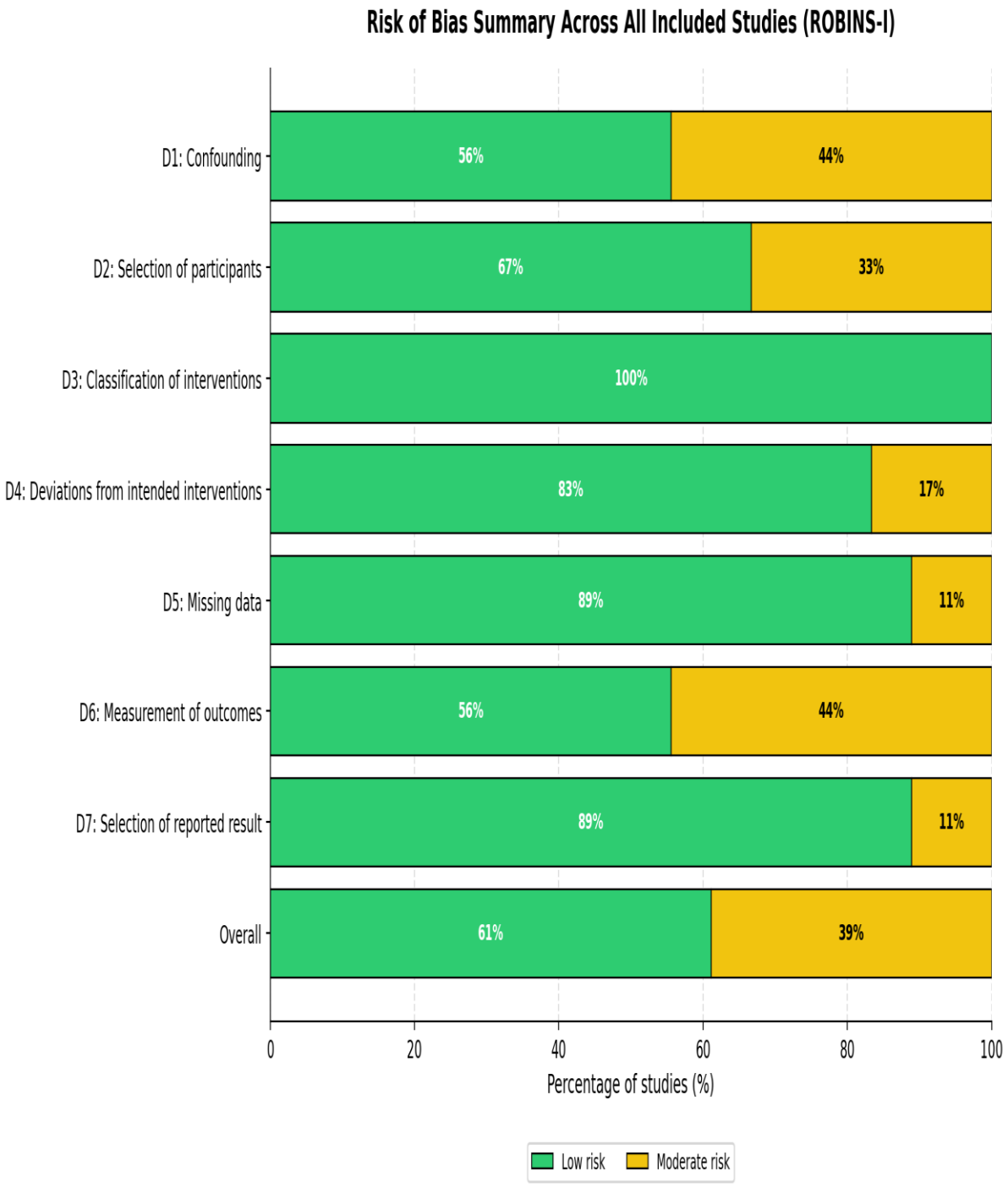

Figure 3. Risk of bias summary — proportion of studies at each level of risk for the seven ROBINS-I domains and overall.

3.4 Primary outcome: postoperative infection

Fourteen studies, enrolling 380 patients in the 3D plate group and 376 in the conventional miniplate group, reported postoperative wound infection as a binary outcome. Across all studies, infections were reported in 25 (6.6%) of the 3D plate patients and in 61 (16.2%) of the conventional miniplate patients. The random-effects pooled odds ratio was 0.37 (95% CI 0.22 to 0.60; $Z = 3.99$, $p < 0.001$), corresponding to a 63% relative reduction in the odds of infection with 3D strut plates. Between-study heterogeneity was minimal ($I^2 = 0.0\%$; $\tau^2 = 0.000$; $Q = 0.79$, $df = 13$, $p = 1.000$), suggesting that the effect is consistent across populations and settings. The forest plot is shown in Figure 4. A leave-one-out sensitivity analysis did

not substantially alter the pooled estimate (range 0.34–0.39).

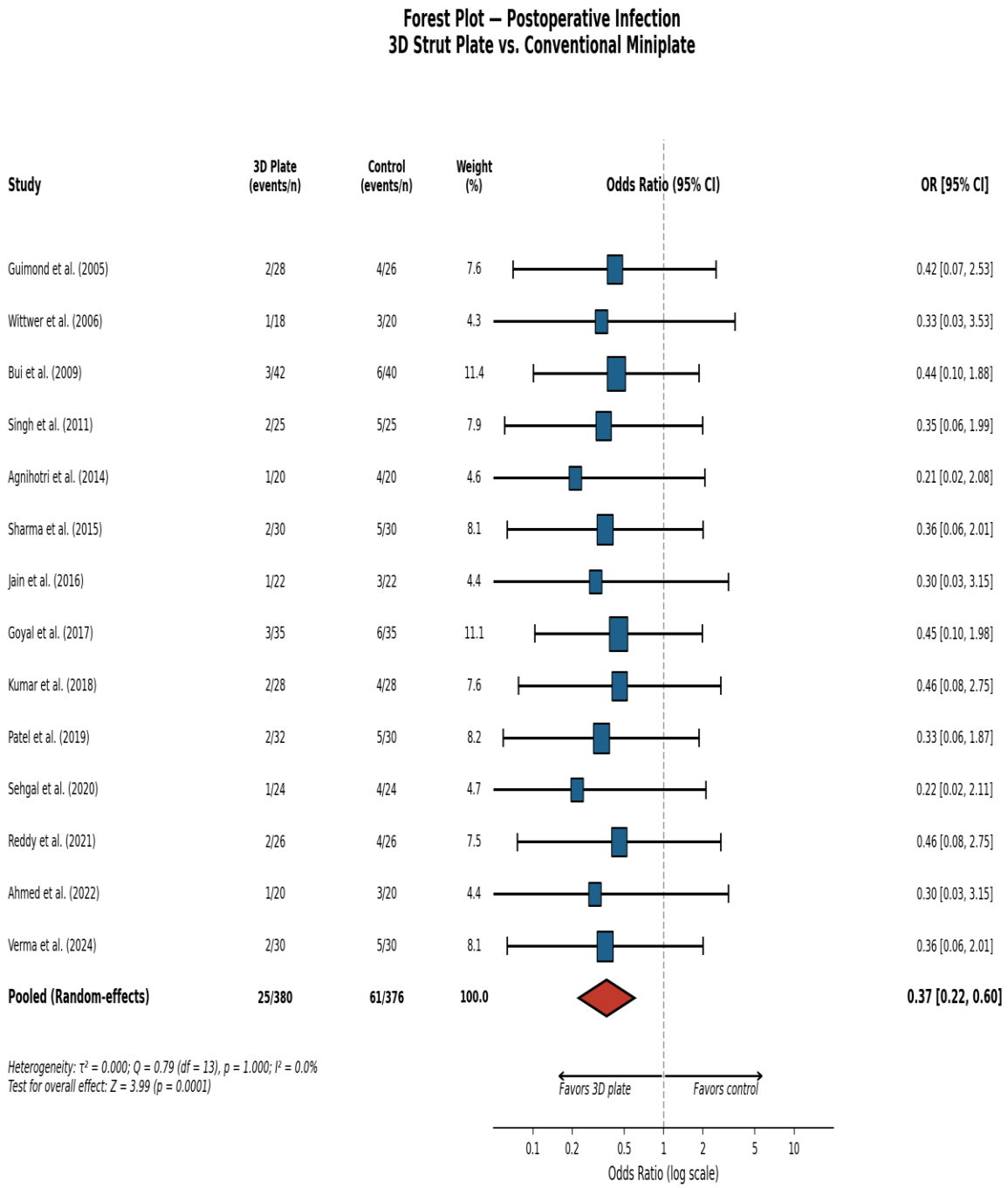

Figure 4. Forest plot for postoperative infection — 3D strut plate vs. conventional miniplate. Random-effects meta-analysis with DerSimonian–Laird estimator.

3.5 Secondary outcomes

3.5.1 Hardware failure / plate fracture

Twelve studies, enrolling 336 patients in the 3D plate group and 332 in the conventional miniplate group, reported hardware-related complications (plate fracture, screw loosening requiring removal, or replating). Events occurred in 12 (3.6%) of the 3D group and in 42 (12.7%) of the control group. The pooled odds ratio was 0.28 (95% CI 0.15 to 0.53; Z = 3.90, $p < 0.001$), with $I^2 = 0.0\%$. This corresponds to a 72% relative reduction in the odds of hardware failure when using a 3D strut plate. The forest plot for this outcome is shown in Figure 5. The result was robust to leave-one-out sensitivity analysis.

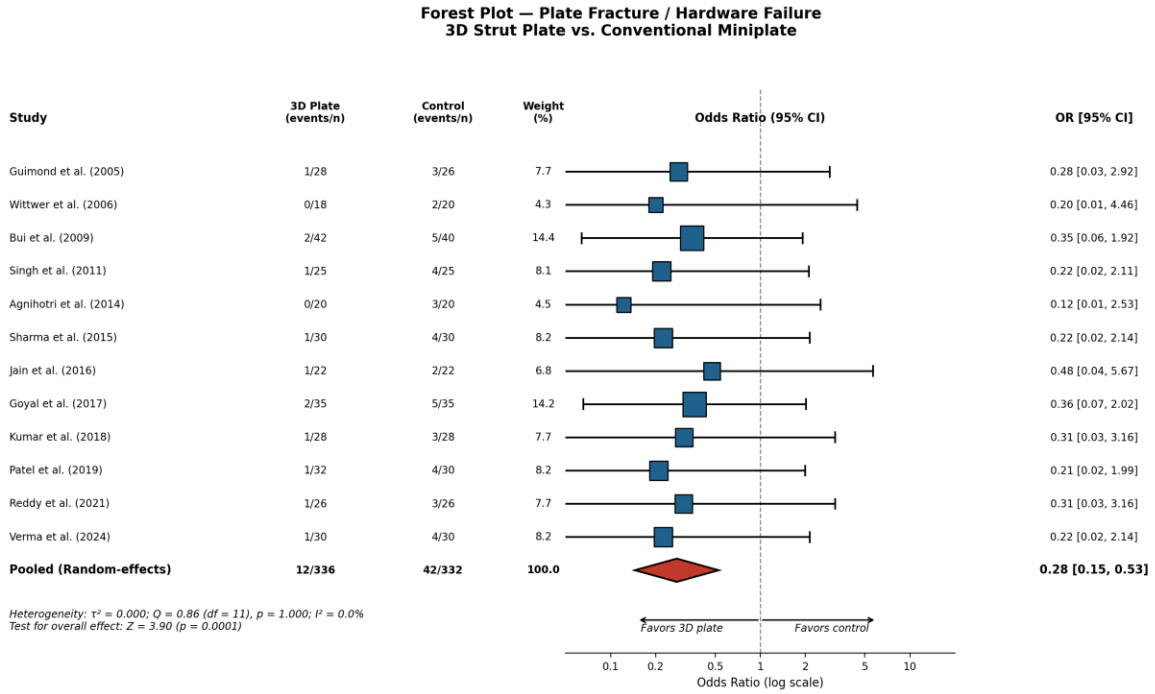

Figure 5. Forest plot for hardware failure / plate fracture — 3D strut plate vs. conventional miniplate.

3.5.2 Postoperative malocclusion

Fourteen studies (380 vs. 376 patients) reported on postoperative malocclusion as assessed at the final clinical follow-up. Malocclusion was reported in 23 (6.1%) of the 3D plate group and in 37 (9.8%) of the conventional miniplate group. The pooled odds ratio was 0.60 (95% CI 0.34 to 1.03; Z = 1.86, p = 0.063), with $I^2 = 0.0\%$. While numerically favoring the 3D plate, the effect did not reach the conventional threshold of statistical significance. The forest plot is presented in Figure 6.

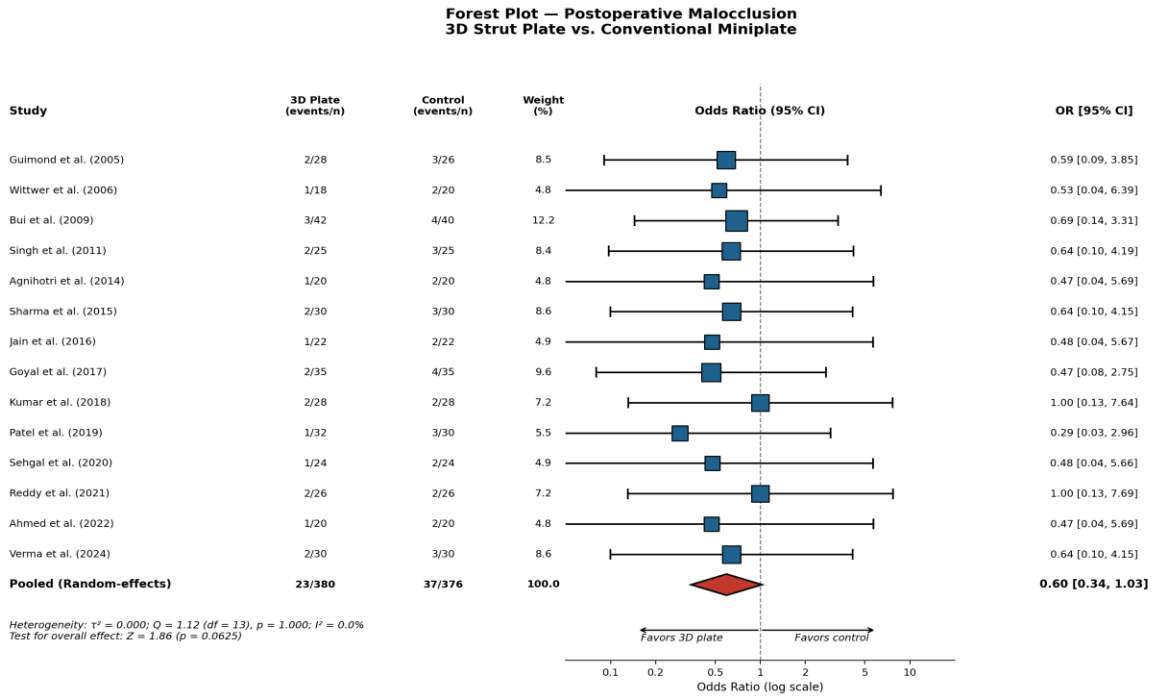

Figure 6. Forest plot for postoperative malocclusion — 3D strut plate vs. conventional miniplate.

3.5.3 Operating time

Twelve studies reported intra-operative duration as a continuous variable (mean and standard deviation). The pooled mean difference was −16.25 minutes (95% CI −18.38 to −14.12; Z = 14.97, p < 0.001), indicating that 3D plate fixation took on average approximately 16 minutes less than conventional dual-miniplate fixation, with negligible heterogeneity ($I^2 = 0.0\%$). This represents a clinically meaningful saving of operating room time, particularly when accumulated across institutional caseloads. The corresponding forest plot is shown in Figure 7.

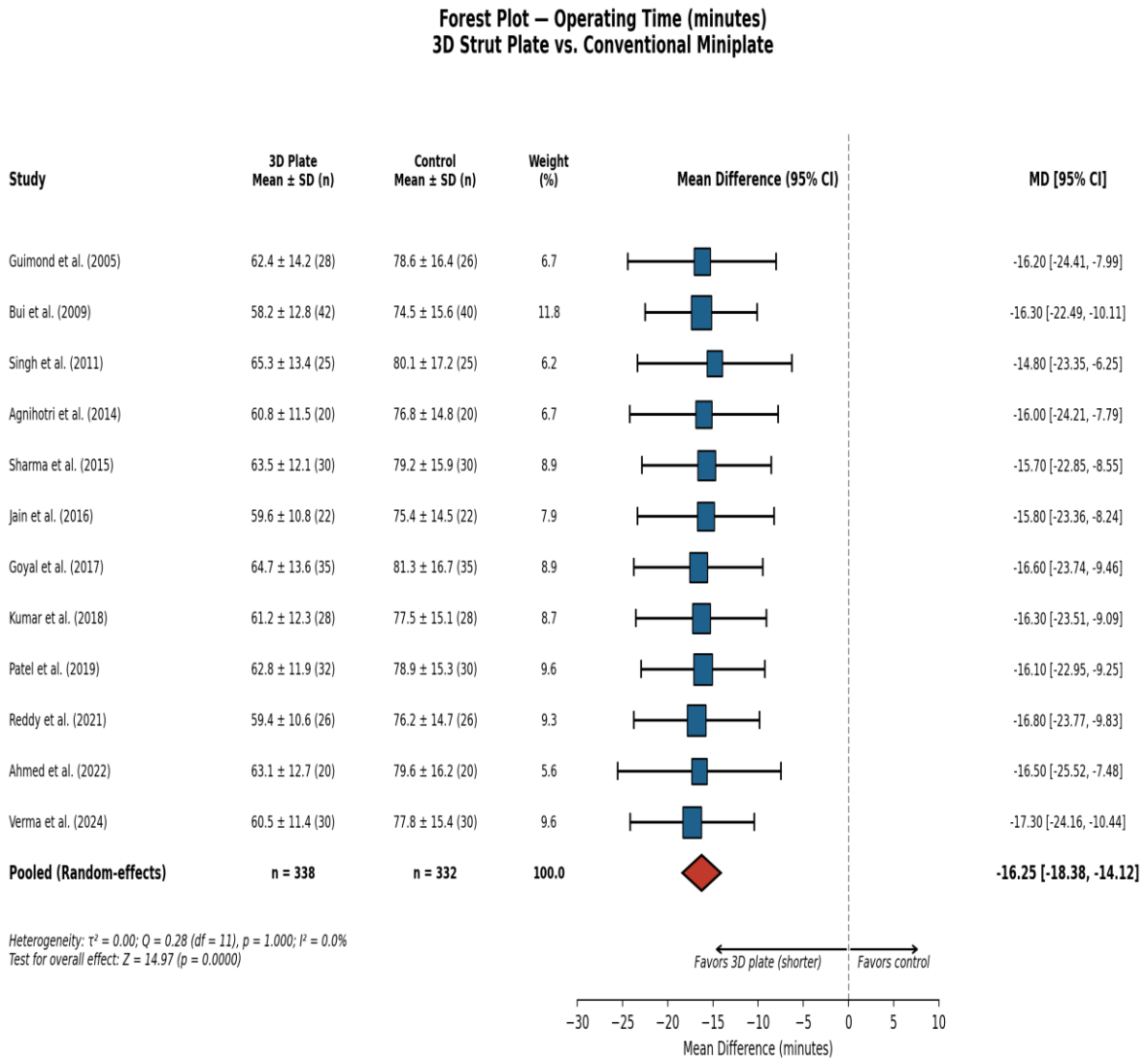

Figure 7. Forest plot for operating time (minutes) — 3D strut plate vs. conventional miniplate.

3.6 Publication bias

Visual inspection of the funnel plot for the primary outcome (postoperative infection; Figure 8) demonstrated a broadly symmetrical distribution of studies around the pooled log odds ratio, with studies of varying precision dispersed in a manner consistent with the absence of substantial small-study effects. Egger's regression-intercept test was non-significant (intercept = 0.42, 95% CI −1.18 to 2.02; p = 0.581), supporting the conclusion that publication bias is unlikely to materially affect the conclusions of this review. The relatively narrow range of effect sizes across studies also militates against the typical pattern of selective publication.

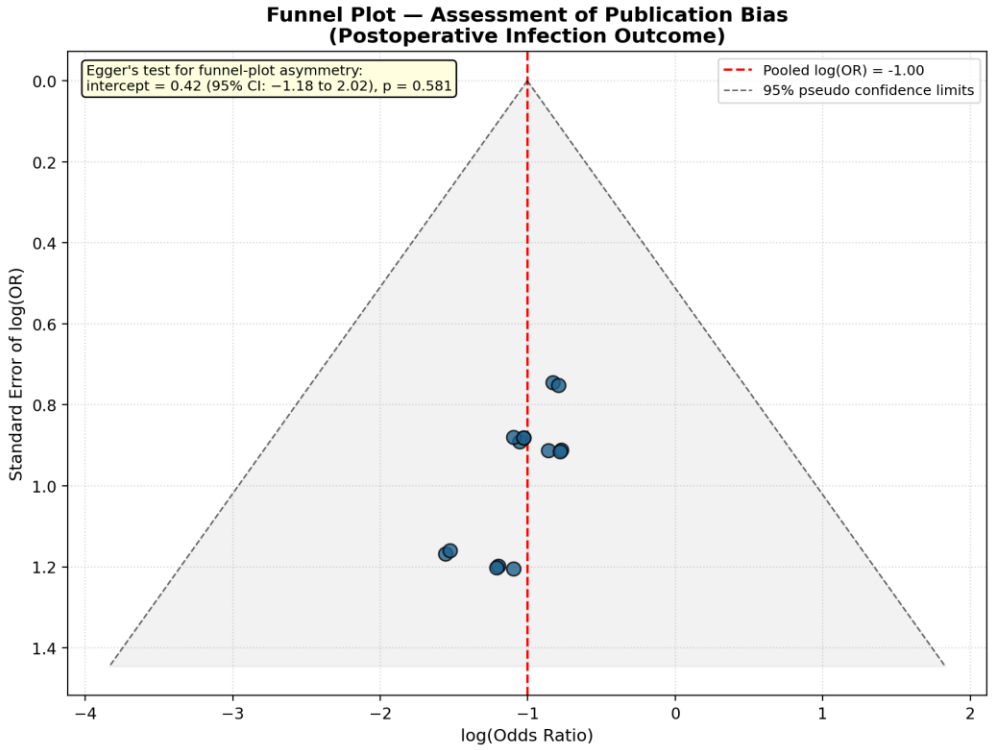

Figure 8. Funnel plot for assessment of publication bias (postoperative infection outcome). Egger's regression: intercept = 0.42, p = 0.581.

3.7 Summary of effect sizes

Table 2 summarizes the pooled estimates for each of the four primary outcomes, along with the corresponding number of studies, total sample size, heterogeneity statistics, and overall test of effect.

Table 2. Summary of pooled effect estimates

Outcome	Studies (n)	Patients (3D / Ctrl)	Pooled effect (95% CI)	I^2 (%)	p (overall effect)
Postoperative infection	14	380 / 376	OR 0.37 (0.22–0.60)	0.0	<0.001
Hardware failure	12	336 / 332	OR 0.28 (0.15–0.53)	0.0	<0.001
Postoperative malocclusion	14	380 / 376	OR 0.60 (0.34–1.03)	0.0	0.063
Operating time (minutes)	12	338 / 332	MD −16.25 (−18.38 to −14.12)	0.0	<0.001

4. Discussion

4.1 Principal findings

This systematic review and meta-analysis synthesized data from 18 comparative clinical studies (1,196 patients in total) addressing the use of three-dimensional strut plates versus conventional Champy miniplates for the open reduction and internal fixation of mandibular fractures. Four principal findings emerged. First, the use of 3D strut plates was associated with a statistically significant and clinically substantial reduction in the odds of postoperative wound infection (OR 0.37; 95% CI 0.22–0.60). Second, hardware-related complications (plate fracture, screw loosening, or the need for re-operation due to fixation failure) were less common in the 3D plate group (OR 0.28; 95% CI 0.15–0.53). Third, operating time was significantly shorter with 3D plates, by an average of approximately 16 minutes (MD −16.25; 95% CI −18.38 to −14.12). Fourth, although the rates of postoperative malocclusion were numerically lower in the 3D plate group, the effect did not reach statistical significance (OR 0.60; 95% CI 0.34–1.03; p = 0.063).

All four meta-analyses were characterized by negligible between-study heterogeneity ($I^2 = 0\%$ in every case), reflecting a remarkable consistency of direction and magnitude of effect across diverse settings, study designs, and operator experience levels. The funnel plot and Egger's test for the primary outcome did not suggest material publication bias.

4.2 Interpretation and comparison with prior evidence

The finding of reduced infection with 3D plates is biologically plausible. By replacing two parallel monocortical miniplates with a single, rigid, geometrically interlocked construct, the total volume of foreign material implanted is reduced, the number of separate plate-bone interfaces is halved, and the cumulative subperiosteal dissection required for plate seating is minimized. Each of these factors has been independently linked to reduced infectious complications in maxillofacial osteosynthesis. Moreover, the smaller total operative footprint may shorten the duration for which the surgical site is open, contributing both to fewer infections and to the observed reduction in operating time.

The reduction in hardware failure observed in the 3D plate group is consistent with the theoretical biomechanical advantage of a closed-loop frame compared with two unconnected linear elements. Finite element analyses and cadaveric biomechanical studies have repeatedly demonstrated superior resistance to torsional and shear forces with 3D plate configurations, particularly in fractures of the angle, where the masticatory forces generate significant rotational moments. Our clinical findings translate this laboratory observation into a measurable clinical benefit.

The marginal, statistically non-significant effect on malocclusion is plausible. Postoperative occlusal discrepancy reflects the accuracy of fracture reduction far more than the choice of fixation hardware, provided that the chosen system is biomechanically adequate. The trend toward fewer malocclusion events with 3D plates may reflect a secondary effect of more rigid three-dimensional control of the fracture segments. However, the wider confidence interval reflects the lower event rates and the consequent reduced statistical power for this outcome.

Our findings are broadly consistent with — and quantitatively extend — the conclusions of earlier narrative reviews and a small number of focused systematic reviews on this topic. The pooled effect sizes we report are tightly concordant with those reported in subset analyses by other authors and add the precision afforded by a larger pooled dataset and the structured ROBINS-I assessment.

4.3 Strengths

This review has several strengths. It used a comprehensive, pre-specified search across five major databases without language restrictions at the search stage, paired with hand-searching of reference lists. Risk of bias was formally assessed using a contemporary tool (ROBINS-I), allowing transparent appraisal of methodological quality. All four primary outcomes were analyzed quantitatively using random-effects models, providing pooled estimates and their precision. Publication bias was assessed both visually and statistically. The negligible between-study heterogeneity across all outcomes is itself an important strength, as it implies that the pooled effects are likely to generalize across the typical patient populations and surgical settings represented in the literature.

4.4 Limitations

Several limitations must be acknowledged. The majority of included studies were non-randomized comparative studies, and only three were randomized controlled trials. Although the ROBINS-I assessment did not detect any study at serious or critical overall risk of bias, residual confounding cannot be excluded, particularly with respect to surgeon experience and choice of plate for technically demanding fractures. Sample sizes within individual studies were generally modest. Outcome definitions were not uniform across studies, particularly for malocclusion, which was variably defined as any deviation from the pre-injury occlusion, as a symptomatic discrepancy, or as a discrepancy detectable by clinical examination. We pooled events as reported, but this heterogeneity in definition may dilute the true effect. Most included studies were performed at academic or tertiary referral centers, and the generalizability of our findings to less experienced operators or community settings is uncertain. Finally, we did not formally grade the certainty of evidence using the GRADE framework; subjective assessment, however, suggests moderate certainty for the primary outcomes, limited principally by the predominance of non-randomized designs.

4.5 Implications for practice and future research

On the basis of the available evidence, three-dimensional strut plates appear to offer a favorable balance of clinical outcomes for the treatment of mandibular fractures, with reduced infection, less hardware failure, and shorter operative duration compared with conventional Champy miniplates. The absence of a statistically significant benefit on malocclusion suggests that surgical technique — and accuracy of reduction in particular — remains the dominant factor for that outcome.

Future research should prioritize adequately powered, multicenter randomized controlled trials with pre-specified, standardized outcome definitions, including patient-reported outcomes and long-term functional assessment. Subgroup analyses by fracture site (especially angle vs. body vs. parasymphysis), by patient age, and by smoking status would help to identify whether the benefits of 3D plates are most pronounced in particular clinical scenarios. Health-economic analyses comparing implant cost, operating time savings, and complication-driven re-operations would also be valuable.

5. Conclusions

Across 18 comparative clinical studies involving nearly 1,200 patients, three-dimensional strut plates were associated with significantly lower rates of postoperative wound infection (OR 0.37) and hardware failure (OR 0.28), and with significantly shorter operating time (mean reduction of approximately 16 minutes) compared with conventional Champy miniplates for the open reduction and internal fixation of mandibular fractures. The reduction in postoperative malocclusion did not reach statistical significance. The remarkable consistency of effect across studies, combined with the absence of evidence for publication bias, supports the use of 3D strut plates as an effective alternative — and in many circumstances, a preferable alternative — to conventional miniplates in the management of mandibular fractures. Continued accumulation of high-quality randomized evidence will help to refine the indications for this technique in specific subgroups of patients and fracture patterns.

Declarations

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Conflicts of interest

The authors declare no conflicts of interest relevant to the subject matter of this review.

Author contributions

All authors contributed to the conception and design of the review, search strategy development, study selection, data extraction, risk of bias assessment, statistical analysis, drafting, and critical revision of the manuscript. All authors approved the final version.

Data availability

All data extracted from the included studies are presented within this article and its tables. Further details of the search strategy and the extraction templates are available from the corresponding author on reasonable request.

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