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Comparison of the Accuracy of Conventional, Digital, and Stereophotogrammetric Impression Techniques in Implant-Supported Restorations: A Systematic Review

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ABSTRACT

Introduction: This systematic review and meta-analysis evaluated the primary digital accuracy outcomes, including trueness and precision, and the secondary clinical adaptation outcome, prosthetic fit, of conventional, digital, and stereophotogrammetric (SPG) impression techniques in implant-supported restorations. This review proposes that digital and SPG techniques offer higher accuracy relative to conventional techniques.

Materials and Methods: Following PRISMA 2020 guidelines, five databases were searched between December 2024 and September 2025. Of 28,922 screened records, 13 in vitro studies met inclusion criteria. Data extraction was independently conducted by two reviewers. Methodological quality was assessed using the QUIN tool, and random-effects meta-analyses (RevMan and CMA) were performed to calculate standardized mean differences (SMD, 95% CI).

Results: For the primary digital accuracy outcomes, SPG generally achieved the highest trueness and precision, with significant advantages in several comparisons (SMD = −1.60 to −3.80, $p < 0.05$). For the secondary clinical adaptation outcome, digital impressions showed significantly improved prosthetic fit compared with conventional techniques (SMD = −1.65, $p = 0.001$).

Conclusion: In vitro evidence suggests that digital impressions provide better fit than conventional techniques, while SPG achieves the highest overall accuracy. High-quality clinical studies are needed to confirm these findings and determine their long-term prosthetic and biological implications.

Keywords: Dental implants; Dental prosthesis; Dental impression technique; Stereophotogrammetry.

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Introduction

Dental implants provide a predictable and long-term solution for edentulous patients, enabling functional and aesthetic rehabilitation [1]. Modern implant dentistry has transitioned from solely surgical methodologies to an emphasis on prosthetic-focused and digitally connected procedures. Virtual treatment planning and computer-assisted protocols allow clinicians to optimize anatomical, functional, and aesthetic outcomes simultaneously, underscoring the importance of accuracy at every stage of implant rehabilitation [2]. The success of implant-supported prostheses mainly relies on accurate impression techniques. Even minimal discrepancies in transferring implant positions can lead to prosthetic misfits, resulting in mechanical complications, occlusal inaccuracies, or reduced longevity of restorations [3]. Over the last few decades, imprint techniques have changed from traditional methods to fully digital methods, and more recently, stereophotogrammetric methods [4]. Conventional techniques, such as the splinted open-tray (pick-up) and closed-tray (transfer) techniques, remain the gold standard in terms of accuracy, particularly in full-arch and multiple-implant cases [5-7].

Digital impression techniques using intraoral scanners (IOS) have gained substantial attention as a reliable alternative. Studies demonstrate comparable accuracy and clinically acceptable passive fit between digital and conventional techniques, especially in single-tooth and partially edentulous cases [8-10]. In full-arch rehabilitations, conventional impressions may still demonstrate slightly higher trueness; however, the use of optimized scan bodies, auxiliary geometric devices, and advanced scanning strategies significantly improves digital accuracy [11,12]. Meta-analyses have produced conflicting conclusions. Some identify superior 3D accuracy for digital impressions, while others favor conventional techniques for single-implant precision [13,14]. In addition to accuracy, digital workflows make patients more comfortable, shorten treatment times, and make it easier to manage data [15]. However, accuracy in IOS is influenced by factors such as implant angulation, inter-implant distance, scanner type, and operator experience [16,17]. Stereophotogrammetry (SPG) has recently emerged as an innovative digital technique for capturing implant positions without physical impressions or intraoral scanning distortion. SPG uses several calibrated cameras to record the spatial coordinates of scan markers, which results in very accurate 3D information. Numerous in vitro and in vivo investigations consistently reveal that SPG achieves greater trueness and precision compared with both IOS and conventional procedures, particularly in complete-arch and multi-implant situations [4,18-21]. SPG accuracy also appears less affected by implant inclination or arch span, making it a robust workflow for extensive restorations. Despite these advantages, the need for a prototype try-in and system calibration remains critical, and clinical validation in diverse populations is still limited [20,21]. Comparisons of conventional, digital, and SPG impression techniques indicate progress, yet demonstrate variability in accuracy and passive fit. Performance depends on arch length, implant angulation, and scanner type. Digital impressions sometimes make superior fit with smaller marginal gaps [22-25]. Conversely, other studies demonstrate higher trueness for conventional impressions, particularly in full-arch or mandibular models, emphasizing limitations of intraoral scanners over long spans [26-28]. SPG consistently demonstrates the highest trueness and precision, remaining largely unaffected by implant angulation or arch span, which makes it a dependable option for complex restorations [18,29-31]. However, results may still differ based on implant distribution, scanner type, scanning technique, and SPG calibration, and there is no agreement on the ideal approach for full-arch or long-span prostheses.

Despite the advances in digital and SPG technologies, direct comparisons with conventional impressions remain limited, and most studies are in vitro or outdated. Existing reviews have not included all techniques or performed meta-analyses [20,32,33], highlighting the need for an updated systematic review to assess their accuracy and clinical relevance in implant-supported restorations. This systematic review and meta-analysis aimed to compare the primary digital accuracy outcomes, namely trueness and precision, of conventional, digital, and stereophotogrammetric impression techniques for implant-supported restorations in in vitro studies. Prosthetic fit was evaluated as a secondary clinical adaptation outcome. This review hypothesizes that digital and SPG impression techniques will demonstrate superior trueness and precision compared to conventional methods.

Materials and Methods

This systematic review and meta-analysis was conducted in accordance with the PRISMA 2020 guidelines [34], and aimed to compare the primary digital accuracy outcomes, including trueness and precision, of conventional, digital, and stereophotogrammetric impression techniques for implant-supported resto-

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rations based on in vitro studies. Prosthetic fit, including marginal and internal fit/gap, was assessed as a secondary clinical adaptation outcome. All processes, from systematic search to data synthesis, were independently performed by two calibrated reviewers, with disagreements resolved by a third reviewer. The study was approved by the Ethics Committee of the Faculty of Dentistry, Mashhad University of Medical Sciences (IR.MUMS.DENTISTRY.REC.1404.020).

Search Strategy

A two-stage electronic search was conducted to identify relevant studies that evaluate the accuracy of conventional, digital, and stereophotogrammetric impression techniques in implant-supported restorations. The first search was conducted on December 10, 2024, and the second on September 20, 2025, to make sure that the most recent publications were included. We explored five electronic databases in a systematic way: PubMed, Scopus, Web of Science (ISI), Embase, and the Cochrane Library. Search strategies combined both controlled terms (MeSH terms) and free-text terms related to digital scanning, CAD/CAM, and dental impression techniques. No restrictions were applied regarding publication year. Duplicates were removed prior to screening. Details of the two-stage search strategy and the retrieved records are shown in Table 1. After duplicate removal (8,825 records), 6,302 unique studies were screened by title and abstract. Subsequently, 28 full-text papers were retrieved for detailed eligibility assessment, of which 13 studies met the inclusion criteria and were included in the qualitative and quantitative synthesis. Study selection process is shown in the PRISMA 2020 flow diagram (Figure 1).

Exposure and Outcome

The primary exposure variable was the impression technique applied for the fabrication of implant-supported restorations. Three impression categories were analyzed:

1. Digital impressions (Intraoral or extraoral scanners, e.g., Trios, iTero, Primescan, Cerec, Medit).

2. Conventional impressions using open-tray techniques (splinted or non-splinted copings) and any material type (polyether, polyvinyl siloxane, etc.).

3. Stereophotogrammetric impressions, when evaluated alongside digital or conventional methods.

The primary outcomes were digital accuracy measures, including trueness and precision. Trueness was defined as deviation from the reference model and included 3D deviation, root mean square (RMS), absolute linear deviation, or angular deviation, reported as mean ± SD. Precision was defined as repeatability across repeated measurements and was also reported as mean ± SD. Prosthetic fit/gap, including internal fit, marginal fit, vertical misfit, or marginal gap, was considered a secondary clinical adaptation outcome. All linear measurements were standardized to micrometers (μm), whereas angular outcomes were retained in degrees (°) and analyzed separately.

Study Selection

Two reviewers independently screened all titles and abstracts using Rayyan software. Full-text assessments were conducted for eligible records. Inclusion and exclusion criteria were applied rigorously to ensure methodological comparability. Studies without quantitative data, single-unit implants, or non-fixed prostheses were excluded. Any Disagreements were resolved through consensus discussions among the reviewers. Finally, 13 in vitro studies were included for analysis (n = 13).

Eligibility Criteria

The eligibility criteria were defined to ensure methodological consistency and include studies directly comparing the accuracy of conventional, digital, and, where applicable, stereophotogrammetric impression techniques in implant-supported restorations. Only in vitro experimental studies were included to allow controlled evaluation without clinical confounders. Eligible studies had to be comparative, assessing at least two impression modalities (digital vs. conventional, or including photogrammetry) on multi-unit or full-arch implant models with a minimum of two implants, excluding single-unit abutments and removable prostheses. The intervention was digital impression using any intraoral or extraoral scanner (e.g., Trios, iTero, Primescan, CEREC, Medit), compared to conventional open-tray impressions using any elastomeric material (PVS or PE), with or without splinting. Studies including photogrammetry alongside digital and conventional techniques were also eligible for secondary analyses. Eligible studies had to report quantitative data for at least one predefined outcome: trueness or precision as primary digital accuracy outcomes, or prosthetic fit/gap as a secondary clinical adaptation outcome, in or convertible to micrometers (μm) or degrees (°). Only peer-reviewed articles in English or Persian (or accessible translations) were included. Studies lacking methodological transparency regarding implant systems, scanning protocols, or CAD/CAM workflow, or those with fewer than five specimens per group, were excluded. Studies with fewer than five specimens or repeated measurements per comparison group were excluded because very small in vitro datasets may produce unstable variance estimates and unreliable pooled effect sizes. This threshold was selected to ensure a minimum level of experimental repeatability and statistical reliability for quantitative synthesis.

Exclusion Criteria

Studies were excluded if they did not meet predefined methodological or reporting standards. Specifically, non-comparative studies (e.g., case reports, case series, letters, narrative reviews) or those lacking a direct comparison between at least two impression techniques were excluded. Studies on single-implant restorations, removable prostheses, or non-implant conditions were omitted. Reports presenting only qualitative or non-numeric accuracy data, results in non-convertible units, or insufficient statistical information (e.g., missing SD or only median [IQR]) were also excluded. Additionally, studies focusing on secondary outcomes such as patient satisfaction, procedure time, cost, surgical accuracy, prosthesis maintenance, or long-term complications without assessing impression accuracy were omitted. These criteria ensured inclusion of high-quality, quantitatively comparable in vitro evidence for robust meta-analysis.

Data Extraction

Data extraction was conducted independently by two reviewers using a standard template. For each study, information on study ID (author, year, country), sample characteristics (number of implants, arch type, materials), and experimental design (groups, measurement techniques) was recorded. Details of impression methods, including scanner model, scanning protocol, impression material, tray type, and splinting, were documented. Quantitative data for the primary outcomes, trueness and precision, and the secondary outcome, prosthetic fit/gap, were collected as mean ± SD, along with the assessment method (3D deviation, linear deviation, angular deviation, RMS, marginal gap, internal gap, or vertical misfit) and software used. Discrepancies were resolved by a third reviewer. The finalized dataset was used in meta-analysis.

Quality and Risk of Bias Assessment

The quality assessment tool for in vitro studies (QUIN) was employed to evaluate methodological quality [35]. Each study was assessed across 12 domains: aims, sample size, sampling, comparison group, methodology, operators, randomization, outcome measurement, assessors, blinding, statistics, and results presentation.

Statistical Analysis

Meta-analysis was performed using Review Manager 5.4 and Comprehensive Meta-Analysis version 4.0. Before quantitative synthesis, all linear measurements were standardized to micrometers. Values reported in millimeters were converted to micrometers by multiplying by 1000, whereas angular outcomes were retained in degrees and analyzed separately. The primary digital accuracy outcomes, trueness and precision, and the secondary clinical adaptation outcome, prosthetic fit, were treated as separate outcome domains and were not pooled together. Because the included studies used different measurement protocols, reference models, scanners, and accuracy metrics, standardized mean differences with 95% confidence intervals were used for the primary quantitative synthesis. Multi-arm studies were checked to avoid inappropriate double-counting of shared comparator groups; where necessary, shared comparator groups were split or pairwise comparisons were analyzed separately. Heterogeneity was assessed using the I^2 statistic. Random-effects models were applied when heterogeneity was moderate or high, whereas a fixed-effect model was used when heterogeneity was absent. Statistical significance was set at $p < 0.05$. The magnitude of heterogeneity was interpreted as low, moderate, high, or considerable based on the I^2 statistic, and the corresponding I^2 value was reported for each meta-analysis.

Results

Screening and Study Selection

A comprehensive search was conducted in PubMed, Scopus, ISI Web of Science, Embase, and the Cochrane Library on 20 September 2025, yielding 15,127 records. After removing 8,825 duplicates, 6,302 unique records were screened by title and abstract, resulting in the exclusion of 6,274 articles (3,510 by title, 2,763 by abstract, and 1 due to language). 28 full-text articles were assessed, with two unavailable and thirteen excluded for reasons such as use of auxiliary devices (n = 2), unrelated content (n = 2), qualitative comparison only (n = 3), insufficient data (n = 3), focus on single-unit implants (n = 1), and emphasis on secondary outcomes (n = 2). Finally, 13 in-vitro studies were included in the systematic review and meta-analysis.

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Study Characteristics

Thirteen in-vitro studies published between 2015 and 2025 were included (Table 2), originating from nine countries: Brazil (1), China (2), Egypt (3), France (1), India (1), Italy (1), Lebanon (1), Thailand (1), and Turkey (2). All compared conventional impression techniques (polyether or PVS with open-tray splinted copings; n = 13) with digital scanning methods (IOS = 12; EOS = 1); four also evaluated stereophotogrammetry. Sample sizes ranged from 10–90, typically involving 4–6 implants simulating edentulous full arches (maxilla = 6; mandible = 5) or partial posterior spans (2 studies). Common implant systems included Straumann Bone Level Tapered (n = 4) and Nobel Biocare, among others. Frequently used scanners were 3Shape TRIOS (n = 7), Primescan (n = 5), and Medit i-series (n = 4). Primary outcomes were trueness (3D/RMS/linear/angular deviation; n = 8) and precision (repeatability; n = 6); marginal or internal fit was reported in six studies. Accuracy was mainly assessed via best-fit superimposition of STL files using Geomagic Control X (n = 7) or comparable software, with additional methods including the Sheffield test (n = 3) and silicone replica technique (n = 1).

Risk of Bias and Quality Assessment

Risk of bias was assessed using the QUIN tool across 12 domains, with scores of 0 (high risk), 1 (moderate risk), or 2 (low risk) per domain (Table-3). Total scores ranged from 13 to 21 out of 24, corresponding to 54.2%–87.5%. Studies were classified as low risk of bias when the QUIN score was ≥ 75%, moderate risk when the score was 60%–74.9%, and high risk when the score was < 60%. Based on this classification, five studies were rated as low risk, five as moderate risk, and three as high risk. The high-risk studies were Shaikh et al. (2022), Tohme et al. (2023), and Lyu et al. (2025). Sensitivity analyses were conducted by excluding these high-risk studies to assess the robustness of the pooled estimates. Publication bias assessment was not feasible due to fewer than 10 studies per outcome comparison.

Synthesis of Results

Precision Analysis:

1. Precision (micrometer)–Digital vs. Conventional: The pooled estimate (SMD = −0.39, 95% CI [−0.96,0.19], p = 0.186) indicated no statistically significant difference between digital and conventional impressions (Figure-3A). Heterogeneity for linear precision was moderate (I^2 = 37.9%). Although several studies demonstrated slight advantages for digital workflows, the overall results suggest comparable repeatability and precision between both techniques at the micrometer level. Sensitivity analysis was performed by excluding studies classified as high risk of bias; the direction and statistical significance of the pooled estimate remained unchanged, indicating that the nonsignificant finding for linear precision was robust. Although several studies demonstrated slight advantages for digital workflows, the overall results suggest comparable repeatability and precision between both techniques at the micrometer level.

2. Precision (micrometer)–Stereophotogrammetric vs. Conventional: Stereophotogrammetric (SPG) impressions demonstrated significantly higher precision compared with conventional impressions (SMD = −3.80, 95% CI [−7.27,−0.34], p = 0.032) (Figure-3B). heterogeneity for the SPG-versus-conventional linear precision comparison was low (I^2 = 13.4%). The negative SMD favored SPG, confirming its superior dimensional stability and repeatability in reproducing implant positions under in-vitro conditions.

3. Precision (micrometer)–Stereophotogrammetric vs. Digital: Comparison between SPG and digital impressions showed a statistically significant advantage for SPG (SMD = −2.93, 95% CI [−4.27,−1.59], p < 0.001) (Figure-3C). Heterogeneity for the SPG-versus-digital linear precision comparison was negligible (I^2 = 0.2%). This finding underscores the enhanced reproducibility and reduced linear deviation of SPG systems in implant-level accuracy assessments.

4. Precision (degree)–Digital vs. Conventional: No significant difference was observed in angular precision between digital and conventional impression techniques (SMD = −0.59, 95% CI [−1.75,0.57], p = 0.318) (Figure-4A). Heterogeneity for angular precision was considerable (I^2 = 80.1%). Both methods exhibited similar reliability in capturing implant angulations, suggesting minimal influence of impression type on rotational accuracy.

5. Precision (degree)–Stereophotogrammetric vs. Conventional: Although SPG impressions tended to be more precise, the difference compared with conventional impressions was not statistically significant (SMD = −3.02, 95% CI [−7.61,1.56], p = 0.196) (Figure-4B). Heterogeneity for the SPG-versus-conventional angular precision comparison was low (I^2 = 11.6%). High heterogeneity and limited sample size likely influenced this nonsignificant outcome.

6. Precision (degree)–Stereophotogrammetric vs. Digital: SPG impressions demonstrated significantly higher angular precision than digital methods (SMD = −2.23, 95% CI [−4.41,−0.06], p = 0.044) (Figure-4C). Heterogeneity for the SPG-versus-digital angular precision comparison was negligible to low (I^2 = 1.8%). These results indicate SPG's superior ability to replicate implant angulations with minimal deviation.

Trueness Analysis

1. Trueness (micrometer)–Digital vs. Conventional: The pooled analysis showed no significant difference in trueness between digital and conventional impressions (SMD = 0.36, 95% CI [−0.50,1.21], p = 0.417) (Figure-5A). Heterogeneity for linear trueness was high (I^2 = 66.5%). Despite variability among individual studies, the overall evidence suggests comparable linear dimensional accuracy between the two approaches.

2. Trueness (micrometer)–Stereophotogrammetric vs. Conventional: SPG impressions exhibited no statistically significant difference in trueness when compared with conventional impressions (SMD = −0.53, 95% CI [−1.95,0.88], p = 0.461) (Figure-5B). Heterogeneity for the SPG-versus-conventional linear trueness comparison was moderate (I^2 = 30.5%). While some datasets favored SPG, the overall pooled outcome indicated similar levels of dimensional fidelity.

3. Trueness (micrometer)–Stereophotogrammetric vs. Digital: A statistically significant difference favored SPG impressions over digital methods (SMD = −1.60, 95% CI [−2.22,−0.97], p < 0.001) (Figure-5C). Heterogeneity for the SPG-versus-digital linear trueness comparison was negligible (I^2 = 0.1%). SPG techniques demonstrated superior trueness in reproducing three-dimensional implant positions at the micrometer scale.

4. Trueness (degree)–Digital vs. Conventional: No significant difference was found between digital and conventional impressions for angular trueness (SMD = −0.05, 95% CI [−0.59,0.49], p = 0.858) (Figure-6A). Heterogeneity for angular trueness was low (I^2 = 9.0%). Both approaches yielded similar angular accuracy in implant orientation reproduction.

5. Trueness (degree)–Stereophotogrammetric vs. Conventional: Although the mean effect size slightly favored SPG, no statistically significant difference was identified compared with conventional techniques (SMD = −0.15, 95% CI [−1.19,0.90], p = 0.783) (Figure-6B). Heterogeneity for the SPG-versus-conventional angular trueness comparison was moderate (I^2 = 27.8%). These findings suggest equivalent angular trueness between the two impression methods.

6. Trueness (degree)–Stereophotogrammetric vs. Digital: A significant improvement in angular trueness was observed for SPG impressions compared with digital methods (SMD = −1.04, 95% CI [−1.54,−0.54], p < 0.001) (Figure-6C). Heterogeneity for the SPG-versus-digital angular trueness comparison was low (I^2 = 14.1%). SPG systems demonstrated enhanced capability in accurately transferring implant angulations within the digital workflow. Fit Accuracy: Meta-analysis of studies comparing digital and conventional impression techniques revealed a statistically significant difference favoring digital methods (SMD = −1.65, 95% CI [−2.58,−0.72], p = 0.001) (Figure-2). The negative effect size indicates better fit accuracy for digital impressions. Several individual studies, including those by Saad et al. and El Naggar (2024), strongly supported this finding. Overall, digital techniques achieved improved marginal and internal adaptation in implant-supported restorations.

Table 1. Summary of the two-stage search strategy and retrieved records.

Stage	*Date*	*Database*	*Search Strategy*	*Records Retrieved (n)*
Stage 1	*10 December 2024*	*PubMed, Scopus, ISI, Embase, Cochrane*	*((CAD/CAM) OR (Computer-Aided Design) OR (CAD-CAM) OR (scan*)) AND (Impression) AND (oral OR mouth OR teeth OR tooth OR dent* OR maxilla* OR mandib* OR molar* OR incis* OR palatal* OR lingual)*	*PubMed: 3,212Scopus: 3,801ISI: 2,976Embase: 3,315Cochrane: 591Total (Stage 1): 13,895*
Stage 2 (Updated Search)	*20 September 2025*	*PubMed*	*((CAD/CAM) OR (Computer-Aided Design) OR (CAD-CAM) OR ("Computer-Aided Design"[Mesh]) OR (scan*)) AND ((Impression) OR ("Dental Impression Materials"[Mesh]) OR ("Dental Impression Technique"[Mesh])) AND (oral OR mouth OR ("Mouth"[Mesh]) OR teeth OR tooth OR ("Tooth"[Mesh]) OR dent* OR maxilla* OR ("Maxilla"[Mesh]) OR mandib* OR ("Mandible"[Mesh]) OR molar* OR incis* OR palatal* OR lingual)*	*3,710*

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Stage	Date	Database	Search Strategy	Records Retrieved (n)
		Scopus	((CAD/CAM) OR (Computer-Aided Design) OR (CAD-CAM) OR (scan*)) AND (Impression) AND (oral OR mouth OR teeth OR tooth OR dent* OR maxilla* OR mandib* OR molar* OR incis* OR palatal* OR lingual)	4,094
		Web of Science (ISI)	((CAD/CAM) OR (Computer-Aided Design) OR (CAD-CAM) OR (scan*)) AND (Impression) AND (oral OR mouth OR teeth OR tooth OR dent* OR maxilla* OR mandib* OR molar* OR incis* OR palatal* OR lingual)	3,148
		Embase	((CAD/CAM) OR (Computer-Aided Design) OR (CAD-CAM) OR (scan*)) AND (Impression) AND (oral OR mouth OR teeth OR tooth OR dent* OR maxilla* OR mandib* OR molar* OR incis* OR palatal* OR lingual)	3,561
		Cochrane Library	(CAD/CAM OR «Computer-Aided Design» OR scan*) AND (Impression) AND (oral OR mouth OR teeth OR tooth OR dent* OR maxilla* OR mandib*)	614
-	Total (Stage 2)	-	-	15,127
Combined (Stage 1 + 2)	-	-	-	28,922 (before duplicate removal)

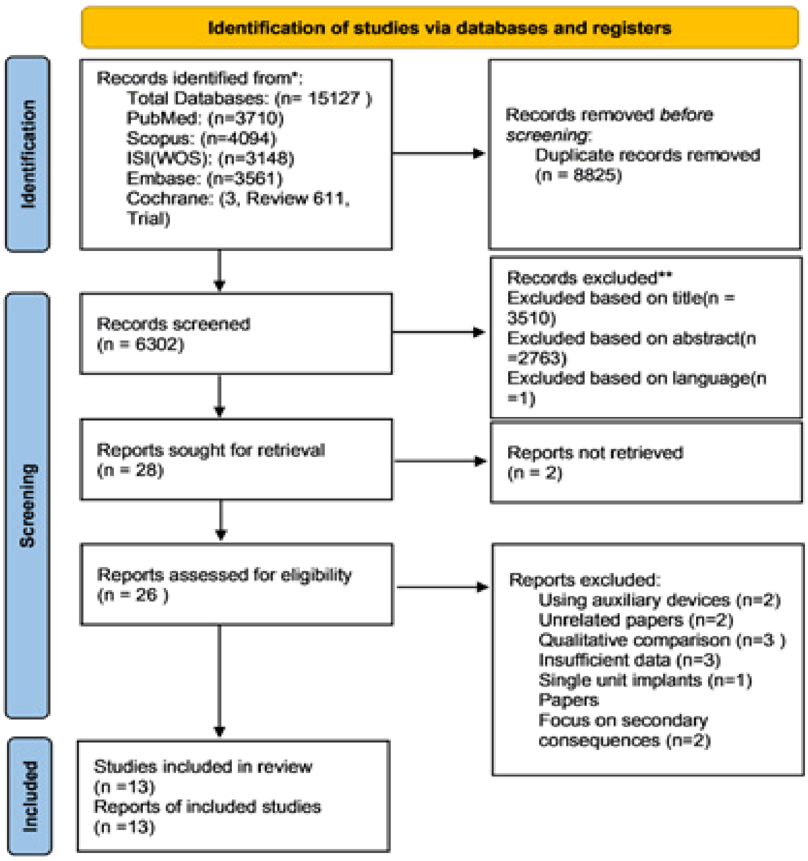

Figure 1. PRISMA flow diagram and the study selection process.

Table 2. Summary of main findings.

Author (Year)	Country	Sample Size	Implant System	Implant Location	Impression Technique	Digital Scanner	Outcome Measures	Accuracy Assessment Method
Presotto et al. (2017) (36)	Brazil	20 frameworks	Brånemark (SIN)	Mandibular posterior	Conventional vs CAD-CAM	Ceramill Map 300	Marginal fit (µm)	Microscope (×120)
Bayramoglu et al. (2015) (37)	Turkey	60 casts	AstraTech	Mandibular posterior	Conventional + CAD-CAM	Cerec inLab Bluecam	Marginal/ internal gap (µm)	Silicone replica + microscopy
Liu et al. (2024) (30)	China	90 models	NobelActive	Maxillary full arch	Conventional vs Digital vs SPG	TRIOS 3, PIC camera	Trueness & precision (µm, °)	3D superimposition
Menini et al. (2018) (23)	Italy	15 impressions/group	Biomet 3i	Full arch	Conventional vs Digital	3M True Definition	Distance & angle error, gap	CMM + stereomicroscope
Shaikh et al. (2022) (28)	India	30 impressions	Straumann BLT	Edentulous mandible	Conventional vs Digital	Primescan, TRIOS	Linear & angular deviation	Geomagic Control X
Drancourt et al. (2023) (27)	France	45 impressions	ETK Naturactis	Edentulous maxilla	Conventional vs Digital	Trios 4, Primescan, CS3600, i500	Trueness & precision	Geomagic Control X
Kosago et al. (2023) (18)	Thailand	40 impressions	Straumann BLT	Edentulous mandible	Conventional vs Digital vs SPG	Trios 4, Primescan, iTero, PIC	Trueness & precision (RMS)	Best-fit alignment
Saad et al. (2024) (24)	Egypt	25 frameworks	J Dental	Mandibular All-on-4	Conventional vs Digital	Primescan, Omnicam, i700, Trios4	Marginal gap (µm)	Sheffield test + ImageJ
Tohme et al. (2023) (31)	Lebanon	45 acquisitions	Straumann RC	Maxillary All-on-4	CI vs DIS vs SPG	TRIOS 3, PiC system	RMS (mm), angular deviation	Geomagic Control X
El Naggar et al. (2024) (22)	Egypt	10 frameworks	Implant Direct	Maxillary All-on-6	Conventional vs Digital	Medit T310 (lab)	Vertical gap (µm)	Stereomicroscope + Motic
Mahmoud et al. (2025) (25)	Egypt	22 frameworks	VITRONEX	Mandibular full arch	Conventional vs Digital	Medit i-700	Vertical misfit (µm)	Sheffield + stereomicroscope
Cevik et al. (2025) (26)	Turkey	n=7/group	Straumann	Full arch	Conventional vs Digital	TRIOS 3	3D deviation (µm)	Artec Micro II + Geomagic
Lyu et al. (2025) (29)	China	n=10/method	Straumann BLT	Edentulous maxilla	Conventional vs IOS vs PG	TRIOS 3, ICam4D	Truness (µm, °) & precision(median)	Best-fit + Bonferroni

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Table 3. Risk of bias assessment using the QUIN tool for included studies.

Study	Aim/objective	Sample-size calculation	Sampling technique	Comparison groups	Methodology details	Operator details	Randomization	Outcome measurement	Assessor details	Blinding	Statistical analysis	Results presentation	Total Score	Final score (%)
A.G.Presotto (2017)	2	1	2	2	2	2	0	2	2	1	2	2	20	83.3
E.Bayramoglu (2015)	2	1	2	2	2	1	0	2	1	0	2	2	17	70.8
M.Liu (2024)	2	1	2	2	2	2	1	2	2	0	2	2	20	83.3
M.Menini (2018)	2	2	2	2	2	2	1	2	1	0	2	2	18	75
M.Shaikh (2022)	2	1	2	2	2	0	0	2	0	0	2	2	13	54.2
N.Drancourt (2023)	2	2	2	2	2	2	0	2	1	0	2	2	17	70.8
P.Kosago (2023)	2	1	2	2	2	1	0	2	0	0	2	2	16	66.7
R.R.Saad (2024)	2	1	2	2	2	2	0	2	0	0	2	2	17	70.8
H.Tohme (2023)	2	1	2	2	2	1	0	2	0	0	2	2	14	58.3
A.EI. Naggar (2024)	2	1	2	2	2	1	0	2	2	1	2	2	17	70.8
R.A.Mahmoud (2025)	2	2	2	2	2	1	0	2	1	0	2	2	18	75
P.Cevik (2025)	2	2	2	2	2	2	2	2	1	0	2	2	21	87.5
M.Lyu (2025)	2	0	1	2	2	1	0	2	0	0	2	2	14	58.3

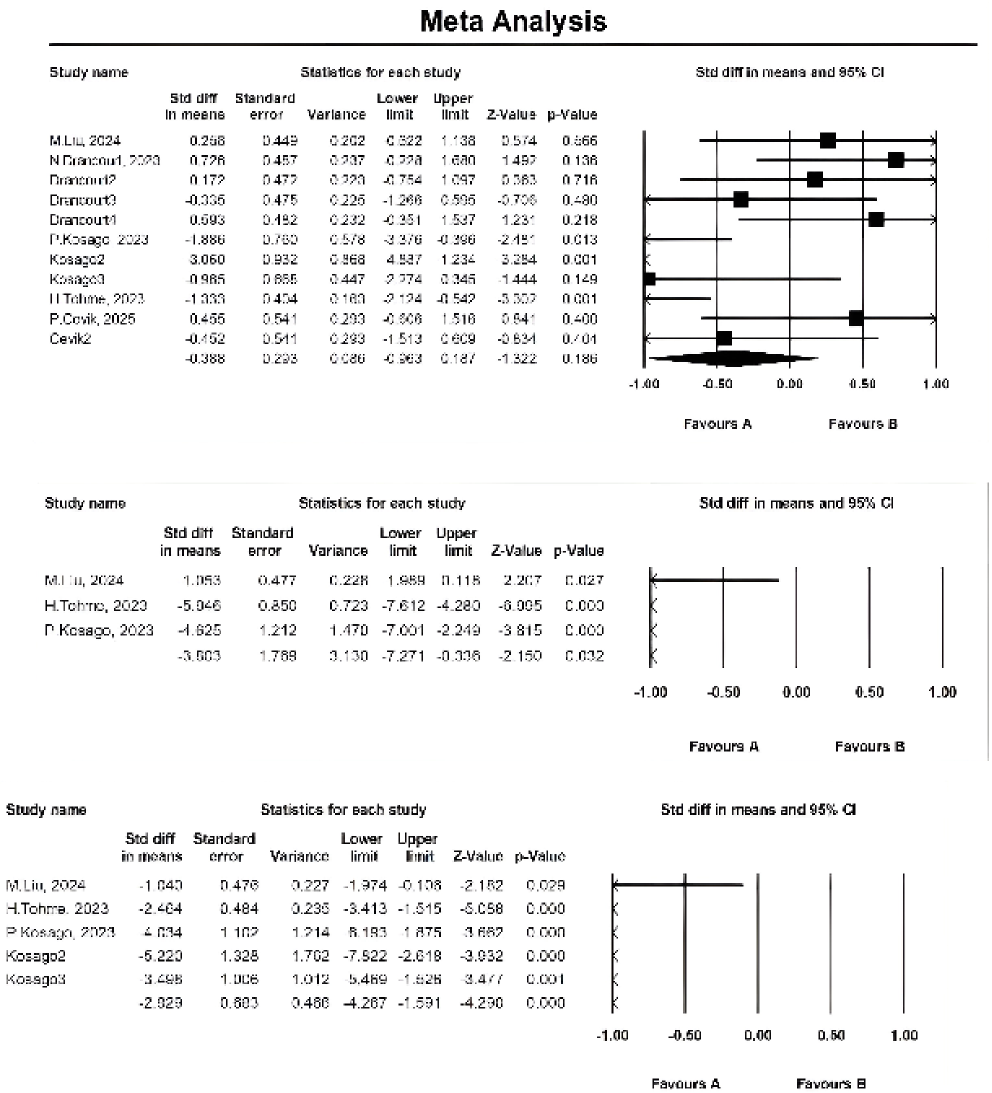

Figure 2. A: Forest plot comparing the linear deviation values of Digital (A) and Conventional (B) technique. B: Forest plot comparing the linear deviation values of SPG (A) and Conventional (B) technique. C: Forest plot comparing the linear deviation values of SPG (A) and Digital (B) technique.

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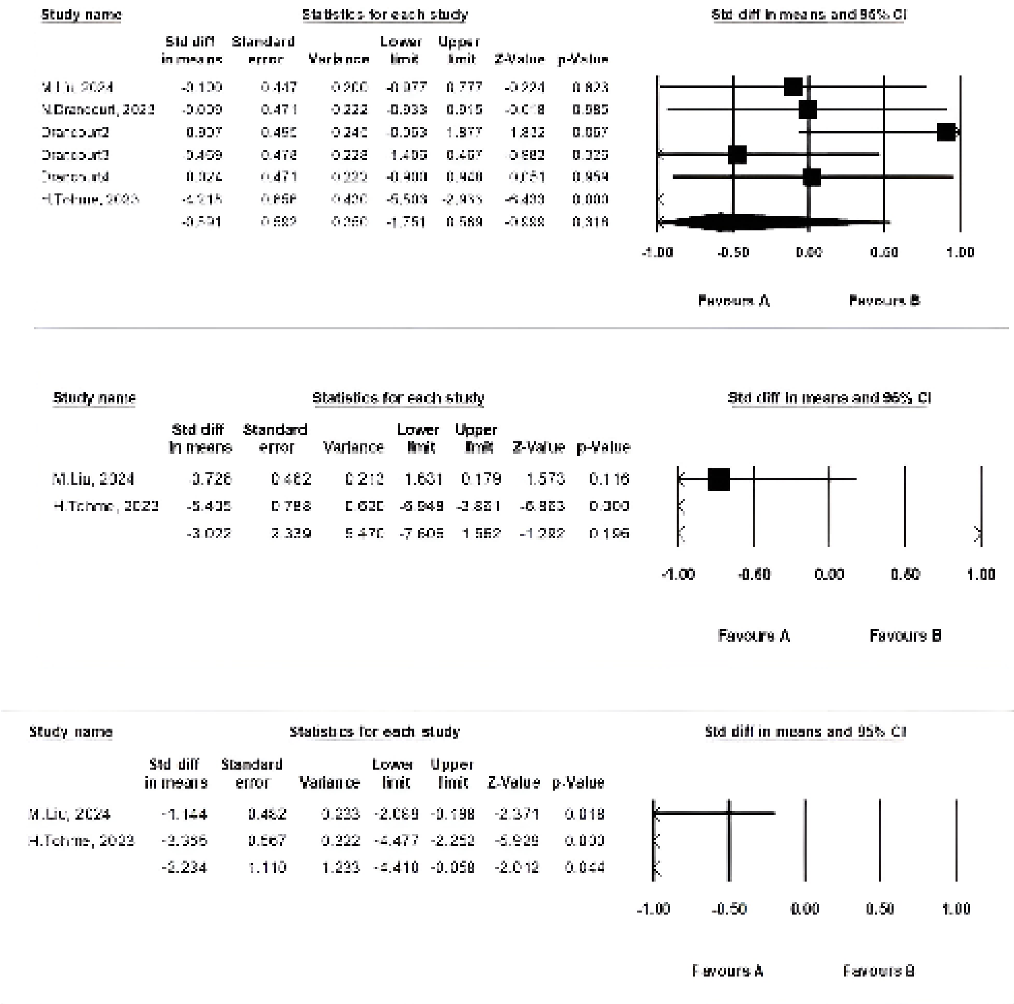

Figure 3. A: Forest plot comparing the linear deviation values of Digital (A) and Conventional (B) technique. B: Forest plot comparing the linear deviation values of SPG (A) and Conventional (B) technique. C: Forest plot comparing the linear deviation values of SPG (A) and Digital (B) technique.

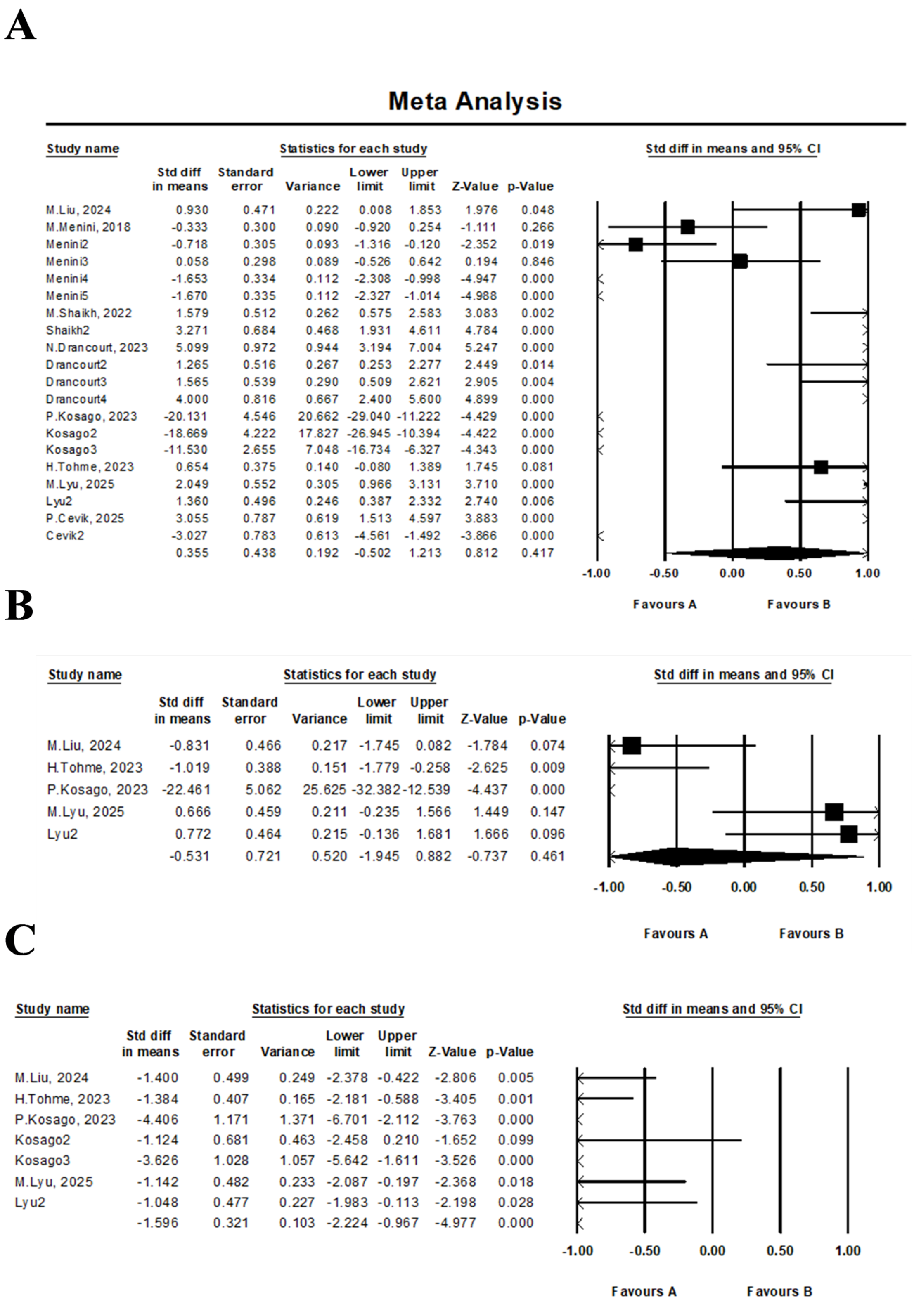

Figure 4. A: Forest plot comparing the linear deviation values of Digital (A) and Conventional (B) technique. B: Forest plot comparing the linear deviation values of SPG (A) and Conventional (B) technique. C: Forest plot comparing the linear deviation values of SPG (A) and Digital (B) technique.

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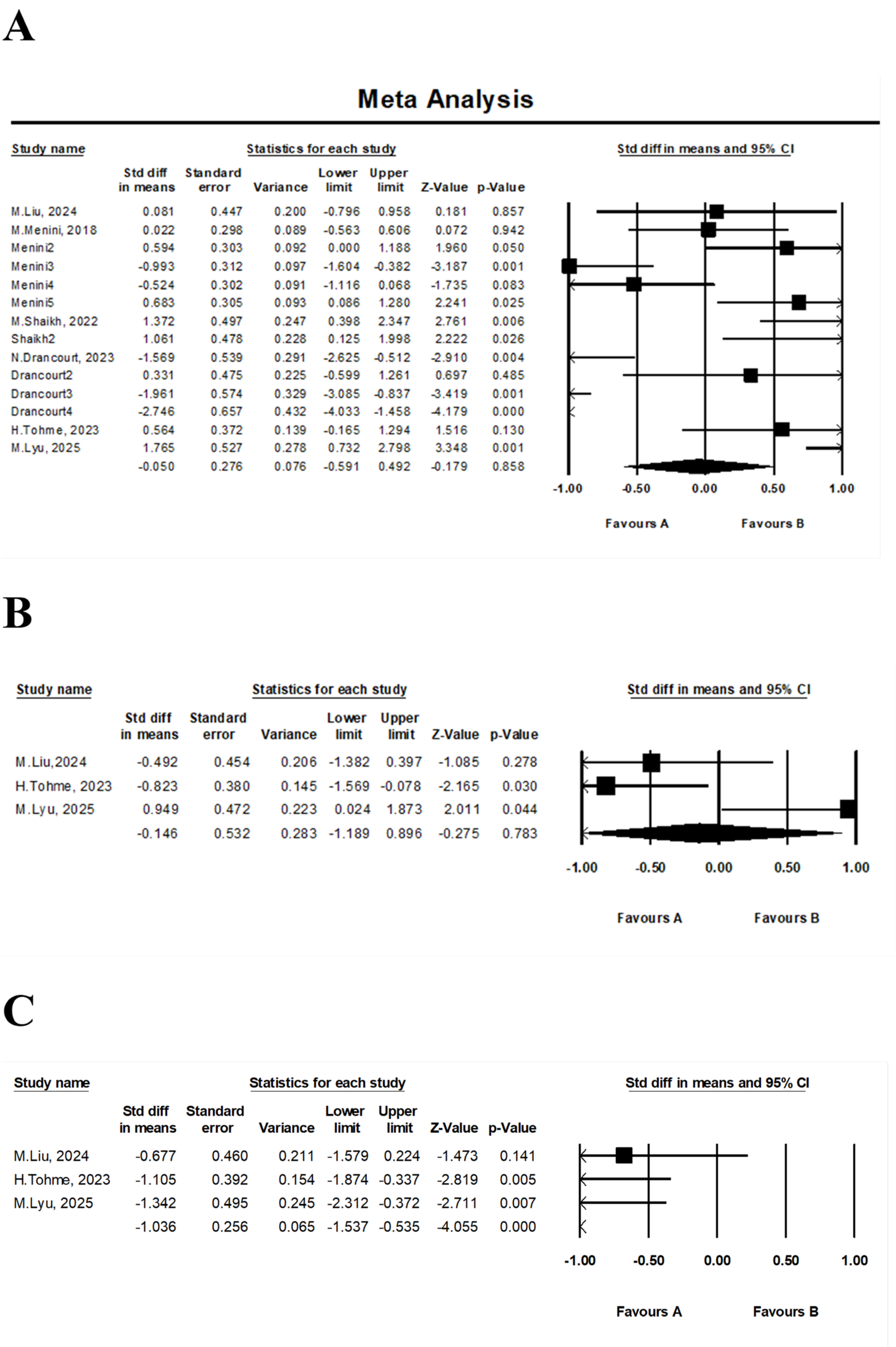

A

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
M.Liu, 2024	0.081	0.447	0.200	-0.796	0.958	0.181	0.857
M.Menini, 2018	0.022	0.298	0.089	-0.563	0.606	0.072	0.942
Menini2	0.594	0.303	0.092	0.000	1.188	1.960	0.050
Menini3	-0.993	0.312	0.097	-1.604	-0.382	-3.187	0.001
Menini4	-0.524	0.302	0.091	-1.116	0.068	-1.735	0.083
Menini5	0.683	0.305	0.093	0.086	1.280	2.241	0.025
M.Shaikh, 2022	1.372	0.497	0.247	0.398	2.347	2.761	0.006
Shaikh2	1.061	0.478	0.228	0.125	1.998	2.222	0.026
N.Drancourt, 2023	-1.569	0.539	0.291	-2.625	-0.512	-2.910	0.004
Drancourt2	0.331	0.475	0.225	-0.599	1.261	0.697	0.485
Drancourt3	-1.961	0.574	0.329	-3.085	-0.837	-3.419	0.001
Drancourt4	-2.746	0.657	0.432	-4.033	-1.458	-4.179	0.000
H.Tohme, 2023	0.564	0.372	0.139	-0.165	1.294	1.516	0.130
M.Lyu, 2025	1.765	0.527	0.278	0.732	2.798	3.348	0.001
	-0.050	0.276	0.076	-0.591	0.492	-0.179	0.858

B

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
M.Liu,2024	-0.492	0.454	0.206	-1.382	0.397	-1.085	0.278
H.Tohme, 2023	-0.823	0.380	0.145	-1.569	-0.078	-2.165	0.030
M.Lyu, 2025	0.949	0.472	0.223	0.024	1.873	2.011	0.044
	-0.146	0.532	0.283	-1.189	0.896	-0.275	0.783

C

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
M.Liu, 2024	-0.677	0.460	0.211	-1.579	0.224	-1.473	0.141
H.Tohme, 2023	-1.105	0.392	0.154	-1.874	-0.337	-2.819	0.005
M.Lyu, 2025	-1.342	0.495	0.245	-2.312	-0.372	-2.711	0.007
	-1.036	0.256	0.065	-1.537	-0.535	-4.055	0.000

Figure 5. A: Forest plot comparing the linear deviation values of Digital (A) and Conventional (B) technique. B: Forest plot comparing the linear deviation values of SPG (A) and Conventional (B) technique. C: Forest plot comparing the linear deviation values of SPG (A) and Digital (B) technique.

Meta Analysis

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
A.G.Presotto, 2017	0.000	0.447	0.200	-0.877	0.877	0.000	1.000
E.Bayramoglu, 2015	0.536	0.455	0.207	-0.356	1.428	1.177	0.239
M.Menini, 2018	-0.361	0.190	0.036	-0.733	0.012	-1.898	0.058
R.R.Saad, 2024	-9.469	2.210	4.883	-13.800	-5.138	-4.285	0.000
Saad2	-3.857	1.070	1.144	-5.953	-1.761	-3.606	0.000
Saad3	-5.538	1.391	1.934	-8.264	-2.813	-3.983	0.000
Saad4	-4.282	1.148	1.317	-6.531	-2.033	-3.732	0.000
A.El.Naggar, 2024	-1.431	0.709	0.502	-2.820	-0.042	-2.019	0.044
R.A.Mahmoud, 2025	0.032	0.426	0.182	-0.803	0.868	0.076	0.939
Mahmoud2	-1.534	0.485	0.235	-2.485	-0.583	-3.162	0.002
	-1.650	0.475	0.226	-2.582	-0.718	-3.470	0.001

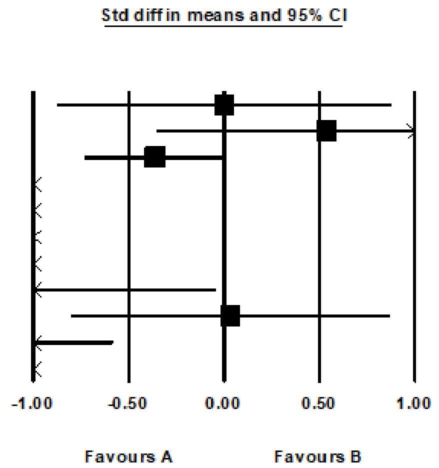

Figure 6. Forest plot comparing the linear deviation values of Digital (A) and Conventional (B) technique.

Discussion

This systematic review and meta-analysis synthesized in-vitro studies comparing conventional, digital, and stereophotogrammetric (SPG) impression techniques in implant-supported restorations. The collected results demonstrate a clear tendency toward improved fit accuracy with digital and SPG workflows compared with conventional impressions, aligning with our hypothesis that digital and SPG techniques may outperform conventional methods despite methodological variability. In the studies analyzed, digital impressions generally yielded reduced linear deviations and superior adaptability compared to conventional techniques. The pooled analysis confirmed a statistically significant improvement in overall fit accuracy favoring digital workflows (SMD = −1.65, p = 0.001). These results are consistent with Saad et al. (2024) and El Naggar et al. (2024), who reported superior marginal adaptation and reduced misfit for digital scanners, particularly with the Primescan system [22,24].

In contrast, Presotto et al. (2017) observed no significant difference, yet their stress distribution data aligned with the trend toward enhanced adaptation using digital workflows [36]. These results indicate that intraoral and digital scanning techniques can enhance the passive fit of implant frameworks in a clinically significant process under controlled conditions. No significant difference emerged between digital and conventional techniques for either linear or angular precision. This aligns with prior meta-analyses that have shown overlapping performance for short-span restorations but greater divergence in full-arch scenarios. Interestingly, SPG systems displayed significantly higher linear and angular precision compared with both digital and conventional impressions. This observation corresponds with the extremely low trueness deviations reported by Tohme et al. (2023) and Kosago et al. (2023) for photogrammetric systems such as PIC [18,31]. These technologies, which use synchronized camera triangulation and fixed reference markers, appear to minimize cumulative stitching errors inherent in intraoral optical scanning. Lyu et al. (2025) and Liu et al. (2024) further confirmed this advantage, reporting lower RMS and angular deviations for SPG compared with IOS systems such as iTero and Trios [29,30]. The trueness data reinforced this trend. While digital and conventional impressions did not differ significantly in either linear or angular trueness, SPG consistently outperformed both, achieving sub-10 μm RMS deviations in several studies.

These findings emphasize the potential of photogrammetry as the most accurate current approach for multi-implant frameworks, though the lack of standardized hardware calibration and operator-dependent setup remains a limiting factor. It is essential to emphasize that the comparisons between SPG and conventional techniques were not statistically significant in all analyses. This is probably because of heterogeneity, small sample sizes, and methodological diversity. Quality assessment using the QUIN tool revealed moderate methodological rigor overall, with risk-of-bias scores ranging from 54.2% to 87.5%. Frequent deficiencies included absence of sample-size justification, unclear randomization, and lack of blinding or assessor calibration. These limitations introduce uncertainty regarding reproducibility and external validity. The similar direction of effect across numerous separate studies

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confirms the robustness of the primary outcome: that digital and SPG techniques often improve in-vitro accuracy compared to conventional impressions. The observed heterogeneity reflects fundamental differences in study designs, scanner generations, implant systems, and evaluation protocols. Variations in scanning strategy, environmental lighting, reference model type, and coordinate-measurement approaches significantly influenced reported deviations. Moreover, none of the included studies incorporated operator learning curves or time-efficiency metrics, which could influence real-world performance. While in-vitro designs eliminate patient-related confounders, they also preclude assessment of soft-tissue dynamics, saliva interference, and intraoral access limitations, all of which can affect scanning accuracy in clinical settings. Therefore, the clinical translation of these laboratory-based advantages remains uncertain.

From a practical standpoint, digital workflows appear to offer reproducible accuracy comparable to or exceeding that of conventional impressions, with clear efficiency and patient comfort advantages. SPG systems, while demonstrating superior precision and trueness in vitro, currently require specialized equipment and calibration, limiting widespread adoption. Nevertheless, as photogrammetric hardware becomes more accessible and integrated into digital workflows, these systems may redefine the standard for full-arch implant impressions. Future investigations should prioritize standardization of experimental conditions, scanner calibration, and measurement methodologies to reduce interstudy variability. Cross-platform comparisons between SPG and intraoral scanner systems using identical reference frameworks are essential. Additionally, robust clinical trials are required to ascertain whether the higher in-vitro accuracy of SPG and digital techniques results in improved prosthetic fit, reduced screw loosening, and superior long-term outcomes.

Studies integrating accuracy with cost-effectiveness, operator experience, and patient satisfaction will help clarify the true clinical benefit of these evolving technologies. In summary, this review suggests that digital impression techniques generally provide better fit accuracy than conventional methods for implant-supported restorations. SPG systems, in particular, consistently show the highest accuracy when precision and trueness are considered, outperforming both digital and traditional workflows. Although these findings should be interpreted with some caution due to differences in study designs and other methodological limitations, the overall picture is encouraging. Digital and photogrammetric approaches appear to be steadily improving, and they are likely to play an increasingly important role in shaping the future of implant prosthodontics

Conclusion

Within the limits of current in-vitro evidence, this systematic review and meta-analysis suggests that digital impression techniques generally provide better fit accuracy than conventional methods for implant-supported restorations. Although digital and traditional workflows performed similarly when accuracy was divided into trueness and precision, stereophotogrammetric (SPG) systems consistently achieved the highest accuracy across both linear and angular measurements. However, these encouraging results should be interpreted with care, as the evidence remains limited by methodological variability, moderate risk of bias, and the lack of clinical validation. To determine whether the strong laboratory performance of digital and SPG techniques truly translates into meaningful clinical benefits, such as improved prosthetic fit, enhanced long-term stability, and fewer mechanical complications, well-designed clinical trials are still needed.

Conflict of Interest

There is no conflict of interest to declare.

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