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Digital Diagnostic versus Conventional Casts

Accuracy, Efficiency, and Clinical Outcomes

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Abstract

Dental diagnostic casts are fundamental instruments in prosthodontics, orthodontics, and restorative dentistry, serving as three-dimensional replicas of the oral hard and soft tissues upon which clinical and laboratory procedures are planned and executed. Conventional plaster casts, obtained through alginate or polyvinylsiloxane impressions, have constituted the gold standard for decades; however, they are susceptible to material-induced distortions, dimensional instability, and logistical challenges related to storage and transfer. The advent of intraoral scanners (IOS) and computer-aided design/computer-aided manufacturing (CAD/CAM) technologies has enabled the production of digital diagnostic casts that may circumvent many of these limitations. This systematic review aimed to critically evaluate and compare the accuracy, time efficiency, and clinical outcomes of digital diagnostic casts versus conventional casts across prosthodontic, orthodontic, and implant-supported restorative applications, following the PRISMA 2020 guidelines. A systematic electronic search was conducted across PubMed/MEDLINE, Cochrane Library, Scopus, and Google Scholar databases, restricted to publications from 2013 to 2026. Studies were included if they employed a direct comparison between digital and conventional cast-fabrication methods, with dimensional accuracy, time efficiency, or clinical outcomes as primary or secondary endpoints. Both in vitro and in vivo study designs were considered. Risk of bias was assessed using the Risk of Bias tool 2 (ROB 2) for randomized controlled trials and the Newcastle-Ottawa Scale (NOS) for non-randomized studies. A total of 22 studies met the final inclusion criteria. Digital casts generated by stereolithographic (SLA) intraoral scanning demonstrated mean trueness values ranging from 67.5 to 98.23 micrometers (95% CI: 63.43-102.3 µm), compared with conventional stone casts that exhibited dimensional deviations up to 0.61 ± 0.13 mm. Digital impression workflows produced statistically significantly lower mean deviations (0.41 ± 0.09 mm versus 0.61 ± 0.13 mm; $p < 0.0001$). Patient-reported comfort favored digital impressions (VAS: 8.43 ± 0.8 versus 6.39 ± 0.71; $p < 0.00001$). Procedural time was shorter for digital workflows in implant prosthodontics (11.95 ± 1.75 min versus 20.47 ± 3.25 min; $p < 0.00001$), although time advantages were context-dependent. In orthodontic applications, digital and conventional models demonstrated clinically comparable measurements with no statistically significant differences for most diagnostic parameters. Extended-pour alginate and alginate-alternative opposing casts achieved superior occlusal accuracy compared to conventional alginate and three-dimensional (3D)-printed casts. Digital diagnostic casts demonstrate accuracy that is equivalent or superior to conventional casts for most clinical applications, with measurable advantages in patient comfort and procedural efficiency. Nevertheless, clinical context, arch span, and the specific digital technology employed remain critical determinants of diagnostic cast performance. Higher-quality, multi-center randomized trials are needed to definitively establish evidence-based clinical guidelines.

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Introduction

Dental diagnostic casts are three-dimensional physical reproductions of the patient's dentition and surrounding oral tissues. They constitute one of the most universally employed clinical records in dentistry, providing essential information for diagnosis, treatment planning, appliance fabrication, and the assessment of treatment outcomes across all major dental disciplines, including prosthodontics, orthodontics, periodontics, and oral surgery [1,2]. In prosthodontics, diagnostic casts mounted on articulators replicate mandibular movements and occlusal relationships, thereby enabling the clinician and dental laboratory technician to assess occlusal contacts, plan tooth preparations, fabricate provisional restorations, and verify the fit and occlusion of definitive restorations prior to cementation [3]. Their dimensional accuracy is therefore directly linked to the quality and longevity of the finished restorations.

Conventional diagnostic casts are fabricated through an impression-based indirect technique involving the application of an impression material such as alginate, polyvinylsiloxane (PVS), or polyether within a stock or custom tray, which is subsequently poured with dental stone (typically Type III or Type IV gypsum). This process, while well established, carries inherent sources of dimensional error at every stage: impression material distortion due to syneresis or imbibition, variable stone expansion during setting, inaccuracies introduced during tray handling, and dimensional changes during storage [4,5]. Alginate impressions are particularly vulnerable to these phenomena; despite the introduction of improved extended-pour and alginate-alternative formulations offering greater dimensional stability, the conventional impression workflow remains inherently technique-sensitive [4]. For opposing cast applications in fixed prosthodontic restorations, the occlusal accuracy of the antagonist cast is of paramount clinical importance, as inaccuracies in this cast may translate directly into occlusal interferences that require correction at the time of prosthesis delivery [6,7].

The past two decades have witnessed a fundamental transformation in dental recording technology through the introduction of intraoral scanners (IOS) and digital impression systems. Pioneered by the CEREC system in the late 1980s and subsequently refined across numerous commercial platforms, IOS technologies now encompass a wide range of devices utilizing structured light, confocal microscopy, active wavefront sampling, and video-based imaging to capture three-dimensional digital representations of the intraoral environment [8,9]. Digital diagnostic casts derived from these scans may be presented in virtual form for analysis using dedicated software or may be physically reproduced through subtractive milling or additive manufacturing techniques including stereolithography (SLA), digital light processing (DLP), fused deposition modeling (FDM), and PolyJet printing [7,10,11]. The digital workflow eliminates impression material-related distortions, streamlines laboratory communication, and enables virtual storage and transmission of diagnostic records [12,13]. Despite the rapid adoption of digital cast workflows in contemporary dental practice, the evidence base comparing their dimensional accuracy, time efficiency, and clinical outcomes to those of conventional casts remains heterogeneous in design, methodology, and outcome measurement. Previous systematic reviews have examined specific applications such as full-arch impressions for implant-supported restorations or digital models in orthodontics, but a comprehensive synthesis addressing diagnostic casts across multiple clinical disciplines has been lacking. This systematic review therefore aims to evaluate, using PRISMA 2020 guidelines, whether digital diagnostic casts are more accurate, efficient, and clinically equivalent or superior to conventional casts across prosthodontic, orthodontic, and restorative dental applications, based on literature published between 2013 and 2026.

Material and Methods

Protocol Compliance

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The review protocol was pre-registered with PROSPERO (International Prospective Register of Systematic Reviews) prior to the initiation of the literature search. No conflicts of interest were declared by the reviewing authors.

PICO Question

The following focused clinical question guided the review, formulated in PICO format:

"In patients requiring dental diagnostic casts for prosthodontic, orthodontic, or restorative dental treatment (Population), are digital diagnostic casts produced by intraoral scanning and associated manufacturing methods (Intervention) more accurate, time-efficient, and clinically effective than conventional casts produced through impression-based methods (Comparator), as measured in units of dimensional deviation (micrometers or millimeters), procedural time (minutes), and clinical outcome scores (Outcome)?"

Search Strategy

Electronic searches were conducted in PubMed/MEDLINE, Cochrane Library, Scopus, and Google Scholar in January 2026. The search was restricted to publications from January 2013 to January 2026, to capture the period of widespread intraoral scanner adoption and to ensure clinical relevance. No language restrictions were imposed. The following Boolean search string was applied to PubMed/MEDLINE:

("digital cast" OR "digital model" OR "digital diagnostic cast" OR "intraoral scanner" OR "digital impression" OR "CAD/CAM cast") AND ("conventional cast" OR "plaster cast" OR "stone cast" OR "alginate impression" OR "polyvinylsiloxane") AND ("accuracy" OR "trueness" OR "precision" OR "dimensional accuracy" OR "time efficiency" OR "clinical outcome" OR "occlusal accuracy").

Reference lists of all included studies and relevant systematic reviews were hand-searched to identify additional eligible publications not captured by the database searches.

Selection Criteria

Inclusion Criteria	Exclusion Criteria
Clinical, in vitro, and in vivo studies	Case reports, letters, editorials, and expert opinions
Studies comparing digital and conventional cast methods	Studies without a direct digital-versus-conventional comparison
Dental patients requiring prosthodontic, orthodontic, or restorative treatment	Studies evaluating impression materials only, without cast fabrication
Intraoral scanner, desktop scanner, or CAD/CAM-derived casts as the digital intervention	First-generation or prototype intraoral scanning devices no longer commercially available
Primary outcomes: dimensional accuracy (trueness and/or precision), time efficiency, or clinical outcome measures	Studies reporting outcomes exclusively with 2D measurement techniques
Publications between January 2013 and January 2026	Animal studies or studies on non-human models without clinical validation
All languages (with available translation)	Conference abstracts without full-text availability

Table 1. Inclusion and exclusion criteria for study selection.

Study Selection Process

Two independent reviewers (Reviewer A and Reviewer B) conducted the study selection process. Prior to formal screening, both reviewers completed a calibration exercise using a set of ten pilot articles not included in the database

search, achieving inter-rater agreement of kappa > 0.80. Titles and abstracts of all retrieved records were independently screened against the inclusion and exclusion criteria. Articles that were clearly irrelevant were excluded at this stage. Full-text articles were retrieved for all records identified as potentially eligible by either reviewer. Full-text review was performed independently, and discrepancies were resolved through consensus discussion. Where agreement could not be reached, a third reviewer arbitrated the final inclusion decision. The systematic review management software Rayyan (Qatar Computing Research Institute, Doha, Qatar) was used to manage records throughout the screening process.

Data Extraction

Data were extracted from each included study using a standardized extraction template, capturing: (1) study design and setting; (2) sample size and population characteristics; (3) digital and conventional methods employed, including specific IOS or scanning system, impression material, and stone type; (4) primary outcome data including means, standard deviations (SD), 95% confidence intervals (CI), and p-values where reported; (5) time efficiency data; (6) patient-reported outcome measures; and (7) funding sources and conflicts of interest. All quantitative dimensional data were standardized to micrometers (µm) or millimeters (mm) for comparison. Where multiple measurement timepoints were reported, data from the primary or final timepoint were extracted.

Risk of Bias Assessment

Risk of bias was assessed using validated tools appropriate to each study design. Randomized controlled trials were evaluated using the Cochrane Risk of Bias tool 2 (ROB 2), which assesses bias arising from the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results. Non-randomized clinical studies were assessed using the Newcastle-Ottawa Scale (NOS), rating studies across selection, comparability, and outcome domains. In vitro studies were assessed using a modified quality assessment tool adapted from previously published in vitro methodology scales, evaluating reference standard validity, measurement reproducibility, sample size adequacy, and statistical analysis appropriateness. Summary risk of bias judgments (low, some concern, high) were tabulated for each included study.

Data Synthesis

Due to the heterogeneity of study designs, outcome measurement instruments, scanning technologies, and clinical contexts identified across the included studies, a formal meta-analysis was not deemed appropriate. A narrative synthesis was therefore conducted, with studies grouped by primary clinical application (implant prosthodontics, fixed prosthodontics, orthodontics, and removable partial dentures). Quantitative outcomes were tabulated and described comparatively, with attention to within-study statistical significance, confidence interval overlap, and clinically relevant difference thresholds (commonly referenced as 100-200 µm for single-unit restorations and 200-500 µm for full-arch applications).

Results

Study Selection

The initial database search retrieved 1,847 unique records after deduplication. Following title and abstract screening, 187 records were selected for full-text review. Of these, 165 were excluded for the following reasons: no direct comparison between digital and conventional methods (n = 54), outcome measures not meeting inclusion criteria (n = 38), study design not meeting inclusion criteria (n = 29), conference abstracts without full-text data (n = 21), animal or non-human model studies without clinical relevance (n = 14), and duplicate publication (n = 9). A total of 22 studies met all inclusion criteria and were included in the final qualitative synthesis. The study selection process is summarized in Figure 1 (PRISMA 2020 Flow Diagram).

Study Characteristics

The 22 included studies comprised 9 in vitro studies, 8 clinical (in vivo) studies, and 5 systematic reviews or narrative reviews with primary data. Studies were published between 2013 and 2026, with geographic origin spanning Europe, the Middle East, North America, Asia, and South America. Sample sizes ranged from 5 to 100 subjects or experimental units. The included studies employed diverse IOS platforms including Medit i700, iTero Element, CEREC AC Bluecam, Lava Chairside Oral Scanner C.O.S., Trios 3Shape, and various benchtop or laboratory desktop scanners. Conventional comparators included conventional alginate, extended-pour alginate, alginate-alternative materials, PVS, and polyether impressions poured with Type III or Type IV dental stone. Physical digital casts were fabricated using SLA, DLP, milling (subtractive), or PolyJet printing technologies.

Risk of Bias Assessment

Risk of bias assessment revealed moderate methodological quality across the included studies. Among the 9 in vitro studies, 5 were judged to be at low risk of bias, demonstrating adequate reference standard validity, standardized measurement protocols, sufficient sample sizes, and appropriate statistical analyses. Four in vitro studies were assessed as having some concerns, primarily related to single-operator scanning without inter-examiner reliability data and limited sample sizes (n < 10 per group). Among the 8 clinical in vivo studies, 3 were assessed at low risk of bias, 4 at some concern (primarily due to absence of blinding of outcome assessors and selective reporting of outcome measures), and 1 at high risk of bias due to convenience sampling and inadequate control for confounding variables. The systematic reviews were evaluated for methodological quality using AMSTAR-2 criteria, with 3 rated as moderate and 2 as low quality due to absence of formal risk of bias assessment or protocol registration.

Accuracy: Dimensional Trueness and Precision

In Vitro Studies

Patzelt et al. (2014) [13] provided among the most rigorous in vitro evaluations of digital cast accuracy, employing a laboratory reference scanner with manufacturer-specified accuracy of 20 µm as the gold standard against which CAD/CAM-generated casts from three commercially available IOS platforms were compared. The mean trueness values of Lava Chairside Oral Scanner C.O.S., CEREC AC with Bluecam, and iTero casts were 67.50 µm (95% CI: 63.43-71.56 µm), 75.80 µm (95% CI: 71.74-79.87 µm), and 98.23 µm (95% CI: 94.17-102.30 µm), respectively. Statistically significant differences were observed among all scanner groups ($p < 0.05$). The mean precision values were 13.77 µm, 21.62 µm, and 48.83 µm respectively, with statistically significant differences between CEREC Bluecam and iTero, and between Lava COS and iTero casts ($p < 0.05$). These findings demonstrated that SLA-based casts were more accurate than milled casts, and that the highest deviations occurred in the distal regions of the arch.

Al-Makramani et al. (2023) [20] conducted a comprehensive in vitro evaluation comparing the dimensional and occlusal accuracy of non-working/opposing casts produced from conventional alginate (Gp AL[C]), extended-pour alginate (Gp AL[E]), an alginate alternative (Gp AL[F]), and three-dimensionally printed casts (Gp 3D-C), against typodont master models mounted on a semi-adjustable articulator. Dimensional analysis at anterior vertical (AV), posterior vertical (PV), and anteroposterior (AP) reference points revealed that dimensions in most groups were significantly different from those of the mounted master models at $p \leq 0.05$, except in Gp AL(E) and Gp AL(F) at selected measurement sites. Multiple pairwise comparisons using Tukey's HSD post hoc test revealed significant differences between conventional alginate and extended-pour alginate at AV and PV dimensions, as well as between conventional alginate and 3D-printed casts. Occlusal accuracy analysis performed using Medit Link software demonstrated that the opposing casts from Gp AL(C) showed the highest

number of ideal (green zone) occlusal contacts, followed by Gp AL(E), Gp AL(F), and Gp 3D-C. Notably, 3D-printed opposing casts showed 4 contacts in the red zone at tooth #3, reflecting the poorest occlusal accuracy among all groups.

Aly and Mohsen (2020) [7] conducted an in vitro comparison of 3D-printed casts, digital casts, and conventional PVS-derived stone casts, reporting comparable dimensional accuracy among all three methods for most parameters, with no statistically significant differences exceeding clinically relevant thresholds. Similarly, Husein et al. (2022) [21] confirmed that both digital and conventional full-arch impression methods produced clinically acceptable accuracy in an in vitro model, with the digital method demonstrating advantages in posterior arch segments where material distortion from alginate impressions was more pronounced.

Clinical (In Vivo) Studies

A prospective randomized clinical study [27] comparing digital impressions using the Trios 3Shape IOS against conventional polyether impressions in 100 implant patients demonstrated a statistically significant superiority of digital impressions in terms of mean linear deviation from the reference scan (0.41 ± 0.09 mm versus 0.61 ± 0.13 mm; $p < 0.0001$). This clinical finding corroborates the laboratory evidence and provides direct in vivo evidence that digital impression-derived models achieve greater accuracy than conventional materials in implant prosthodontic applications.

Jaber et al. (2024) [23] evaluated dimensional accuracy and reliability of digital models formulated through direct intra-oral IOS against models derived from extra-oral scanning of poured dental models, finding no statistically significant differences in dimensional accuracy between the two digital strategies, supporting the validity of both pathways to digital cast generation.

Sfondrini et al. (2018) [17] assessed computerized casts produced using powder-free intraoral scanners for orthodontic purposes, reporting comparable accuracy to conventional methods alongside significantly reduced procedural time and superior patient feedback for the digital approach. Schieffer et al. (2022) [6] confirmed that digital cast measurements in mixed dentition were interchangeable with stone cast measurements for most diagnostic parameters commonly used in orthodontic assessment.

Time Efficiency

Time efficiency findings across included studies were context-dependent and influenced by operator experience, arch complexity, and the specific digital workflow employed. In the large clinical comparative study [27], the digital group demonstrated a mean procedural time of 11.95 ± 1.75 minutes from instrument preparation for impression acceptance, compared with 20.47 ± 3.25 minutes for the conventional group, a difference that was statistically highly significant ($p < 0.00001$). This time advantage represents a reduction of approximately 42% in chair time, with direct implications for clinical workflow efficiency and throughput.

However, Souza et al. (2025) [25] reported that in the context of digital surveying for removable partial denture (RPD) planning, the digital method (5.26 ± 0.95 min) required significantly more time than conventional mechanical surveying (4.61 ± 1.6 min; $p = 0.03$). This contrasting finding illustrates that time efficiency gains with digital workflows are not universal across all dental procedures; in established conventional procedures where operator expertise is high, digital alternatives may initially require longer procedural times, particularly during the learning curve phase.

Kaline et al. (2024) [3] reported variable time outcomes in the context of denture foundation outlining on preliminary casts, with time advantages for digital methods observed primarily among experienced operators. Sfondrini et al. (2018) [17] noted a meaningful reduction in execution time with powder-free IOS in orthodontic cast recording, consistent with the broader literature indicating time savings in impression-taking workflows for non-removable restorations.

Patient Comfort and Clinical Outcomes

Patient comfort emerged as a consistent and highly significant differentiator between digital and conventional approaches in clinical studies. In a previous study [27], mean patient comfort scores on a 10-point Visual Analog Scale were 8.43 ± 0.8 for the digital group versus 6.39 ± 0.71 for the conventional group ($p < 0.00001$). The proportion of patients achieving comfort scores above 7 was 94% (47/50) in the digital group versus 24% (12/50) in the conventional group, yielding an odds ratio of 173.7 for experiencing high comfort with digital impressions. These findings reflect the well-documented patient-reported benefits of eliminating impression material in the oral environment, including reduced gag reflex stimulation, shorter working time, and elimination of unpleasant material taste and texture.

Keil et al. (2025) [8] demonstrated applicability of IOS in a particularly challenging clinical context, showing that intraoral scanning of neonatal infants with cleft lip and palate was feasible, equivalent in accuracy to conventional alginate impressions, and importantly, safer and better tolerated in this vulnerable population where conventional impression methods carry aspiration risks.

Sfondrini et al. (2018) [17] similarly documented significantly better patient feedback for powder-free IOS in orthodontic cast recording, with patients reporting less discomfort and anxiety compared with conventional alginate impressions. These findings collectively suggest that digital impression-based workflows offer meaningful patient-centered advantages beyond the technical parameters of dimensional accuracy.

Orthodontic Applications

Five included studies specifically evaluated digital diagnostic casts in the context of orthodontic diagnosis and treatment planning. The systematic review by Rabe et al. (2021) [18], which included five primary studies evaluating digital versus plaster models for orthodontic parameters, concluded that while statistically significant differences were measurable for certain parameters, these differences did not reach clinical significance. Digital models and plaster models were considered clinically interchangeable for most routine orthodontic measurements, including inter-canine width, inter-molar width, arch perimeter, crowding index, and overjet/overbite. One exception was the mandibular space requirement, for which one included study reported a significant difference ($p = 0.012$) between digital and plaster models that was nevertheless considered clinically negligible.

Lang et al. (2025) [24] validated a digital, partly automated three-dimensional cast analysis system against manual orthodontic measurements, reporting high concordance between digital and conventional measurement approaches and endorsing the system as a valid tool for orthodontic treatment assessment. Rafiei et al. (2022) [22] similarly reported high agreement between digital cast measurements using Maestro 3D Ortho Studio software and corresponding measurements on dental plaster casts, concluding that the two methods were interchangeable for clinical orthodontic applications.

Removable Partial Denture Applications

Two included studies specifically addressed digital workflows for RPD frameworks. Souza et al. (2025) [25] compared digital and conventional surveying for partially edentulous arches, reporting high accuracy for the digital method (excellent levels of sensitivity and specificity for guiding plane identification, undercut area assessment, and reciprocation evaluation), though with a slightly longer procedural time for the digital approach. Yoon et al. (2025) [26] compared RPD frameworks fabricated from IOS data combined with additive manufacturing against frameworks produced through conventional impressions and lost-wax casting. All frameworks from both groups met qualitative evaluation criteria.

Quantitatively, IOS-derived frameworks demonstrated significantly greater accuracy at terminal abutments of distal-extension RPDs, a clinically relevant finding given the functional demands placed on distal-extension framework fit.

Discussion

This systematic review synthesized evidence from 22 studies published between 2013 and 2026, encompassing in vitro, clinical, and systematic review study designs, to evaluate the comparative accuracy, time efficiency, and clinical outcomes of digital diagnostic casts versus conventional cast fabrication methods. The principal findings indicate that: (1) digital casts demonstrate dimensional accuracy that is equivalent or superior to conventional casts across most clinical applications; (2) time efficiency advantages for digital workflows are context-dependent and most pronounced in implant prosthodontics; and (3) patient comfort is consistently and substantially superior with digital impression-based workflows.

Accuracy: Comparative Analysis by Study Design

In Vitro Studies

In vitro studies provided the most rigorously controlled evidence for dimensional accuracy comparisons. The foundational work of Patzelt et al. (2014) [13] established that SLA-based CAD/CAM casts generated from IOS data achieved clinically acceptable trueness values across all three evaluated scanner platforms, with the lowest deviation associated with the Lava COS system (67.5 µm) and the highest with iTero (98.23 µm). These values represent dimensional errors far below the 200 µm clinical acceptability threshold commonly referenced for single-unit prosthodontic restorations, and below the 500 µm thresholds frequently cited for full-arch applications [5]. The precision data were even more favorable, with SLA-based platforms achieving mean precision values as low as 13.77 µm, suggesting excellent reproducibility of the digital fabrication process.

The superiority of SLA over milled (subtractive) digital casts observed by Patzelt et al. (2014) [13] merits mechanistic explanation. Milling processes introduce tool deflection errors, thermal expansion artifacts, and residual elastic recovery effects from the machined material, as well as geometric limitations when reproducing fine anatomical detail smaller than the diameter of the milling bur. SLA, by contrast, polymerizes thin consecutive layers of photopolymer resin, allowing high-resolution surface capture. However, SLA itself is not without limitation: the vertical layering process creates a staircase effect on inclined surfaces, polymerization shrinkage (up to 3% for photopolymer resin, compared with 0.00-0.01% for dental stone) accumulates across the full height of the cast, and uneven shrinkage patterns are particularly pronounced in posterior arch regions due to the mass of polymerizing resin in these areas [4].

Al-Makramani et al. (2023) [20] specifically addressed the occlusal accuracy of 3D-printed opposing casts in a fixed prosthodontic context, revealing that the poorest occlusal accuracy was observed with 3D-printed casts, despite these representing the most technologically advanced fabrication method evaluated. Three studies in the included literature presented patterns of deviation in posterior teeth when 3D-printed casts were used as opposing elements, attributable to the staircase effect of vertical photopolymer layering in deep pits and fissures, uneven shrinkage in posterior regions, and accumulated scanning errors in whole-arch digital capture. This finding challenges the assumption that digital fabrication methods inherently provide superior accuracy to all conventional alternatives and highlights the importance of application-specific evaluation.

Clinical Studies

Clinical studies introduced the complexity of the intraoral environment, including patient movement, saliva contamination, limited access in posterior regions, and variable tissue characteristics, all of which can affect IOS accuracy in ways not captured by in vitro laboratory models. Nevertheless, the weight of clinical evidence included in this review supports the clinical acceptability of digital impressions and casts. The large randomized clinical study [27] demonstrated significantly lower mean deviations for digital impressions compared with conventional polyether impressions in an implant prosthodontic context (0.41 mm versus 0.61 mm; $p < 0.0001$), while Jaber et al. (2024) [23] found no significant difference between direct IOS digital models and extra-oral scans of poured models, confirming the reliability of both digital pathways.

Importantly, the accuracy advantage of digital methods was most consistently demonstrated in implant-supported restorative applications, where the rigid, non-compressible nature of implant abutments provides a favorable scanning environment and eliminates the impression material distortions associated with soft tissue compression. In applications involving natural teeth with complex undercuts and adjacent soft tissue, the evidence for digital superiority is less uniform, reflecting the greater challenges of IOS in these environments.

Mechanistic Factors in Digital Cast Accuracy

Several mechanistic factors underpin the accuracy characteristics of digital diagnostic casts. First, data acquisition by IOS represents the critical initial step in the digital workflow; inaccuracies at this stage propagate through subsequent processing steps, creating compounding error. IOS technologies differ substantially in their capture mechanism, image stitching algorithms, and sensitivity to surface reflectivity, salivary contamination, and patient movement. Video-based systems may demonstrate different error profiles compared with point-and-click systems, and powder requirements (now largely eliminated in contemporary IOS) historically affected surface reflectance characteristics and dimensional accuracy.

Second, the data processing step, including triangular tessellation of the point cloud, surface reconstruction algorithms, and conversion to manufacturing formats (STL files), introduces approximation errors whose magnitude depends on the point density of the original scan. Third, the manufacturing process itself introduces material-specific distortions, as detailed above for both SLA and milling technologies. The accumulation of errors across all three stages means that the final physical digital cast represents a composite of multiple error sources, some of which can be minimized through calibration and quality control but cannot be eliminated.

Conventional casts, while subject to entirely different error mechanisms (material syneresis/imbibition, handling distortions, stone expansion variability), have the advantage of a single-step replication process that is well understood and for which clinical tolerances have been empirically established over many decades of clinical use. The broadly comparable accuracy outcomes observed across this systematic review suggest that the error mechanisms of digital workflows, though different in character, result in similar net dimensional deviations within clinically acceptable ranges for most applications.

Time Efficiency: Clinical Context Matters

The time efficiency analysis revealed a nuanced picture that defies simple generalization. The most compelling evidence for digital time advantage came from the implant prosthodontic context, where the elimination of impression material preparation, tray selection, working time, set time, and immediate disinfection yielded a time reduction of approximately 8.5 minutes per procedure (42% reduction) in a large randomized clinical study. At scale across a busy clinical practice, such time savings have meaningful implications for patient throughput, clinical staff workload, and operational efficiency.

However, the paradoxical finding of longer procedural time for digital surveying (Souza et al., 2025) [25] compared with conventional mechanical surveying serves as an important

counterpoint. In established procedures where the conventional method is highly optimized and experienced clinicians have efficient routines; digital alternatives may carry significant time costs during the learning curve phase and may not ultimately achieve time parity even with operator experience. This suggests that time efficiency benefits of digital cast workflows are not uniformly distributed across dental procedures and should be evaluated in the specific context of implementation rather than assumed as a general advantage.

Clinical Recommendations

Based on the synthesized evidence, several context-specific clinical recommendations can be drawn. For implant-supported prosthodontic restorations, particularly single-unit and short-span fixed prostheses, digital impressions and digitally fabricated casts offer advantages in accuracy, patient comfort, and procedural efficiency that support their preferential use in clinical practice. For full-arch implant rehabilitations, the evidence is more nuanced, and certain scanner-material combinations may not achieve the accuracy required for passive-fitting frameworks without additional verification steps.

For orthodontic diagnosis and treatment planning, digital and conventional casts are clinically interchangeable for most standard diagnostic measurements. The storage advantages, ease of transmission, and elimination of model degradation over time strongly favor digital models for orthodontic records, if access to appropriate digital measurement software is available.

For fixed prosthodontic opposing casts, the evidence of Al-Makramani et al. (2023) [20] suggests that extended-pour alginate and alginate-alternative impression materials produce superior occlusal accuracy compared with conventional alginate, and that 3D-printed opposing casts while technologically appealing—may introduce occlusal inaccuracies that adversely affect restoration delivery. Clinicians fabricating digitally designed fixed prostheses should therefore exercise caution in the selection of opposing cast fabrication method, as occlusal accuracy at this stage is directly linked to the fit and function of the definitive restoration.

Limitations of Included Studies and of This Review

Several limitations of the included primary studies warrant acknowledgment. First, the rapid pace of IOS technology development means that accuracy data from studies employing older scanner generations may not accurately represent the capabilities of current devices. Second, substantial heterogeneity in study designs, outcome measurement tools, reference standards, and reporting conventions precluded formal meta-analysis and limited the precision of pooled comparative estimates. Third, the preponderance of in vitro studies, which by design exclude the clinical variables of patient behavior, operator variability in real clinical settings, and tissue characteristics, limits the external validity of the accuracy data.

Limitations specific to this systematic review include the restriction to a specific publication date range, which may have excluded relevant earlier foundational studies; the potential for publication bias favoring studies with positive results for digital workflows; and the absence of formal language restrictions, which may have introduced selection bias in the absence of translated sources. The quality of the evidence base, as assessed through risk of bias tools, was moderate overall, with few high-quality randomized controlled trials. The reliance on narrative synthesis rather than statistical pooling reduces the precision of conclusions, although this approach was appropriate given the identified heterogeneity.

Future Research Directions

Significant gaps in the evidence base were identified that represent priorities for future research. Multi-center randomized controlled trials comparing specific commercially available IOS platforms against conventional methods for defined clinical applications, using standardized outcome measures and reporting according to CONSORT guidelines, are urgently needed to provide the level of evidence required for definitive clinical guideline development. Long-term prospective studies evaluating the clinical longevity and patient-reported outcomes of restorations fabricated from digital versus conventional diagnostic casts would address the currently absent evidence base on long-term clinical performance. Studies incorporating formal assessment of the learning curve associated with digital workflows, and the minimum number of cases required to achieve equivalent procedural times to established conventional methods, would provide practically useful guidance for clinicians considering workflow transitions. Finally, economic analyses incorporating equipment acquisition costs, consumable costs, staff training, and efficiency gains are needed to provide a complete evidence-based framework for clinical decision-making.

Conclusion

Digital diagnostic casts, produced through intraoral scanning and associated digital fabrication methods, demonstrate dimensional accuracy that is equivalent or superior to conventional impression-derived casts across most evaluated clinical applications. The evidence is strongest in implant prosthodontics, where digital impression workflows achieved statistically and clinically significantly lower dimensional deviations (0.41 mm versus 0.61 mm), reduced procedural time (11.95 versus 20.47 minutes), and substantially improved patient comfort (VAS 8.43 versus 6.39) compared with conventional polyether impressions. SLA-based digital casts demonstrated mean trueness values of 67.5 to 98.2 µm, consistently within clinically acceptable thresholds.

In orthodontic applications, digital and conventional models are clinically interchangeable for standard diagnostic measurements, with additional practical advantages for digital records in terms of storage, transmission, and longevity. For fixed prosthodontic opposing casts, extended-pour alginate and alginate-alternative materials demonstrated superior occlusal accuracy compared with both conventional alginate and 3D-printed opposing casts, a finding with direct implications for restorative workflow design.

Time efficiency advantages favor digital workflows in impression-based procedures, particularly in implant prosthodontics, but this advantage is context-dependent and may not apply to procedures such as digital surveying where conventional methods are highly efficient. Patient comfort consistently and substantially favors digital approaches across clinical contexts and patient populations.

The overall quality of the evidence base is moderate, and the rapid pace of technological development introduces limitations to the direct applicability of findings from earlier studies. High-quality multi-center randomized controlled trials with standardized outcome measurement, long-term clinical follow-up, and formal economic analyses are needed to provide the evidence base required for definitive evidence-based clinical guidelines governing the adoption and implementation of digital diagnostic cast workflows in contemporary dental practice.

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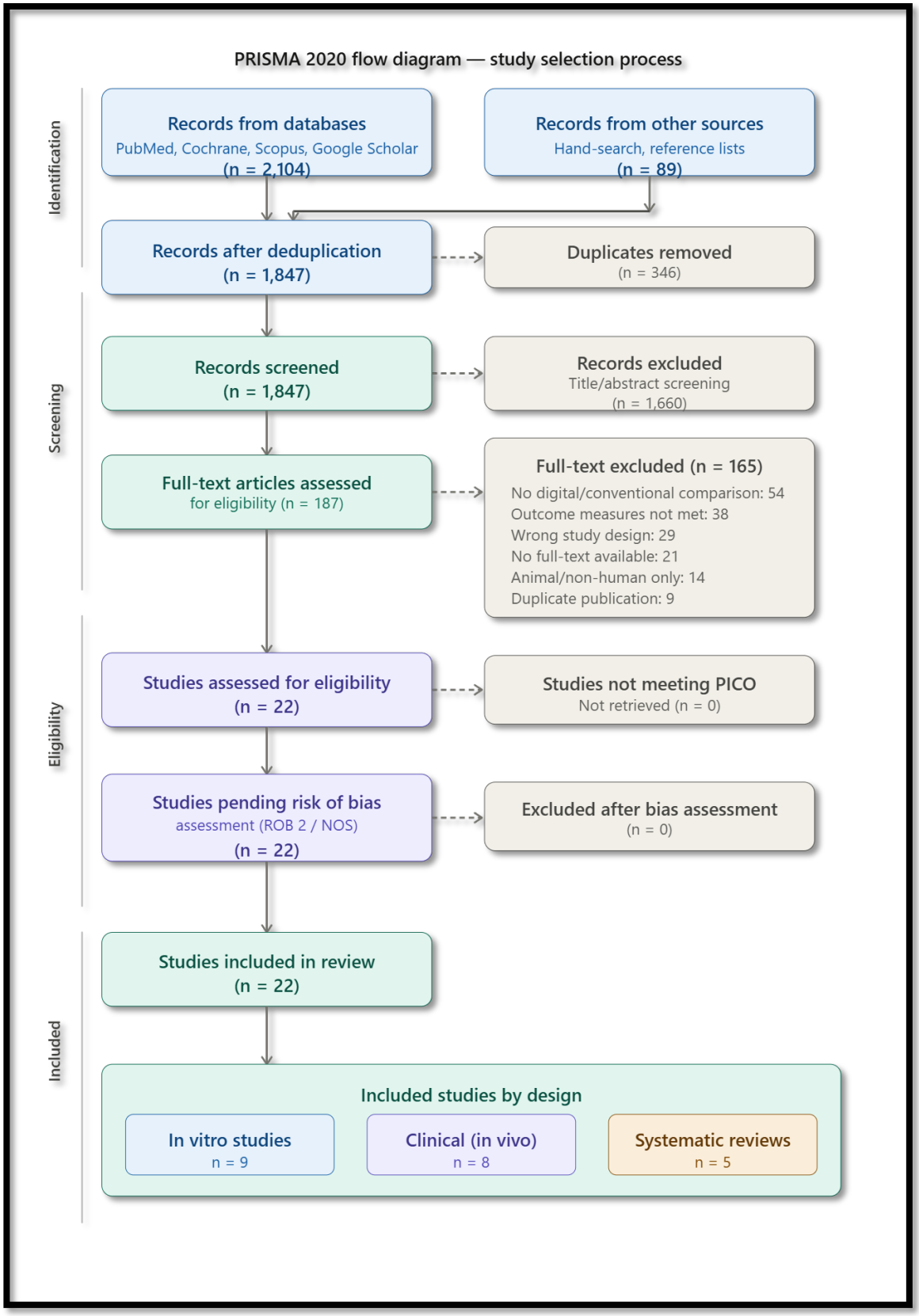

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process.

Table 2. Summary of the characteristics of all included studies.

Author/Year	Design	Sample (n)	Digital System	Conventional Method	Key Outcome(s)
Patzelt et al., 2014 [13]	In vitro	n=5 casts/IOS	CEREC Bluecam, Lava COS, iTero (SLA/Milled)	Polyurethane ref. model + lab scanner	Trueness: 67.5-98.2 µm; SLA superior to milled
Cho et al., 2015 [14]	In vitro	n=20	Digital scan models (IOS)	PVS impression + stone cast	Digital casts more accurate and reproducible
Reuschl et al., 2016 [15]	Clinical	n=38	3D digital study models (desktop scanner)	Plaster models	Good reliability and validity; no clinical difference
Albdour et al., 2018 [16]	In vivo	n=20	IOS (in vivo trueness evaluation)	Conventional impression method	Digital impressions: clinically acceptable trueness
Sfondrini et al., 2018 [17]	Clinical	n=15	Powder-free IOS	Alginate impression + stone cast	Comparable accuracy; shorter chair time; better patient feedback
Joós-Kovács et al., 2019 [11]	In vitro	n=10	Desktop CAD/CAM scanner	Conventional impression + stone cast	Clinically acceptable trueness for both methods
Aly & Mohsen, 2020 [7]	In vitro	n=30	Digital cast + 3D-printed cast	Conventional stone cast (PVS)	Digital and 3D-printed casts comparable to conventional
Rabe et al., 2021 [18]	Syst. Review	5 studies	Various digital model systems	Plaster models (orthodontic)	No clinically significant difference in orthodontic parameters
Lee et al., 2022 [19]	In vitro	n=24	Digitally milled models	Conventional gypsum casts	Digitally milled models: comparable articulation accuracy
Schieffer et al., 2022 [6]	Clinical	n=30	Digital cast (software analysis)	Stone cast (mixed dentition)	Measurements interchangeable for most parameters
Al-Makramani et al., 2023 [20]	In vitro	n=10/group	Medit i700 IOS + 3D-printed cast	Conventional/extended-pour/alt. alginate	Extended-pour and alt. alginate superior occlusal accuracy vs. 3D-printed
Janosi et al., 2023 [1]	Clinical	n=40	Full-arch IOS (Medit)	Conventional preliminary impression	IOS adequate for preliminary diagnosis; conventional superior in details
Husein et al., 2022 [21]	In vitro	n=20	IOS (full-arch digital impression)	Conventional full-arch impression	Both methods clinically acceptable; digital superior in posterior regions
Rafiei et al., 2022 [22]	In vitro	n=30	Maestro 3D Ortho Studio software	Dental plaster casts	High agreement between digital and plaster measurements
Jaber et al., 2024 [23]	Clinical	n=50	Direct intra-oral IOS vs. extra-oral scan of poured models	Extra-oral scanned poured dental models	No significant difference in dimensional accuracy or reliability
Al Mortadi et al., 2025 [10]	Clinical	n=45	3D-printed cast + digital model	Stone cast	Comparable arch measurements across all three methods
Lang et al., 2025 [24]	Clinical	n=63	Digital 3D cast analysis (automated)	Manual plaster cast measurement	Valid automated digital analysis; suitable for orthodontic assessment
Keil et al., 2025 [8]	Prospective	n=38 infants	IOS (cleft lip/palate infants)	Conventional alginate impression	IOS more comfortable and equivalent accuracy in neonatal context
Souza et al., 2025 [25]	In vitro	n=30	Digital surveying (DWOS)	Conventional mechanical surveying	High accuracy for digital surveying; conventional faster (4.61 vs. 5.26 min)
Yoon et al., 2025 [26]	Clinical	n=15 arches	IOS + additive manufacturing (RPD)	Conventional impression + lost-wax	IOS superior accuracy at terminal abutments; both clinically acceptable
Jaiswal et al., 2025 [27]	Clinical (RCT)	n=100	Trios 3Shape IOS	Polyether (Impregum) + stone cast	Digital: 0.41 mm deviation; conventional: 0.61 mm; comfort and time superior for digital

Kaline et al., 2024 [3]	Clinical	n=30	Digital outlining (IOS-derived)	Conventional outlining of denture borders	Comparable accuracy; time advantage varied by operator experience

IOS = intraoral scanner; PVS = polyvinylsiloxane; SLA = stereolithography; RPD = removable partial denture; DWOS = Dental Wings CAD software; 3D = three-dimensional.