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Review Article

3D Printed Try-in for Complex Ceramic Veneers: A Systematic Review

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Abstract

Aims: To systematically evaluate the effectiveness, clinical outcomes, material performance, patient satisfaction, and technological limitations associated with 3D-printed try-ins for complex ceramic veneers.

Data Sources: A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, and Google Scholar covering publications from January 2010 to September 2025.

Study Eligibility Criteria: Peer-reviewed studies assessing 3D-printed try-ins within ceramic veneer workflows were included. Eligible designs comprised clinical trials, experimental studies, observational studies, and systematic reviews reporting quantitative or qualitative outcomes. Case reports, editorials, non-English articles, and studies unrelated to ceramic veneers or try-in fabrication were excluded.

Materials and Methods: This review examines its impact on clinical outcomes, patient satisfaction, and technological limitations. A systematic search of PubMed, Scopus, Web of Science, and Google Scholar from 2010 to 2025 identified 2,173 records, of which 19 studies met the inclusion criteria following PRISMA guidelines. Data extraction focused on study characteristics, digital workflows, material properties, clinical outcomes, and technological considerations

Results: Most included studies were published after 2020 and originated primarily from Europe and Asia, with significant contributions from the United States. The studies showed significant differences in the properties of test materials between 3D-printed try-ins and conventional mock-ups. The 3D-printed try-ins had 25-55% greater tensile and compression strength, and flexural strength was increased by 70-100%. They also demonstrated superior fatigue resistance, volumetric stability, and cell proliferation. Overall, 3D printing improved precision, durability, and patient satisfaction, though material standardization and long-term validation remain necessary.

Conclusion: 3D-printed try-ins provide improved mechanical performance, precision, and clinical workflow efficiency in complex ceramic veneer procedures compared with conventional techniques. Despite promising outcomes, standardized materials, optimized printing protocols, and long-term clinical validation are necessary to support broader clinical adoption

Keywords: 3D Printing, Ceramic veneers, Digital dentistry, CAD/CAM, Provisional restoration, Restorative dentistry.

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INTRODUCTION

Digital dentistry is an interdisciplinary field with significant potential to enhance restorative and aesthetic workflows, improving precision, predictability, and efficiency. Among modern prosthodontic innovations, 3D printing stands out for enabling precise digital design, fabrication, and evaluation of restorations, surpassing traditional methods (1,2).

The integration of computer-aided design and manufacturing (CAD-CAM) systems streamlines challenging steps in the restorative process by producing accurate try-in and provisional prostheses, especially in complex cases. Small changes in shape, contour, volume, or color can significantly impact the aesthetic outcome, highlighting the value of precise digital construction (3,4).

Traditional methods of try-in, such as using wax-up prototypes or even mock-up try-ins, can often be time-consuming, inefficient, unreproducible, and inaccurate in fit. In addition, the time-consuming manual approach may lead to uncontrolled variabilities that require modifications during the final cementation phase, increasing clinical chair time and wasting cement materials (5,6). In the case of 3D printed try-ins, however, designers can accurately assess the pre-evaluation stage of the veneer design, including marginal adaptation, occlusal, shade integration, and the overall predictability relative to targeted aesthetics, functional predictability, and harmony. The digital approach improves workflow and inter-professional communication relations between the clinician, the dental technician, and even the patient for collaborative real-time alterations and decision-making prior to the definitive ceramic fabrication (7,8).

Recent literature indicates that the use of 3D-printed try-ins enhances treatment precision, operational efficiency, and patient contentment. (9,10) High-resolution, additively manufactured photopolymer and hybrid resin restorations capture fine structural details while maintaining dimensional stability (11,12). A fully digital workflow from diagnosis to bonding supports minimally invasive, patient-centered care (13,14). Despite these benefits, adoption in aesthetic dentistry remains inconsistent, influenced by technology availability, operator expertise, and material differences (15,16). A systematic review is needed to consolidate recent advancements and evaluate the effectiveness, feasibility, and clinical value of 3D-printed try-ins. The purpose of the systematic review is to assess the existing literature to identify the efficacy and practicability of 3D-printed try-ins in complex ceramic veneers. The review analyzes how the results of the research on clinical accuracy and outcomes, material characteristics, cost-effectiveness, technological limitations, and the implications and possible impact of the findings on future research and practice in digital restorative dentistry were incorporated.

MATERIALS AND METHODS

Study Design

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological transparency and reproducibility. A predefined review protocol guided study selection, data extraction, and synthesis procedures. The protocol for this review was not preregistered in PROSPERO.

Search Strategy and Information Sources

A systematic literature search was performed across PubMed, Scopus, Web of Science, and Google Scholar. Additional manual screening of reference lists of included studies was conducted to identify potentially relevant articles. The search covered publications from 1 January 2010 to 30 September 2025, and the final search was conducted on 30 September 2025.

The main search concepts encompassed "3D printing," "ceramic veneers," "mock-up or try-in restorations," and "digital dentistry." The general search syntax applied across databases was "3D printing" AND "porcelain veneers" OR "ceramic veneers" AND "mock-up" OR "provisional restoration" OR "try-in" AND "CAD/CAM" OR "digital dentistry" AND "restorative dentistry" OR "dental prosthetics". Search limits included language as English and availability of full text. Adaptations to keywords specific to the database were made as needed.

Eligibility Criteria

Table 1 outlines the inclusion and exclusion criteria that were applied in the selection of studies for this review. The inclusion criteria emphasize on peer-reviewed research from the years 2010 to 2025 that concerned 3D-printed try-ins in workflows for ceramic veneers. Exclusion criteria include case reports, documents that lack complete text, and studies that do not pertain to ceramic veneers or the fabrication of try-ins. During synthesis, studies were grouped according to study design, type of material, characteristics of the digital workflow, and clinical or mechanical outcomes reported.

Table (1): Inclusion and Exclusion Criteria for Study Selection

Inclusion	Exclusion
• Articles published between 2010-2025.	• Case reports or clinical series with fewer than three patients.
• Peer-reviewed original research, clinical trials, cohort studies, cross-sectional studies, in-vitro studies, clinical studies, experimental studies, systematic reviews, and meta-analyses.	• Editorials, letters, reviews, or conference abstracts.
• Full-text availability in English.	• Articles without full text.
• Studies evaluating or comparing 3D-printed try-ins in ceramic veneer workflows.	• Studies unrelated to ceramic veneers or try-in fabrication.
• Studies reporting quantitative or qualitative outcomes related to accuracy, fit, patient satisfaction, or workflow efficiency.	• Duplicate records across databases.

Study Selection Process

The screening database contained all retrieved records, and prior to assessment, duplicate records were removed. According to preset eligibility criteria, two independent reviewers evaluated titles and abstracts. Potentially relevant studies were then evaluated to determine if the full-text articles warranted inclusion. Discrepancies between reviewers were reconciled through discussion. No automation tools were utilized in this study selection process.

Data Collection Process

Two reviewers extracted data independently using a standardized template. Information was cross-verified for accuracy and completeness. Disagreements were settled through discussion. In instances of ambiguous or incomplete information, careful examination of the study's methods and findings was used to draw a clear interpretation.

Risk of Bias Assessment

Risk of bias assessment was conducted using validated tools appropriate to the design of each included study. Randomized controlled trials were evaluated using the Cochrane Risk of Bias Tool 2.0, while prospective clinical studies, experimental studies, and in vitro observational studies were assessed using the Newcastle-Ottawa Scale, with scores categorized as low (7–9), moderate (4–6), or high risk (0–3). The methodological quality of included systematic and narrative reviews was appraised using AMSTAR-2. Two reviewers independently performed all assessments, and the results were cross-checked to ensure consistency. Any disagreements were resolved through discussion or, when required, consultation with a third reviewer. No automation tools were used in this process. The final assessments were reported at both the domain level and as an overall risk of bias judgment for each study.

Data Extraction and Synthesis

The synthesis of data used a narrative approach in combining results from different study designs. The subsequent variables included country, study design, type of sample or model, type of 3D printer and materials, and the main conclusion or findings. Other variables included the flow of 3D-printed try-in fabrication, the time and spatial range, and the comparative evaluation of key metrics such as mean ± SD for the 3D-printed and conventional try-ins to highlight the improvement or difference. Such synthesis provided a holistic view of the integrated technological workflows and spatial and temporal performance as well as the global research for 3D printed try-ins for ceramic veneers.

Study Classification and Synthesis Approach

Included studies were categorized based on levels of evidence into three groups: (1) in vitro/experimental studies, (2) clinical studies (randomized and non-randomized), and (3) systematic reviews. Findings were synthesized separately for each category to avoid inappropriate comparisons across heterogeneous evidence levels. Due to substantial heterogeneity in study designs, outcome measures, and reporting formats, a meta-analysis was not performed. Therefore, results were synthesized using a structured narrative approach.

RESULTS

Search Outcomes

Figure 1. PRISMA flow diagram showing the study selection process. An initial database search on PubMed, Scopus, Web of Science, and Google Scholar was conducted, producing 2,173 records (Web of Science = 823; PubMed = 1,054; Scopus = 47; Google Scholar = 249). Applying filters within the timeframe of 2010-2025 resulted in 1,712 items; after narrowing to research and review articles, this yielded 919 items, and subsequently 773 English articles. Following the deduplication of 24 records, 749 records underwent title and abstract screening, during which 538 were deemed irrelevant and excluded. 211 studies underwent full-text review, 192 of which were excluded because of topic irrelevance, lack of full-text access, were considered a narrative review or methodological 42, or were case reports with fewer than three patients 14. Ultimately, 19 (17–35) studies were included in this systematic review, meeting the established inclusion criteria.

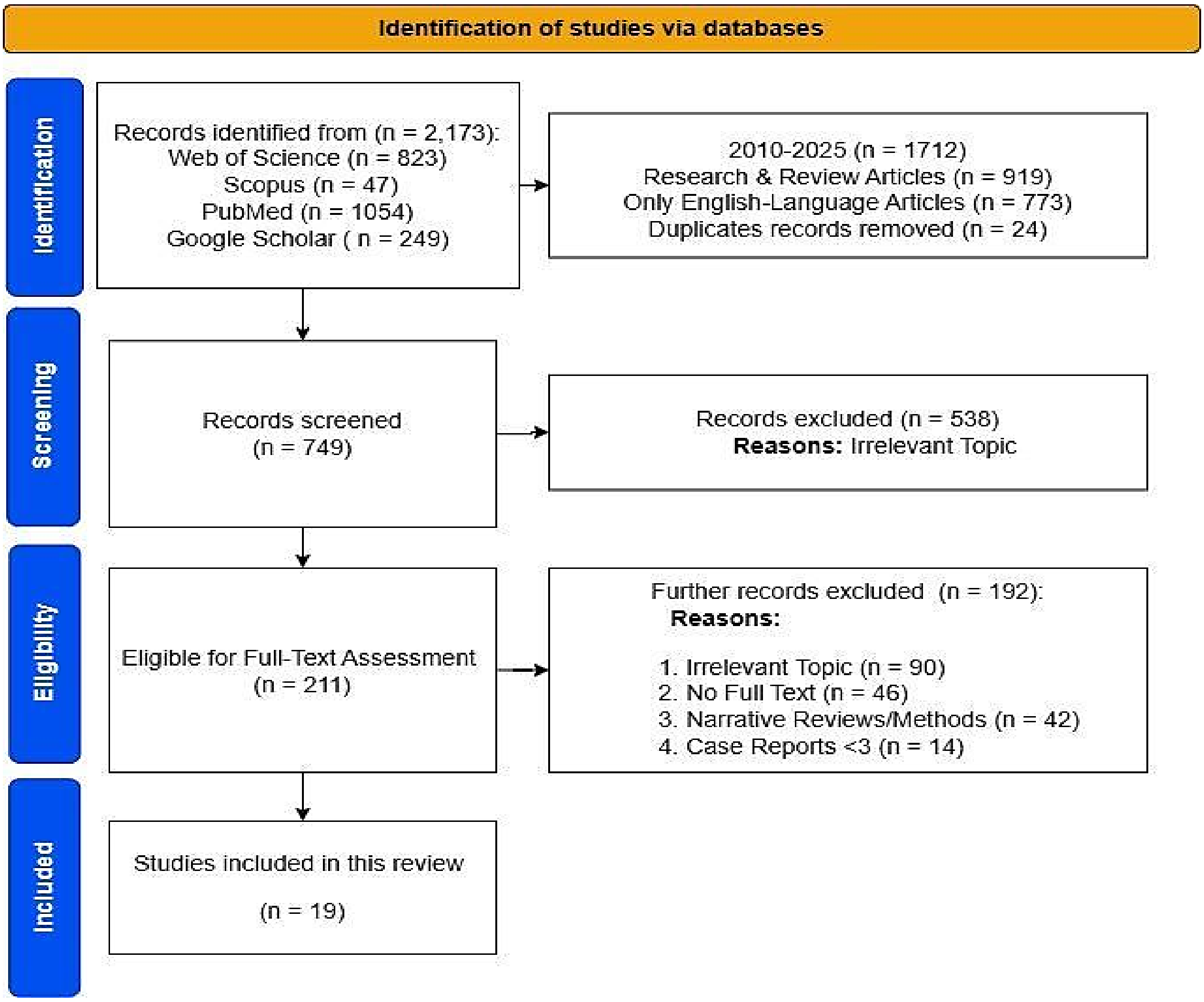

Figure (1): PRISMA Flow Diagram

Characteristics of Included Studies

The characteristics of the included studies are summarized in Table 2. Most studies 57.9% studied 3D printing applications in esthetic veneer fabrications in Europe. Most of the studies 42.1% from South Korea, Saudi Arabia, Japan, and Yemen and were from Asia. Most publications were published after 2020, likely due to the rapid advancement of digital technology in esthetic veneer fabrication. Studies included in the analysis ranged from in vitro studies, randomized clinical trials, and systematic reviews, providing a balance between experimental research and clinical practice of 3D-printed try-in restorations.

Table (2): Characteristics of the included studies

Author (s) (Year)	Country	Study Design	Sample / Model Type
Hassan et al. (2017)[19]	Germany	Prospective clinical study	10 patients
Bojko et al. (2022)[17]	Poland	Experimental	25 specimens
Alhallak et al. (2023)[21]	UK	Systematic narrative review	20 studies
Czigola et al. (2019)[22]	Hungary	In vitro CAD/CAM study	40 crowns
Pilecco et al. (2024) [23]	Netherlands	Experimental in vitro	120 samples
Mancuso et al. (2024)[24]	Italy	In vitro	100 samples
Mühlemann et al. (2022)[25]	Switzerland	Prospective controlled clinical	59 patients
Porojan et al. (2022)[26]	Romania	In vitro	40 samples
Derksen et al. (2021) [18]	Netherlands	Randomized clinical trial	32 patients
Jeong et al. (2019)[27]	South Korea	In vitro	120 samples
Yeslam et al. (2023) [28]	Saudi Arabia	In vitro	100 samples
Jensen et al. (2024)[29]	Sweden	Experimental in vitro	36 impressions
Espinar et al. (2023) [30]	Spain	Experimental in vitro	12 samples
Lee et al. (2025)[31]	South Korea	Experimental	120 samples
Alrabeah et al. (2023)[32]	Saudi Arabia	Experimental study	40 samples
Al-Akhali et al. (2023)[33]	Yemen	In vitro observational	50 samples
Oros et al. (2025)[34]	Serbia & Luxemburg	Systematic review	19 studies
Tsuji et al. (2025)[20]	Japan	Experimental in vitro	26 samples
Ganbold et al. (2019)[35]	South Korea	Experimental in vitro	52 samples

In Vitro and Experimental Studies

The in vitro and experimental studies in this review, summarized in Table 3, demonstrate that 3D-printed try-ins and digitally fabricated veneer-related restorations can achieve high mechanical strength, dimensional accuracy, and acceptable marginal fit under laboratory conditions. Most of these papers have shown enhanced fatigue behavior, higher color masking, and increased predictability of material behavior using 3D-printed or CAD/CAM materials in comparison to the analog or milled counterparts. These observations, however, do not apply to real-world scenarios and are restricted to controlled circumstances and not the subjective patient outcomes of comfort, real-time aesthetics, or long-term biocompatibility.

Clinical Studies (Randomized Controlled Trials and Prospective/Controlled Clinical Studies)

The clinical trials, such as one randomized clinical trial and a few prospective controlled or clinical trials as described in Table 3, suggest that chairside digital workflows with 3D-printed or CAD/CAM based try-ins can minimize the time of adjustment, simplify the making of impressions, and enhance operatory time efficiency. These studies are highly consistent in their findings of high prosthetic accuracy and patient satisfaction, but the evidence is limited by small sample sizes, single-center studies, and comparatively short follow-up.

Systematic and Narrative Reviews

The two incorporate systematic or narrative reviews, summarized in Table 3, that additive manufacturing and CAD/CAM technologies permit cost-effective and accurate dental restorations and have the ability to save fabrication time and effort relative to traditional procedures. Both reviews state that there is limited evidence on long-term clinical outcomes and that long-term, high-quality trials and formal meta-analyses are required.

Table (3): Summary of the findings of the included studies

Author (s) (Year)	3D Printer / Material Used	Key Findings / Conclusions
Hassan et al. (2017) [19]	CAD/CAM workflow integrating 3D facial scanning (PritiMirror), lab scanning (Dental Wings iSeries DWOS), and 5-axis milling (M7 CNC) using PMMA	Fully digital workflow improved esthetic visualization, clinical fit, and communication; reduced treatment time and cost.
Bojko et al. (2022) [17]	CAD/CAM and DMLS (EOSINT M270, CORiTEC 350i); Ti6Al4V and Co-Cr alloys	DMLS frameworks showed superior mechanical strength and elasticity, suitable for fixed prostheses under load.
Alhallak et al. (2023) [21]	CAD/CAM milling and 3D printing (SLA, DLP, SLS) with PMMA and resin composites	CAD/CAM dentures had higher retention and strength; 3D printed dentures reduced cost and time but need long-term validation.
Czigola et al. (2019) [22]	Everest KaVo CAM, 3Shape TRIOS scan, lithium disilicate (IPS e.max CAD)	Crown shade affected by ceramic thickness and translucency; LT blocks gave better masking than HT.
Pilecco et al. (2024) [23]	CAD/CAM lithium disilicate (IPS e.max CAD, Ivoclar)	Air-water spray cleaning preserved fatigue resistance; aging decreased strength in most groups.

Mancuso et al. (2024) [24]	CAD/CAM (Tetric CAD) vs 3D printing (PrograPrint PR5, Ivoclar)	Resin cement and design affected seating accuracy; CAD/CAM overlays showed reliable volumetric precision.
Mühlemann et al. (2022) [25]	Intraoral scanner (TRIOS 3), CAD/CAM (Atlantis WebOrder), zirconia crowns	Chairside digital workflow improved time efficiency; both methods achieved high prosthetic accuracy and satisfaction.
Porojan et al. (2022) [26]	CAD/CAM composites (Vita Enamic, Lava Ultimate, etc.)	Luting agent and substrate color significantly affected color and masking ability of restorations.
Derksen et al. (2021) [18]	CAD/CAM, intraoral optical scanning (3M TDS)	Digital impressions reduced adjustment time; similar survival and fewer complications than conventional methods.
Jeong et al. (2019) [27]	3D printing (Nextdent C&B) vs milling (PMMA blocks)	CAD/CAM and 3D printed provisionals had acceptable strength; surface treatment improved bond durability.
Yeslam et al. (2023) [28]	CAD/CAM hybrid materials (GR, VE, PEEK, CT, VB)	GR and PEEK maintained flexural strength after thermocycling; feldspar ceramic had lowest performance.
Jensen et al. (2024) [29]	Digital impressions + SLM vs conventional VPS casting	Digital SLM method achieved superior internal fit at apical and coronal regions.
Espinar et al. (2023) [30]	3D printing (additive manufacturing resins)	Printing angle (0° vs 90°) significantly influenced color and translucency.
Lee et al. (2025) [31]	Vat photopolymerization (DLP, LCD)	DLP printers provided highest accuracy (lowest RMS); cleaning and post-processing critical for precision.
Alrabeah et al. (2023) [32]	CAD/CAM technology, zirconia & lithium disilicate	Cement shade altered final color but not translucency; material type determined translucency.
Al-Akhali et al. (2023) [33]	3D printing (Dental Sand), CAD/CAM (Ceramill Temp), manual PMMA	CAD/CAM PMMA had best color stability; 3D printed composites most affected by staining (khat extract).
Oros et al. (2025) [34]	FDM, SLA, DLP, SLS, SLM, LCM methods	AM enables cost-efficient, precise dental restorations; clinical validation still limited.
Tsuji et al. (2025) [20]	DLP printer (Cara Print 4.0, Kulzer); UDMA resins + S-PRG filler	3D printed UDMA-S-PRG composites met ISO strength and released beneficial ions (Sr, F, B).
Ganbold et al. (2019) [35]	Selective Laser Melting (Co-Cr) vs casting	SLM Co-Cr showed superior stem cell adhesion and biocompatibility compared with Ni-Cr controls.

Risk of Bias in Studies

The majority of in vitro and experimental studies scored 7/9 stars or above on the NOS, indicating low risk of bias. The key strengths were evident exposure/intervention criteria, conventional laboratory procedures, and objective mechanical or optical outcome measures, which minimized measurement bias under controlled situations.

Five studies received moderate scores (5–6/9), primarily due to limited reporting on sample representativeness and inadequate description of follow-up or aging conditions. Notably, only 12 specimens with limited color-angle conditions, reducing the generalizability of the findings as shown in Table 4a.

Table (4a): Newcastle–Ottawa Scale (NOS) for Observational, Experimental, and In Vitro Studies

Author (Year)	Study Design	Selection (0–4★)	Comparability (0–2★)	Outcome (0–3★)	Total (/	Overall
Hassan et al. (2017)	Prospective clinical	★★★	★	★★	6/9	**Moderate**
Bojko et al. (2022)	Experimental	★★★	★★	★★	7/9	**Low**
Czigola et al. (2019)	In vitro CAD/CAM	★★★	★★	★★	7/9	**Low**
Pilecco et al. (2024)	Experimental in vitro	★★★	★★	★★	7/9	**Low**
Mancuso et al. (2024)	In vitro	★★★	★	★★	6/9	**Moderate**
Mühlemann et al. (2022)	Prospective controlled	★★★★	★★	★★	8/9	**Low**
Porojan et al. (2022)	In vitro	★★★	★	★★	6/9	**Moderate**
Jeong et al. (2019)	In vitro	★★★	★★	★★	7/9	**Low**
Yeslam et al. (2023)	In vitro	★★★	★★	★★	7/9	**Low**

Author (Year)	Study Design	Selection (0–4★)	Comparability (0–2★)	Outcome (0–3★)	Total (/	Overall
Jensen et al. (2024)	Experimental in vitro	★★★	★★	★★	7/9	**Low**
Espinar et al. (2023)	Experimental in vitro	★★	★	★★	5/9	**Moderate**
Lee et al. (2025)	Experimental	★★★	★★	★★	7/9	**Low**
Alrabeah et al. (2023)	Experimental	★★★	★★	★★	7/9	**Low**
Al-Akhali et al. (2023)	In vitro observational	★★★	★★	★★	7/9	**Low**
Tsuji et al. (2025)	Experimental in vitro	★★★	★★	★★	7/9	**Low**
Ganbold et al. (2019)	Experimental in vitro	★★★	★★	★★	7/9	**Low**

NOS Domains — Selection (max 4★): representativeness, sample size, non-respondents, ascertainment of outcome. Comparability (max 2★): comparability of groups based on design/analysis. Outcome (max 3★): assessment, follow-up length, adequacy of follow-up. Total Score: Low risk = 7–9★; Moderate = 4–6★; High = 0–3★.

The single RCT was rated as low overall risk of bias across all five RoB 2 domains. Randomization was appropriately conducted, outcome assessors were blinded, missing data were minimal, and the protocol was consistent with reported outcomes. This study provides the highest level of clinical evidence within this review; however, the limited sample size (32) and single-center design reduce its power to detect rare complications, as shown in Table 4b.

Table (4b): Cochrane RoB 2.0 for RCTs

Author (Year)	Design	D1 Randomization	D2 Deviations	D3 Missing Data	D4 Measurement	D5 Reporting	Overall
Derksen et al. (2021)	RCT	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**

RoB 2 Domains — D1: Randomization process; D2: Deviations from intended intervention; D3: Missing outcome data; D4: Measurement of outcomes; D5: Selection of reported results. Judgments: Low / Some Concerns / High risk.

Both systematic/narrative reviews were rated as moderate risk by AMSTAR-2 criteria. While both conducted comprehensive database searches, neither reported a pre-registered protocol, and neither performed a formal meta-analysis or provided a GRADE certainty of evidence assessment. Grey literature was not systematically searched in either review. Despite these methodological gaps, both reviews synthesized a sufficient breadth of primary studies and their conclusions are broadly consistent with other included evidence in this SLR, as shown in Table 4c.

Table (4c): AMSTAR-2 for Systematic and Narrative Reviews

Author (Year)	Design	Protocol Registered	Search Comprehensive	Grey Searched	RoB of Primary Studies	Overall
Alhallak et al. (2023)	Systematic narrative review	**Yes**	**Partial**	**No**	**Partial**	**Moderate**
Oros et al. (2025)	Systematic review	**Yes**	**Partial**	**No**	**Partial**	**Moderate**

AMSTAR-2 key domains assessed: protocol registration, comprehensiveness of literature search, grey literature inclusion, and assessment of risk of bias in primary studies. Overall rating: Low / Moderate / High methodological quality concern.

The predominance of low-risk in vitro studies provides a strong mechanistic foundation for the clinical application of CAD/CAM and 3D printing technologies in dentistry. However, the limited number of clinical trials and the moderate quality of the two included reviews mean that direct clinical evidence remains sparse. In vitro results must be taken with care when projecting them to patient outcomes. Future research must focus on randomized clinical trials that utilize larger sample sizes, standard outcome reporting, and long-term follow-up to confirm the laboratory findings that have been summarized in this review. Reporting bias could not be formally evaluated because meta-analysis was not performed and the results and study designs, as well as reporting formats, were very heterogeneous.

Workflow of 3D Printed Try-in Fabrication

The process of creating and assessing 3D printed dental try-ins is systematically depicted in Figure 2. Workflow Diagram of 3D Printed Try-In Fabrication and Clinical Validation. The sequence of activities begins with the capture of digital impressions using intraoral scanners and continues with the computer-aided design of veneers as well as try-in prototypes. The subsequent step is the additive manufacturing of try-ins using SLA/DLP 3D printing technology employing light-cured photopolymer resins. After printing, the try-ins undergo clinical assessments focusing on marginal adaptation, esthetics, and occlusal harmony following cleaning, curing, polishing, and other post-processing steps. The workflow concludes with the final fabrication of the ceramics and cementation after the fitting and function of the try-in have been verified satisfactorily. The clinical documentation narrating the history of the process outlines the iterative refinements made in response to clinical input and adaptations in the use of the try-in.

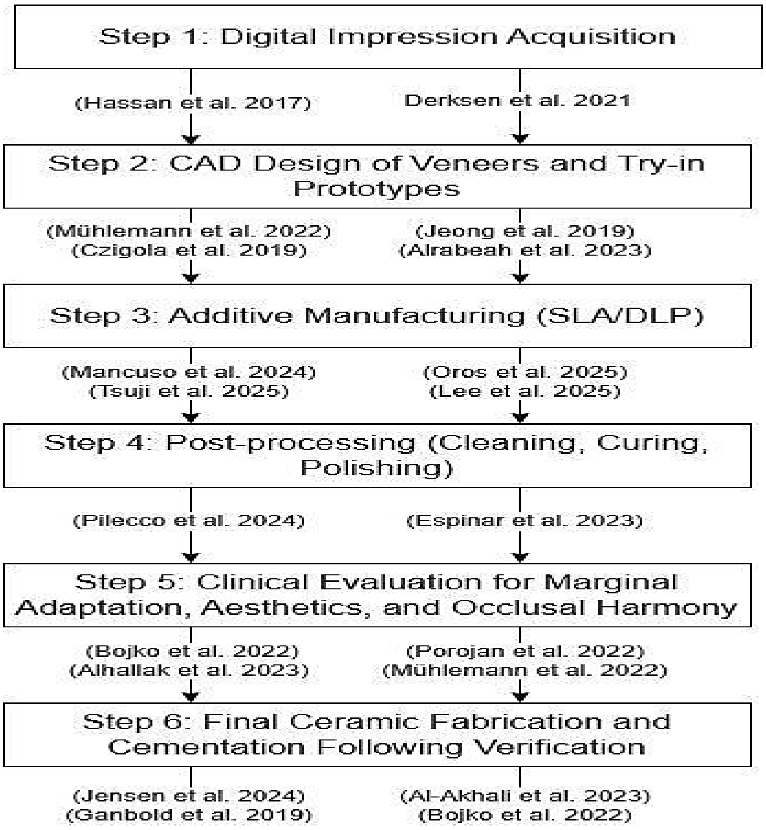

Figure (2): Workflow diagram of 3D printed try-in fabrication and clinical validation
Source: Summarized by the author based on analysis. [17–27,29,31–34]

Geographical and Temporal Distribution

Figure 3 illustrates the temporal distribution of all records identified in the initial database search (n = 2,173) related to 3D Printed Try-in for Complex Ceramic Veneers rather than the final 19 studies included. The period analyzed shows that 2023 recorded the highest number of publications, 87. The increasing interest in 3D printers for dental try-ins, particularly complex ceramic veneers, is evident. 2023 (58 studies) and 2022 (61 studies) also contributed significantly to the publication record, indicating a continuous interest in advancing 3D printing within the discipline. An annual decline in the number of studies is apparent when the years are reviewed backwards, with 2010 exhibiting the fewest publications, at 20. Overall, this distribution illustrates the increasing literature available in recent years, as the literature begins to emphasize more the use of digital workflows and integrated 3D printing.

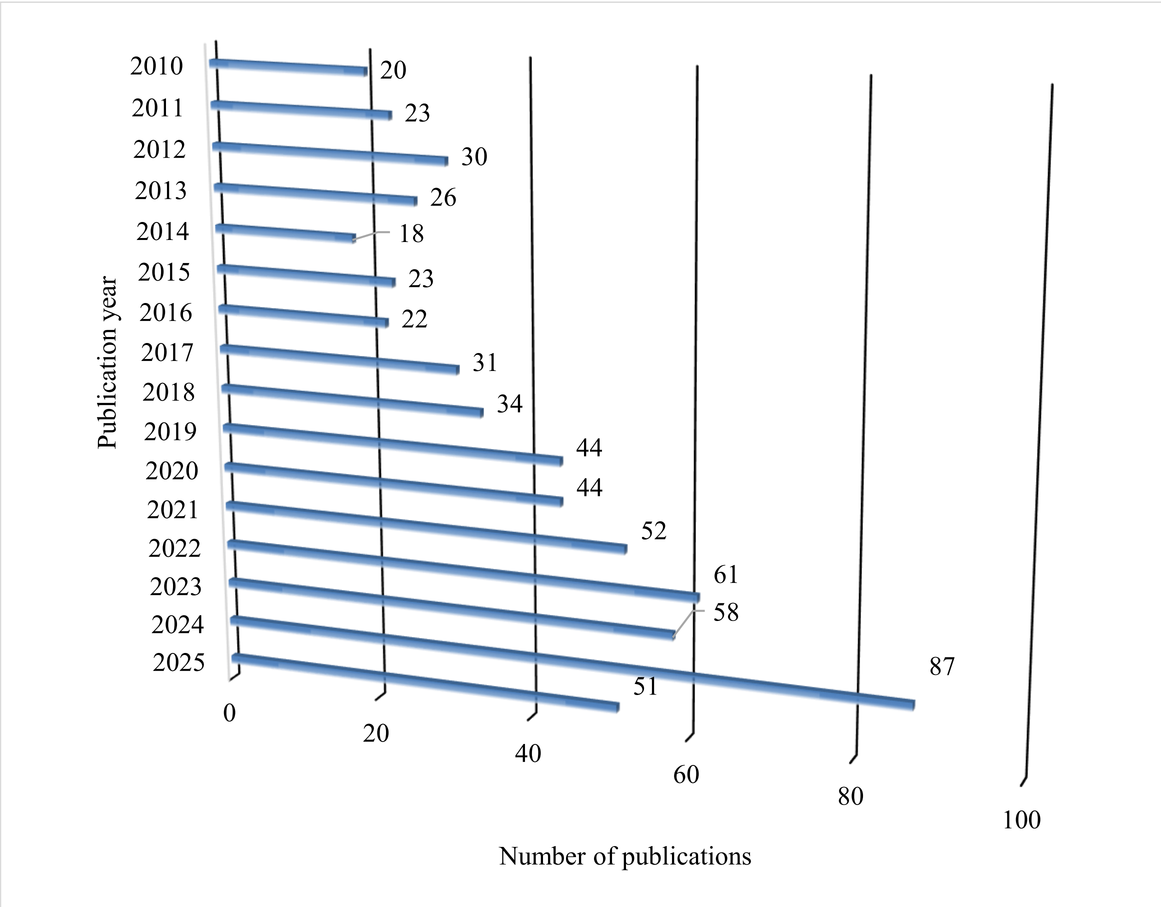

Figure (3): Temporal distribution of all records identified in the initial database search (n = 2,173).

Figure 4 illustrates the geographical distribution of all records identified in the initial database search (n = 2,173) related to 3D Printed Try-in for Complex Ceramic Veneers rather than the final 19 studies included. The first descriptive analytics point toward a notable concentration of research activity in the more technologically advanced nations. In particular, the USA stands out as the leading contributor to the publishing activity, with a total of 166 studies. Italy, Brazil, and Germany, with 54, 52, and 46 publications respectively, appear to consolidate research-led initiatives in Europe and the Americas. Spain also contributed research substantially, with 46 publications, as well as Poland (35 studies) and People's R China (32 studies). The research output from South Korea, Switzerland, and Saudi Arabia, each with 32 to 30 publications, illustrates a strong global interest in the 3D printing of dental prosthetics. The geographical spread of research activity illustrates the global interest and potential the dental profession has in the 3D-printed try-ins for complex ceramic veneer procedures, which spans numerous continents.

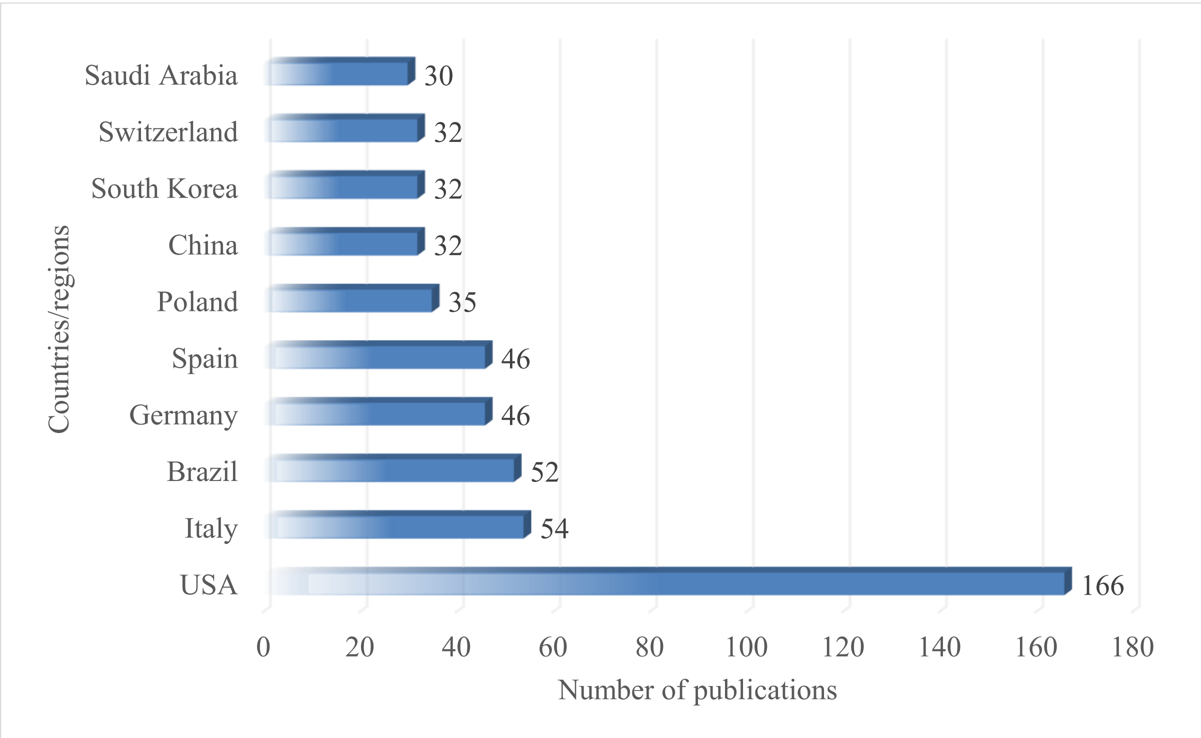

Figure (4): Geographical distribution of all records identified in the initial database search (n = 2,173).

Comparative Analysis of Key Outcomes

Table 5 provides a quantitative comparison of 3D-printed try-ins versus conventional mock-ups. It shows differences regarding tensile strength, as 3D-printed Ti6Al4V and CoCrMo alloys have 25-55% higher strength than conventional milled Ti6Al4V and cast CoCrMo. In compression strength, 3D-printed materials have 25-55% advancement as opposed to conventional cast CoCrMo. In fatigue testing, force-to-failure was reported for 3D-printed materials, whereas cycles-to-failure were reported for conventional samples; these metrics are not directly comparable and should not be used to infer relative fatigue performance. While 3D-printed materials exhibited high strength-to-failure values, the available data do not permit a valid comparison of fatigue life between the two groups.

The volumetric increase is higher in 3D-printed HC as compared to conventional materials. The increase in flexural strength of 3D-printed materials, as compared to PMMA control, is 70-100%. Finally, in roughness surface analysis, the 3D-printed Co-Cr alloys showed 80% higher cell proliferation than the conventional Ni-Cr alloys.

Table (5): Comparative performance of 3D printed try-ins versus conventional mock-ups.

Parameter	3D Printed Try-in (Mean	Conventional Try-in (Mean ± SD)	Units	Improvement / Difference
Tensile Strength	Ti6Al4V: 984 ± 25; CoCrMo: 1180 ± 19	Milled Ti6Al4V: 731 ± 13; Cast CoCrMo: 646 ± 17	MPa	25-55% higher strength (depending on alloy)
Compressi on Strength	Ti6Al4V: 1641 ± 38; CoCrMo: 1619 ± 52	Cast CoCrMo: 1176 ± 36	MPa	25-55% improvement in compression strength
Fatigue: Failure Force (peak load to failure)	IVOC: 963 ± 122; SPRAY: 880 ± 56; HPO: 930 ± 56	Not reported (original sources for conventional samples reported cycles to failure rather than force)	N (Newto ns)	Not directly comparable; different outcome measures reported (see "Fatigue: Life")
Fatigue: Life (cycles to failure)	Not reported / N/A (no cycles data available for 3D printed samples)	IVOC: 153,709 ± 25,204; SPRAY: 145,667 ± 14,864	cycles	Not directly comparable; different outcome measures reported (cannot be

				combined with force data)
Volumetric Increase	RC: 28.5 ± 6.1; HC: 61.4 ± 16.6	RC: 51.3 ± 16.9; HC: 68.2 ± 11.5	μm^3	HC shows higher volumetric increase
Flexural Strength	3D printed: 119.6 ± 7.3 (after thermocycling)	PMMA control: 52.9 ± 5.4 (24 h)	MPa	70–100% higher flexural strength in 3D printed group
Surface Roughness (Ra)	Co Cr: 0.42 ± 0.06	Ni Cr: 0.23 ± 0.08	µm	Associated with 80% higher cell proliferation for Co Cr in the cited study

Note: Fatigue outcomes are not directly comparable because 3D-printed and conventional samples report different metrics (force-to-failure vs cycles-to-failure) and should not be interpreted as a direct performance comparison.

DISCUSSION

The use of try-ins made with 3D printing technology in dentistry, especially in complex esthetic cases, integrating veneers, and esthetic dentistry has made considerable progress. This review article has consolidated findings from previous works about the outcome and advantages of 3D try-ins versus standard 3D try-ins. Esthetic dentistry has benefitted from the use of digital workflows and 3D print technology, considering the high level of precision, the shortened time, and the level of patient satisfaction. There are technologies, materials, and prices that are probably the most important issues in which needs to be solved within the potential of the technology in therapeutic use.

Mechanical Properties

The current systematic review highlights that 3D printed try-ins are not only more accurate but also have superior mechanical properties compared to traditional mock-ups. Studies show that the tensile and compressive strengths of the 3D printed Ti6Al4V and CoCrMo are 25–55% greater than those of the alloys that are milled or cast. Such properties translate to superior marginal fit and precision in the intricate applications of veneers. Furthermore, as noted in several recent works, the digital light processing (DLP) 3D printing systems fabricated veneers of high trueness, particularly when built at the ideal angle of approximately 30°, which enhanced dimensional accuracy the most (36). Similarly, 3D-printed resin materials have shown higher tensile, compressive, and flexural strength compared to conventional acrylic resins, which may support their functional performance under masticatory forces (37,38). Studies on additively manufactured alloys also suggest improved fatigue resistance and mechanical stability under controlled conditions (39,40).

These positive results are to be understood with reservations, even though 3D-printed materials can be considered superior to traditional methods. Although improvement in mechanical properties has been experienced, they are yet to be translated to long-term clinical success (41). Moreover, differences in materials, printing methods, and post-processing procedures can affect the results and reduce the possibility of comparing results across studies (42).

The improvement of surface properties and cell growth of Co-Cr alloys formed in 3D printing has also been published, which is indicative of better biocompatibility. Also, 3D-printed denture base polymers have been found to be more resistant to flexural strength and wear than traditional materials (43,44). Research on corrosion resistance shows few discharges of toxic ions, which may justify the clinical safety of these substances. Yet, these results are mostly experimental and need to be supported by additional clinical evidence (45,46). Recent studies propose that 3D printed restorations, including ceramic nanohybrids and Co-Cr frameworks, have better surface characteristics, integration, and the overall quality of restorations because of the development in 3D printing processes and the application of quality materials.(47-49) The effect of printing orientation, finishing, and other post-printing processes on the mechanical properties of rigid dental prosthetics is also reported. These mechanisms are very important in influencing the ultimate strength and flexibility of dental prosthetic materials (50,51).

Clinical Results and Workflow Efficiency

The studies included in this review indicate that 3D-printed try-ins could enhance the efficiency of the chairside and shorten the treatment time. The enhancement of digital processes and 3D printing technology seems to increase the predictability of the treatment and the precision of the fitting, which can lead to higher patient satisfaction. But the evidence that exists is predominantly qualitative, and little is known quantitatively about patient satisfaction and esthetic predictability.

The application of 3D printing technology in dental procedures, such as in the design of veneers and the creation of dentures, is supported by several studies as an efficient way of facilitating the workflow and reducing the time spent at the chairside (52,53). The fabrication of chairside can decrease the number of appointments and reliance on dental laboratories, which might enhance clinical efficiency.

The communication can be also improved with the help of the integration of digital workflow and 3D-printed try-ins that enable patients to visualize the result of treatment. Digital smile design and virtual simulations are some of the tools that can enhance patient knowledge and participation in the treatment decisions (54,55). However, as is emphasized in this review, the bulk of evidence pertaining to patient satisfaction is subjective in nature, as opposed to quantitative measures that are validated. Compared to traditional methods, 3D-printed restorations can be superior in anatomy, esthetics, and marginal fit in some instances. Recent research on ceramic nanohybrids proposes strength, translucency, and shade matching improvement (56,57). Nevertheless, variability in esthetic results has been documented and can be based on the experience of the operator, the complexity of the case, and the choice of the material (58).

Moreover, there are still worries about the wear resistance, durability, and the survival of 3D-printed restorations over time in comparison with milled ones. Such uncertainties point to the necessity of more long-term clinical research of bigger sample sizes (59).

The economic implications of 3D printing have also been discussed in the literature. There is an indication that 3D printing can help lower the direct and indirect treatment costs through a reduction in chair time, material use, and clinical visitation. For instance, Alhallak et al. (2023) (21) reported that 3D printing workflows may be 30–50% less costly than conventional CAD/CAM approaches. Further research shows that subtractive manufacturing methods like CAD/CAM milling can imply more material wastage and the total cost can be more expensive (60,61).

Moreover, 3D-printed restorations have been linked to higher workflow productivity and less manual optimization, which may positively affect patient comfort and clinical productivity (62). The beneficial effect of 3D printing technologies on the overall efficiency of related surgical applications is also evident in related surgical applications (63).

A systematic review has reported that 3D printing may achieve comparable or, in some cases, improved clinical accuracy and patient satisfaction relative to conventional methods, although evidence remains limited (64). Nevertheless, it should be noted that CAD/CAM milling may still provide superior dimensional stability and precision for definitive restorations, whereas 3D-printed try-ins are more suitable for provisional and evaluative purposes (65).

Limitations of Current Evidence

Despite the promising findings, several limitations should be considered. The included studies demonstrate substantial heterogeneity in study design, materials, methodologies, and outcome measures, which limits direct comparisons.

A significant proportion of the evidence is derived from in vitro studies, which may not accurately reflect intraoral conditions. The limited number of randomized clinical trials reduces the strength of clinical conclusions. Additionally, inconsistencies in outcome reporting, such as differences in fatigue measurement methods, further complicate interpretation.

Economic evaluations, although suggesting cost advantages, are often based on indirect evidence rather than robust comparative analyses. Furthermore, variability in printing technologies, post-processing techniques, and operator expertise introduces additional uncertainty

Future Directions

3D-printed try-ins show considerable potential, but several technological challenges remain. Issues related to scan accuracy, printing quality, and equipment limitations continue to affect clinical outcomes. For example, printing orientation has been shown to significantly influence color, translucency, and mechanical properties (30).

Advanced technologies such as lithography-based ceramic manufacturing (LCM) have demonstrated promising results in producing ultra-thin veneers with improved esthetics and fit. However, these techniques require precise control of scanning, printing, and post-processing procedures (66,67).

Recent developments in printable nanohybrid materials have improved optical and mechanical properties, although post-processing remains essential for optimal surface quality (68,69). Additionally, challenges related to calibration, maintenance, and workflow complexity may limit widespread clinical adoption (70,71).

Future advancements may include the integration of artificial intelligence (AI) to optimize design processes, automate workflows, and improve material performance (72–74). These innovations may enhance precision, efficiency, and personalization in restorative dentistry.

Broader perspectives from biomedical and engineering applications further highlight both the potential and the challenges of 3D printing technologies. For example, 3D printing has demonstrated significant advantages in prosthetic design due to its rapid production, cost-effectiveness, and customization capabilities, particularly in low-resource settings (75). Similarly, studies on orthopedic and implant applications report high precision and biocompatibility of 3D-printed components, although issues related to standardization and large-scale clinical adoption remain (76). Furthermore, advancements in tissue engineering emphasize the potential of biocompatible materials and regenerative applications, while also identifying ongoing challenges in regulatory compliance, reproducibility, and quality control (77).

CONCLUSIONS

Within the limitations of the current study, it is possible to conclude that:
This systematic review identifies recent developments in 3D-printed try-ins in complex ceramic veneer cases. There is evidence that they can enhance workflow efficiency, accuracy, and material properties in controlled environments, although the quality of the available literature is poor and disjointed. These biocompatibility and patient experience results are encouraging, but conclusions on clinical benefit should be drawn with reservations. There are still considerable gaps, especially in the long-term clinical outcomes, patient satisfaction, and cost-effectiveness. There are limitations such as lack of scanning and printing specifications and inconsistency in study designs. These findings require high-quality randomized clinical trials with standardized protocols and long-term follow-up to confirm the findings and provide a guideline on routine clinical adoption.

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Authors' Contribution
The author Volodymyr Kachmar designed the study and supervised the work. conducted the experiments, collected data, performed the data analysis, and wrote the manuscript. contributed by providing scientific information and assisting in the study.

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Conflict of interest
The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Availability of data and materials: All data analyzed in this systematic review are publicly available in the published studies cited in the References section. The complete search strategy, inclusion and exclusion criteria, data extraction protocols, and quality assessment procedures are fully described in the Methodology section of this manuscript. The PRISMA flow diagram documents the selection process transparently.

Declaration of Generative AI and AI-assisted technologies
No generative AI or AI-assisted technologies were used in the preparation of this manuscript. All literature searches, study selection, data extraction, quality assessment, analysis, synthesis, and writing were conducted solely by the author without AI assistance.

REFERENCES

1. Beefathimathul H. Precision and Customization: The Role of 3D Printing in Modern Prosthodontics.EurJDent.2025;19(3):580–6. https://pmc.ncbi.nlm.nih.gov/articles/PMC12182399/
2. Suganna M, Kausher H, Tarek Ahmed S, Sultan Alharbi H, Faraj Alsubaie B, DS A, et al. Contemporary Evidence of CAD-CAM in Dentistry: A Systematic Review. Cureus. 2022;14(11):1-8. https://pubmed.ncbi.nlm.nih.gov/36561580/
3. Tribst JPM, Pereira GKR, Kleverlaan CJ. Advancements in Dental Care: The Evolving Landscape of Prosthetic Dentistry. J Clin Med. 2024;13(5):1-4. https://pmc.ncbi.nlm.nih.gov/articles/PMC10932426/
4. Yeslam HE, von Maltzahn NF, Nassar HM. Revolutionizing CAD/CAM-based restorative dental processes and materials with artificial intelligence: a concise narrativereview.PeerJ.2024;12(7):e17793. https://pmc.ncbi.nlm.nih.gov/articles/PMC11262301/
5. Belandria CDA. Comparison between conventional and digital diagnostic wax-ups in the aesthetic and functional predictability of dental prostheses. Revista CPAQV. 2025;17(1):1-6. https://doi.org/10.36692/V17N1-86R
6. Rezaie F, Farshbaf M, Dahri M, Masjedi M, Maleki R, Amini F, et al. 3D Printing of Dental Prostheses: Current and Emerging Applications. J Compos Sci. 2023;7(2):1-24. https://www.mdpi.com/2504-477X/7/2/80/htm
7. Anadioti E, Musharbash L, Blatz MB, Papavasiliou G, Kamposiora P. 3D printed complete removable dental prostheses: a narrative review. BMC Oral Health. 2020;20(1):1-9. https://doi.org/10.1186/s12903-020-01328-8
8. Jun MK, Kim JW, Ku HM. Three-Dimensional Printing in Dentistry: A Scoping Review of Clinical Applications, Advantages, and Current Limitations. Oral. 2025;5(2):1-26. https://www.mdpi.com/2673-6373/5/2/24/htm
9. Chen Y, Wei J. Application of 3D Printing Technology in Dentistry: A Review. Polymers (Basel). 2025;17(7):1-19. https://doi.org/10.3390/polym17070886
10. Kharat S, Dudhani SI, Kouser A, Subramanian P, Bhattacharjee D, Jhamb V. Exploring the Impact of 3D Printing Technology on Patient-Specific Prosthodontic Rehabilitation: A Comparative Study. J Pharm Bioallied Sci. 2024;16(Suppl 1):S423. https://pmc.ncbi.nlm.nih.gov/articles/PMC11001056/
11. Yüceer czge M, Kaynak Öztürk E, Çiçek ES, Aktaş N, Bankoğlu Güngör M. Three-Dimensional-Printed Photopolymer Resin Materials: A Narrative Review on Their Production Techniques and Applications in Dentistry. Polymers. 2025;17(3):1-30. https://www.mdpi.com/2073-4360/17/3/316/htm
12. Duarte S, Phark JH. Advances in Dental Restorations: A Comprehensive Review of Machinable and 3D-Printed Ceramic-Reinforced Composites. Journal of Esthetic and

RestorativeDentistry.2024;37(1):1-20. https://pmc.ncbi.nlm.nih.gov/articles/PMC11913211/

13. AhmedS, HawsahA, RustomR, AlamriA, AlthomairyS, AleneziM, et al. Digital Impressions Versus Conventional Impressions in Prosthodontics: A systematic Review.Cureus.2024;16(1): e51537. https://pmc.ncbi.nlm.nih.gov/articles/PMC10834103/
14. Gawali N, Shah PP, Gowdar IM, Bhavsar KA, Giri D, Laddha R. The Evolution of Digital Dentistry: A Comprehensive Review. J Pharm Bioallied Sci. 2024;16(Suppl 3):S1920. https://pmc.ncbi.nlm.nih.gov/articles/PMC11426768/
15. Bhatt S, Simre SS, Patadiya HH, Yadav D, Deepti B, Sathvi SS, Manamasa Y. 3D printing in dentistry: A review. JAMDSR. 2025;13(1):11-5. https://www.researchgate.net/publication/389888083_Review_Article_3D_Printing_in_Dentistry_A_Review
16. Jeong M;, Radomski K;, Lopez D;, Liu JT;, Lee JD;, Lee SJ, et al. Materials and Applications of 3D Printing Technology in Dentistry: An Overview. Dentistry Journal 2024, Vol 12, Page 1. 2023;12(1):1-15. https://www.mdpi.com/2304-6767/12/1/1/htm
17. Bojko Ł, Ryniewicz AM, Ryniewicz W. Strength Tests of Alloys for Fixed Structures in Dental Prosthetics. Materials (Basel). 2022;15(10):1-13. https://pubmed.ncbi.nlm.nih.gov/35629529/
18. Derksen W, Tahmaseb A, Wismeijer D. Randomized Clinical Trial comparing clinical adjustment times of CAD/CAM screw-retained posterior crowns on ti-base abutments created with digital or conventional impressions. One-year follow-up. Clin Oral Implants Res. 2021;32(8):962–70. https://pubmed.ncbi.nlm.nih.gov/34080238/
19. Hassan B, Greven M, Wismeijer D. Integrating 3D facial scanning in a digital workflow to CAD/CAM design and fabricate complete dentures for immediate total mouth rehabilitation. J Adv Prosthodont. 2017;9(5):381–6. https://lens.org/048-748-934-066-911
20. Tsuji Y, Hiraishi N, Ikeda M, Uo M, Tsuchida Y, Ushijima K, et al. Evaluation of mechanical properties and ion-releasing of 3D printing resins containing S-PRG filler: A preliminary study. Dent Mater J. 2025;44(1):34-40. https://pubmed.ncbi.nlm.nih.gov/39631951/
21. Alhallak K, Hagi-Pavli E, Nankali A. A review on clinical use of CAD/CAM and 3D printed dentures. British Dental Journal 2023. 2023;(2023)1–5. https://www.nature.com/articles/s41415-022-5401-5
22. Czigola A, Abram E, Kovacs ZI, Marton K, Hermann P, Borbely J. Effects of substrate, ceramic thickness, translucency, and cement shade on the color of CAD/CAM lithium-disilicate crowns. J Esthet Restor Dent. 2019;31(5):457–64. https://pubmed.ncbi.nlm.nih.gov/30957412/

23. Pilecco RO, Machry RV, Ribeiro VF, Dal Piva AM de O, Tribst JPM, Kleverlaan CJ, et al. Impact of try-in paste removal on the fatigue behavior of bonded lithium disilicate ceramics. J Mech Behav Biomed Mater. 2024;151(2024):1-8. https://pubmed.ncbi.nlm.nih.gov/38218045/
24. Mancuso E, Gasperini T, Maravic T, Mazzitelli C, Josic U, Forte A, et al. The influence of finishing line and luting material selection on the seating accuracy of CAD/CAM indirect composite restorations. J Dent. 2024;148(2024):1-9. https://pubmed.ncbi.nlm.nih.gov/39043328/
25. Mühlemann S, Lamperti ST, Stucki L, Hämmerle CHF, Thoma DS. Time efficiency and efficacy of a centralized computer-aided-design/computer-aided-manufacturing workflow for implant crown fabrication: A prospective controlled clinical study. J Dent. 2022;127(2022):1-7. https://pubmed.ncbi.nlm.nih.gov/36252858/
26. Porojan L, Vasiliu RD, Porojan SD. Masking Abilities of Dental Cad/Cam Resin Composite Materials Related to Substrate and Luting Material. Polymers (Basel). 2022;14(3):364-364. https://lens.org/027-585-065-624-68X
27. Jeong KW, Kim SH. Influence of surface treatments and repair materials on the shear bond strength of CAD/CAM provisional restorations. J Adv Prosthodont. 2019;11(2):95–104. https://pubmed.ncbi.nlm.nih.gov/31080570/
28. Yeslam HE, Alharbi S, Albalawi W, Hasanain FA. The effect of thermal aging on flexural strength of CAD/CAM hybrid and polymeric materials. Mater Res Express. 2023;10(9):1-14. https://iopscience.iop.org/article/10.1088/2053-1591/acfae9
29. Jensen E, Sayardoust S. Evaluation of Internal Fit in Custom-Made Posts and Cores Fabricated with Fully Digital Versus Conventional Techniques. J Funct Biomater. 2024;15(12):1-10. https://pubmed.ncbi.nlm.nih.gov/39728189/
30. Espinar C, Bona A Della, Pérez MM, Tejada-Casado M, Pulgar R. The influence of printing angle on color and translucency of 3D printed resins for dental restorations. Dent Mater. 2023;39(4):410–7. https://pubmed.ncbi.nlm.nih.gov/36914433/
31. Lee HJ, Jeong CS, Moon JM, Bae JM, Choi EJ, Oh SH. Evaluation of Manufacturing Accuracy in Merlon Fracture Models Fabricated by Vat Photopolymerization 3D-Printing Technologies. Applied Sciences (Switzerland). 2025;15(10):1-13. https://www.mdpi.com/2076-3417/15/10/5595/htm
32. Alrabeah G, Alamro N, Alghamdi A, Almslam A, Azaaqi M. Influences of luting cement shade on the color of various translucent monolithic zirconia and lithium disilicate ceramics for veneer restorations. J Adv Prosthodont. 2023;15(5):238–47. https://pubmed.ncbi.nlm.nih.gov/37936834/
33. Al-Akhali AARM, Al-Hamzi M, Al-Shami IZ, Al-Kholani AI, Madfa AA. Effect of khat extract on color stability of digitally and manually fabricated provisional restorations:

an in vitro comparative study. BMC Oral Health. 2023;23(1):1-10. https://pubmed.ncbi.nlm.nih.gov/37773116/

34. Oros D, Penčić M, Orošnjak M, Kedziora S. Additive Manufacturing Technologies and Their Applications in Dentistry: A Systematic Literature Review. Applied Sciences (Switzerland). 2025 Aug 1 [cited 2025 Oct 23];15(15):8346. https://www.mdpi.com/2076-3417/15/15/8346/htm
35. Ganbold B, Heo SJ, Koak JY, Kim SK, Cho J. Human Stem Cell Responses and Surface Characteristics of 3D Printing Co-Cr Dental Material. Materials (Basel). 2019;12(20):1-12. https://pubmed.ncbi.nlm.nih.gov/31635376/
36. Metin DS, Schmidt F, Beuer F, Prause E, Ashurko I, Sarmadi BS, et al. Accuracy of the intaglio surface of 3D-printed hybrid resin-ceramic crowns, veneers and table-tops: An in vitro study. J Dent. 2024;144(2024):1-9. https://pubmed.ncbi.nlm.nih.gov/38513937/
37. Jain S, Sayed ME, Shetty M, Alqahtani SM, Al Wadei MHD, Gupta SG, et al. Physical and Mechanical Properties of 3D-Printed Provisional Crowns and Fixed Dental Prosthesis Resins Compared to CAD/CAM Milled and Conventional Provisional Resins: A Systematic Review and Meta-Analysis. Polymers (Basel). 2022 14(13):1-40. https://pmc.ncbi.nlm.nih.gov/articles/PMC9269394/
38. Pantea M, Ciocoiu RC, Greabu M, Totan AR, Imre M, Țâncu AMC, et al. Compressive and Flexural Strength of 3D-Printed and Conventional Resins Designated for Interim Fixed Dental Prostheses: An In Vitro Comparison. Materials. 2022;15(9):1-22. https://pmc.ncbi.nlm.nih.gov/articles/PMC9104158/
39. Zhang G, Li J, Wang H, Shangguan C, Xie J, Zhou Y. Research on the Impact Toughness of 3D-Printed CoCrMo Alloy Components Based on Fractal Theory. Biomimetics. 2025;10(5):1-14. https://pmc.ncbi.nlm.nih.gov/articles/PMC12108852/
40. Bajt Leban M, Hren M, Kosec T. The microstructure, mechanical and electrochemical properties of 3D printed alloys with reusing powders. Sci Rep. 2023;13(1):1–16. https://www.nature.com/articles/s41598-023-28971-9
41. Hong JH, Yeoh FY. Mechanical properties and corrosion resistance of cobalt-chrome alloy fabricated using additive manufacturing. Mater Today Proc. 2020;29(2020):196–201. https://www.sciencedirect.com/science/article/abs/pii/S2214785320341468
42. Rouf S, Raina A, Irfan Ul Haq M, Naveed N, Jeganmohan S, Farzana Kichloo A. 3D printed parts and mechanical properties: Influencing parameters, sustainability aspects, global market scenario, challenges and applications. Adv Ind Eng Poly Res. 2022;5(3):143–58. https://www.sciencedirect.com/science/article/pii/S254250482200001X
43. Al-Fodeh RS, Al-Dwairi ZN, Almasri M, Baba NZ. Mechanical properties of 3D-printed resin denture teeth: An in vitro study. J Prosthodont. 2024;(2024) https://pubmed.ncbi.nlm.nih.gov/39210663/

44. Chuchulska B, Dimitrova M, Vlahova A, Hristov I, Tomova Z, Kazakova R. Comparative Analysis of the Mechanical Properties and Biocompatibility between CAD/CAM and Conventional Polymers Applied in Prosthetic Dentistry. Polymers. 2024;16(7):1-20. https://www.mdpi.com/2073-4360/16/7/877/htm
45. Ansarifard E, Farzin M, Parlack AZ, Taghva M, Zare R. Comparing Castability of Nickel-Chromium, Cobalt-Chromium, and Non-Precious Gold Color Alloys, Using two Different Casting Techniques. J Dent. 2022;23(1):7-12. https://pmc.ncbi.nlm.nih.gov/articles/PMC8918635/
46. Tomova Z, Vlahova A, Zlatev S, Stoeva I, Tomov D, Davcheva D, et al. Clinical Evaluation of Corrosion Resistance, Ion Release, and Biocompatibility of CoCr Alloy for Metal-Ceramic Restorations Produced by CAD/CAM Technologies. Dent J (Basel). 2023;11(7):1-12. https://pubmed.ncbi.nlm.nih.gov/37504232/
47. Tichá D, Tomášik J, Oravcová Ľ, Thurzo A. Three-Dimensionally-Printed Polymer and Composite Materials for Dental Applications with Focus on Orthodontics. Polymers. 2024;16(22):1-26. https://www.mdpi.com/2073-4360/16/22/3151/htm
48. Tian Y, Chen CX, Xu X, Wang J, Hou X, Li K, et al. A Review of 3D Printing in Dentistry: Technologies, Affecting Factors, and Applications. Scanning.2021;(2021):1-19. https://doi.org/10.1155/2021/9950131
49. Abad-Coronel C, Freire Bonilla C, Vidal S, Rosero F, Encalada Abad C, Mena Córdova N, et al. Evaluating a Novel 3D-Printed Resin for Dental Restorations: Fracture Resistance of Restorations Fabricated by Digital Press Stereolithography. Polymers. 2025;17(17):1-13. https://www.mdpi.com/2073-4360/17/17/2322/htm
50. Duarte S, Phark JH. Advances in Dental Restorations: A Comprehensive Review of Machinable and 3D-Printed Ceramic-Reinforced Composites. J Esthet Restor Dent. 2025;37(1):257–76. https://doi.org/10.1111/jerd.13371
51. Jurado CA, Afrashtehfar KI, Hyer J, Alhotan A. Effect of sintering on the translucency of CAD–CAM lithium disilicate restorations: A comparative in vitro study. J Prosthodont. 2023;32(9):861–6. https://doi.org/10.1111/jopr.13644
52. Alotaibi HN. Patient Satisfaction with CAD/CAM 3D-Printed Complete Dentures: A Systematic Analysis of the Clinical Studies. Healthcare (Switzerland). 2025;13(4):1-14. https://pmc.ncbi.nlm.nih.gov/articles/PMC11855026/
53. Srinivasan M, Kalberer N, Fankhauser N, Naharro M, Maniewicz S, Müller F. CAD-CAM complete removable dental prostheses: A double-blind, randomized, crossover clinical trial evaluating milled and 3D-printed dentures. J Dent. 2021;115(2021):1-11. https://doi.org/10.1016/j.jdent.2021.103842
54. Ahmed WM, Azhari AA, Sedayo L, Alhaid A, Alhandar R, Almalki A, et al. Mapping the Landscape of the Digital Workflow of Esthetic Veneers from Design to

Cementation: A Systematic Review. Dent J (Basel). 2024;12(2):1-20. https://pmc.ncbi.nlm.nih.gov/articles/PMC10888163/

55. Silva BP, Mahn Arteaga G, Mahn E. Predictable 3D guided adhesive bonding of porcelain veneers using 3D printed trays. Journal of Esthetic and Restorative Dentistry. 2021;33(5):692–701. https://doi.org/10.1111/jerd.12795
56. Alqutaibi AY, Alghauli MA, Aljohani MHA, Zafar MS. Advanced additive manufacturing in implant dentistry: 3D printing technologies, printable materials, current applications and future requirements. Bioprinting.;42(2024):e00356. https://www.sciencedirect.com/science/article/pii/S2405886624000289
57. Alghauli MA, Alqutaibi AY, Wille S, Kern M. The physical-mechanical properties of 3D-printed versus conventional milled zirconia for dental clinical applications: A systematic review with meta-analysis. J Mech Behav Biomed Mater. 2024;156(2024):1-22. https://www.sciencedirect.com/science/article/pii/S1751616124002339
58. Alyami MH, Alyami MH. The Applications of 3D-Printing Technology in Prosthodontics: A Review of the Current Literature. Cureus. 2024;16(9):e68501. http://doi.org/10.7759/cureus.68501
59. Keßler A, Montenbruck L, Schwendicke F, Lüchtenborg J, Kaisarly D. Narrative review of 3D-printed temporary and permanent dental resin restorations. Polym Test. 2025;151(2025):1-9. https://www.sciencedirect.com/science/article/pii/S0142941825002673
60. Wu C jui. CAD/CAM Technology in Dentistry: A Comparative Analysis of Milling and 3D Printing Techniques. MedScien. 2025;1(3):1-9. https://lseee.net/index.php/ms/article/view/308
61. Zandinejad A, Floriani F, Lin WS, Naimi-Akbar A. Clinical outcomes of milled, 3D-printed, and conventional complete dentures in edentulous patients: A systematic review and meta-analysis. J Prosthodont. 2024;33(8):736–47. https://doi.org/10.1111/jopr.13859
62. Yu F, Xiang F, Zhao J, Lin N, Sun Z, Zheng Y. Clinical outcomes of self-glazed zirconia veneers produced by 3D gel deposition: a retrospective study. BMC Oral Health. 2024;24(1):1-17. https://pmc.ncbi.nlm.nih.gov/articles/PMC11020188/
63. Ballard DH, Mills P, Duszak R, Weisman JA, Rybicki FJ, Woodard PK. Medical 3D Printing Cost-Savings in Orthopedic and Maxillofacial Surgery: Cost Analysis of Operating Room Time Saved with 3D Printed Anatomic Models and Surgical Guides. Acad Radiol. 2020;27(8):1103–13. https://pubmed.ncbi.nlm.nih.gov/31542197/
64. Popescu M, Perieanu VS, Burlibașa M, Vorovenci A, Malița MA, Petri DC, et al. Comparative Cost-Effectiveness of Resin 3D Printing Protocols in Dental Prosthodontics: A Systematic Review. Prosthesis. 2025;7(4):1-17. https://www.mdpi.com/2673-1592/7/4/78/htm

65. Borse P, Jain S, Bhasin N, Grover RK, Singh B, Longkumer P. Comparison of Dimensional Accuracy and Stability of 3D-Printed, Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM), and Conventional Polymethyl Methacrylate (PMMA) Denture Base Materials: An In Vitro Study. Cureus. 2025;17(5):e85128. https://doi.org/10.7759/cureus.85128
66. Unkovskiy A, Beuer F, Hey J, Bomze D, Schmidt F. 3D-Printed Ultra-Thin Non-Prep Lithium Disilicate Veneers: A Proof-of-Concept Clinical Case. J Esthet Restor Dent. 2025;37(6):1311–5. https://pubmed.ncbi.nlm.nih.gov/39888218/
67. Sun J, Yu S, Wade-Zhu J, Wang Y, Qu H, Zhao S, et al. 3D printing of ceramic composite with biomimetic toughening design. Addit Manuf. 2022;58(2022):103027. https://www.sciencedirect.com/science/article/abs/pii/S2214860422004195
68. Manicone PF, De Angelis P, Rella E, Damis G, D'addona A. Patient preference and clinical working time between digital scanning and conventional impression making for implant-supported prostheses: A systematic review and meta-analysis. J Prosthet Dent. 2022;128(4):589–96. https://doi.org/10.1016/j.prosdent.2020.11.042
69. Alghauli MA, Almuzaini SA, Aljohani R, Alqutaibi AY. Impact of 3D printing orientation on accuracy, properties, cost, and time efficiency of additively manufactured dental models: a systematic review. BMC Oral Health. 2024;24(1):1-16. https://pmc.ncbi.nlm.nih.gov/articles/PMC11673669/
70. Naveed N. Investigate the effects of process parameters on material properties and microstructural changes of 3D-printed specimens using fused deposition modelling (FDM). Materials Technology. 2021;36(5):317–30. https://doi.org/10.1080/10667857.2020.1758475
71. Liu PYL, Liou JJH, Huang SW. Exploring the Barriers to the Advancement of 3D Printing Technology. Mathematics. 2023;11(14):1-20. https://www.mdpi.com/2227-7390/11/14/3068/htm
72. Luo R, Zhang T, Lin G, Tang Q, Fu Z, Cheng L. Application of Artificial Intelligence Models in Oral and Maxillofacial Prosthesis Restoration: A Systematic Review. Int DentJ.;75(6):1-10. https://www.sciencedirect.com/science/article/pii/S0020653925031478
73. Farhadi F, Barnes MR, Sugito HR, Sin JM, Henderson ER, Levy JJ. Applications of artificial intelligence in orthopaedic surgery. Front Med Technol. 2022;4(2024):1-14. https://doi.org/10.3389/fmedt.2022.995526
74. Kumar R, Sporn K, Ong J, Waisberg E, Paladugu P, Vaja S, et al. Integrating Artificial Intelligence in Orthopedic Care: Advancements in Bone Care and Future Directions. Bioengineering. 2025;12(5):1-21. https://www.mdpi.com/2306-5354/12/5/513/htm
75. Borthakur PP. The Role and Future Directions of 3D Printing in Custom Prosthetic Design. Eng Proc. 2025;81(1):1-20. https://www.mdpi.com/2673-4591/81/1/10/htm

76. Wu Y, Liu J, Kang L, Tian J, Zhang X, Hu J, et al. An overview of 3D printed metal implants in orthopedic applications: Present and future perspectives. Heliyon. 2023;9(7):e17718. https://www.sciencedirect.com/science/article/pii/S2405844023049265
77. Ali F, Kalva SN, Koc M. Advancements in 3D printing techniques for biomedical applications: a comprehensive review of materials consideration, post processing, applications, and challenges. Discov Mater. 2024;4(1):1–38. https://link.springer.com/article/10.1007/s43939-024-00115-4

تجربة الطباعة ثلاثية الأبعاد لقشور السيراميك المعقدة: مراجعة منهجية

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الملخص
الأهداف: تقييم فعالية نماذج تجريبية مطبوعة بتقنية الطباعة ثلاثية الأبعاد لقشور الأسنان الخزفية المعقدة، ونتائجها السريرية، وأداء موادها، ورضا المرضى عنها، والقيود التقنية المرتبطة بها، تقييمًا منهجيًا. **مصادر البيانات**: أُجري بحث شامل في قواعد بيانات PubMed وScopus وWeb of Science وGoogle Scholar، شمل المنشورات من يناير 2010 إلى سبتمبر 2025. **معايير أهلية الدراسة**: شملت الدراسة الأبحاث المُحكّمة التي قيّمت النماذج التجريبية المطبوعة بتقنية الطباعة ثلاثية الأبعاد ضمن إجراءات تصنيع قشور الأسنان الخزفية. تضمنت التصاميم المؤهلة التجارب السريرية، والدراسات التجريبية، والدراسات الرصدية، والمراجعات المنهجية التي تُقدّم نتائج كمية أو نوعية. استُبعدت تقارير الحالات، والمقالات الافتتاحية، والمقالات غير الإنجليزية، والدراسات غير المتعلقة بقشور الأسنان الخزفية أو تصنيع النماذج التجريبية. **المواد وطرائق العمل**: تتناول هذه المراجعة تأثيرها على النتائج السريرية، ورضا المرضى عنها، والقيود التقنية المرتبطة بها. أسفر بحث منهجي في قواعد بيانات PubMed وScopus وWeb of Science وGoogle Scholar للفترة من 2010 إلى 2025 عن تحديد 2173 سجلاً، منها 19 دراسة استوفت معايير الإدراج وفقًا لإرشادات PRISMA. ركز استخلاص البيانات على خصائص الدراسة، وسير العمل الرقمي، وخصائص المواد، والنتائج السريرية، والاعتبارات التقنية. **النتائج**: نُشرت معظم الدراسات المُدرجة بعد عام 2020، وكانت في الأساس من أوروبا وآسيا، مع مساهمات كبيرة من الولايات المتحدة. أظهرت الدراسات اختلافات جوهرية في خصائص مواد الاختبار بين النماذج التجريبية المطبوعة ثلاثية الأبعاد والنماذج التقليدية. تميزت النماذج التجريبية المطبوعة ثلاثية الأبعاد بقوة شد وضغط أعلى بنسبة 25-55%، وقوة انحناء أعلى بنسبة 70-100%. كما أظهرت مقاومة فائقة للإجهاد، وثباتًا حجميًا، وتكاثرًا خلويًا أفضل. بشكل عام، حسّنت الطباعة ثلاثية الأبعاد الدقة والمتانة ورضا المرضى، مع ضرورة استمرار الحاجة إلى توحيد المواد والتحقق من صحتها على المدى الطويل. **الاستنتاجات**: توفر النماذج التجريبية المطبوعة بتقنية الطباعة ثلاثية الأبعاد أداءً ميكانيكيًا ودقةً وكفاءةً أفضل في سير العمل السريري في إجراءات تركيب قشور السيراميك المعقدة، مقارنةً بالتقنيات التقليدية. وعلى الرغم من النتائج الواعدة، إلا أن توحيد المواد، وتحسين بروتوكولات الطباعة، والتحقق السريري طويل الأمد، كلها أمور ضرورية لدعم اعتمادها على نطاق أوسع في الممارسة السريرية.
الكلمات المفتاحية: الطباعة ثلاثية الأبعاد، قشور السيراميك، طب الأسنان الرقمي، التصميم والتصنيع بمساعدة الحاسوب (CAD/CAM)، الترميم المؤقت، طب الأسنان الترميمي.