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SYSTEMATIC REVIEW

DIGITAL TRANSFORMATION OF FORENSIC IDENTIFICATION USING INTRAORAL SCANNERS, CAD/CAM, AND AI

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ABSTRACT

Introduction: *Digital dental technologies have been proposed as alternatives to conventional casts for the creation of ante-mortem (AM) records in forensic identification. However, their accuracy and forensic applicability require systematic evaluation.* ***Aim:*** *This systematic review evaluated original research on intraoral scanners, CAD/CAM systems, and AI-assisted technologies for generating ante-mortem (AM) dental records and their potential forensic applicability, with emphasis on dimensional accuracy, reproducibility, advantages, and limitations.* ***Review*****:** *The literature search was conducted through two major scientific databases, namely Google Scholar and PubMed, to identify relevant studies on digital dental records in forensic contexts. The search strategy was developed using structured keyword combinations related to forensic dentistry, digital dental records, intraoral scanners, CAD/CAM systems, and artificial intelligence. The inclusion and exclusion criteria were determined using the SPIDER framework, which consists of Sample (S), Phenomenon of Interest (PI), Design (D), Evaluation (E), and Research Type (R), to ensure that the selected studies were relevant to the objectives of this review and aligned with the research questions.* ***Conclusion:*** *Existing studies demonstrate that digital dental technologies provide high morphometric accuracy, with three-dimensional deviations remaining within clinically acceptable ranges. STL-based comparisons, surface deviation mapping, and three-dimensional superimposition offer objective analytical approaches that show strong potential for forensic application. However, direct validation under simulated forensic conditions remains limited, and further research is required before full implementation in forensic practice.*

Keywords: *artificial intelligence; CAD/CAM; odontology forensic; intraoral scanner; digital dental records*

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INTRODUCTION

Forensic odontology is a scientific discipline that examines the application of dental science within a legal framework.[1] This field supports law enforcement processes by managing, examining, evaluating, and documenting dental evidence, including human identification, age estimation, bite mark analysis, and assessment of orofacial trauma.[2]

Individual dental morphological variations and the availability of ante-mortem dental records are critical components in forensic human identification. Teeth exhibit high resistance to postmortem changes and extreme environmental conditions, making them a reliable source of morphological data and potential DNA material.[3]

Rapid advancements in digital technology have substantially transformed medical and dental practice, particularly by enhancing diagnostic precision and visualization.[4] These advancements have expanded the application of digital systems in forensic medicine and forensic odontology. Digital dental records such as intraoral scanners (IOS), Computer Aided Design and Computer Aided Manufacturing (CAD/CAM), and Artificial Intelligence (AI) analytical workflows are increasingly proposed as alternatives to conventional casts for ante-mortem (AM) forensic documentation.[5] However, despite technological progress, comprehensive evaluation of their accuracy, forensic reliability, and implementation challenges remains necessary before routine adoption.

This review aims to systematically examine original research indexed in PubMed and Google Scholar concerning the use of intraoral scanners, CAD/CAM systems, and AI-based methods for the acquisition and utilization of ante-mortem (AM) dental records in forensic applications, with emphasis on diagnostic accuracy, forensic validity, advantages, limitations, and implementation barriers.

MATERIALS AND METHODS

Study design

This study was conducted as a systematic literature review (SLR) to evaluate the use of digital dental records, including IOS, CAD/CAM, and AI technologies, as alternatives to conventional gypsum-based dental models in forensic identification. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure methodological transparency and reproducibility.[6] The analysis focused on primary data assessing the accuracy, precision, and forensic applicability of digital dental records.

Due to heterogeneity in study designs and reported outcomes, the findings were synthesized narratively rather than through meta-analysis.[7]

Figure 1. Prisma Chart Flow 2020

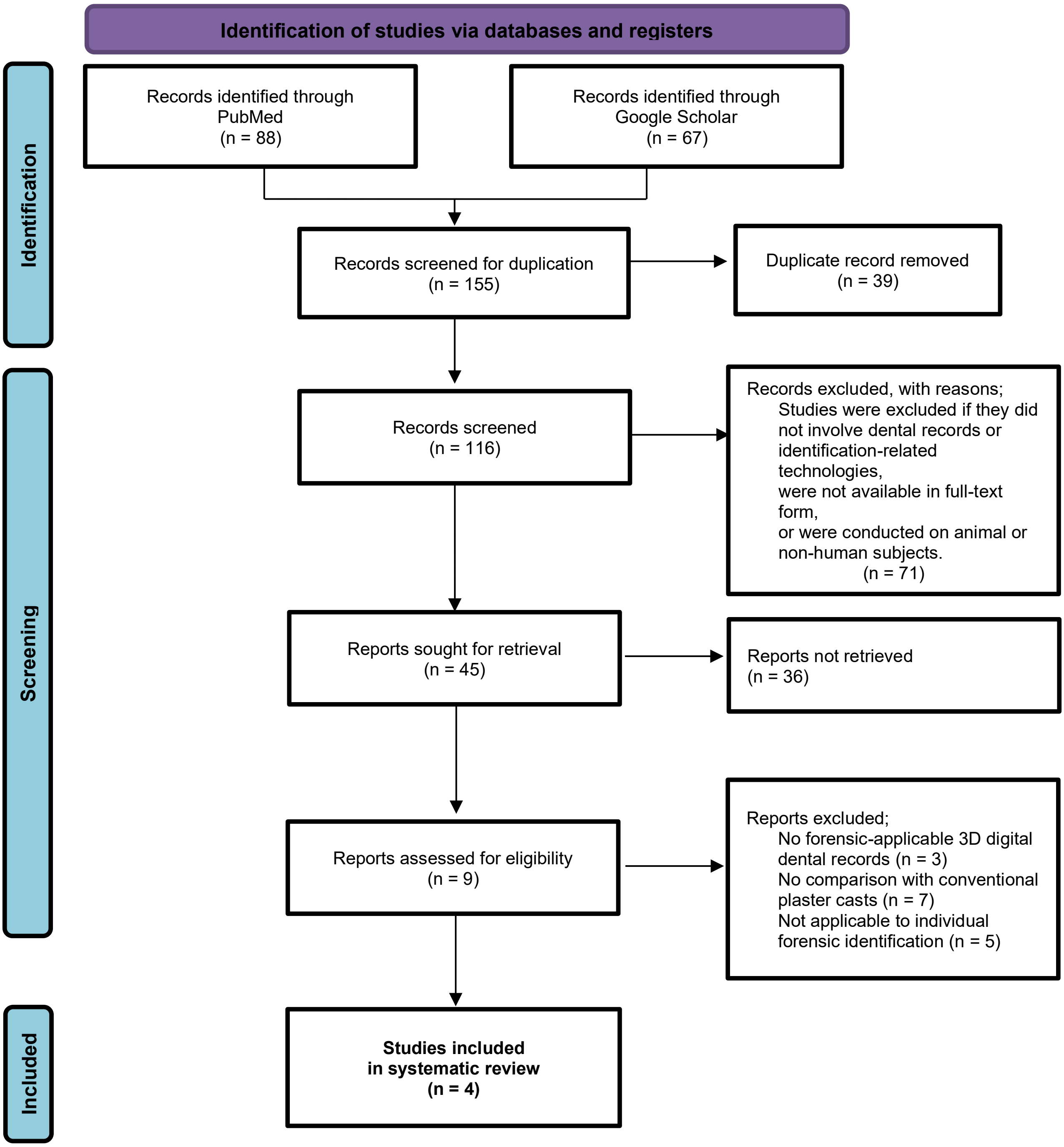

Table 1. Summary of articles included in this systematic review (n=4)

No.	Author(s) (Year)	Title of the Study	Study Objectives	Study Design	Methodology	Country, Study Setting, and Sample Characteristics	Journal Source	Type of Digital Technology	Reported Advantages	Reported Limitations	Key Findings
1	D-o-nghao Wei1 · Xiaosong Yi1, Ye Lin1, Ping Di (2024)	*An Innovative evaluation method for clinical comparative analysis of occlusal contact regions obtained via intraoral scanning and conventional impression procedures: a clinical trial*	To evaluate and compare the accuracy and consistency of occlusal contact region (OCR) recordings obtained using an intraoral scanner and conventional impression techniques through an innovative three-dimensional analytical method.	*Clinical Comparative Study*	The study included 15 participants with complete dentition and stable centric occlusion. Three occlusal recording methods were compared: 100 µm articulating paper as the control, intraoral scanning as the first test method, and conventional impression as the second test method. Occlusal contact regions were analyzed using three-dimensional superimposition. Consistency rate, positive rate, and occlusal clearance were calculated to assess recording accuracy and occlusal tightness across methods.	Beijing, China; Peking University School and Hospital of Stomatology; 15 participants with complete dentition and stable centric occlusion.	*BMC Oral Health*	Intraoral scanner (3Shape TRIOS 4); CAD/CAM-generated digital models (PLY/STL files); reverse engineering software for three-dimensional superimposition analysis (Geomagic Control).	The digital approach demonstrated high accuracy, objective quantitative analysis, and reduced errors associated with conventional methods, such as impression distortion and gypsum model dimensional changes. Digital models also allow long-term storage without physical degradation.	The accuracy of results depends on initial scan quality and software performance, with potential alignment errors related to algorithm limitations.	- The intraoral scanner demonstrated a significantly higher OCR consistency rate compared with conventional impressions (0.73 ± 0.17 vs 0.23 ± 0.13; p < 0.001). - The positive OCR rate was higher in the digital method (0.67 ± 0.15) than in the conventional method (0.56 ± 0.23), although the difference was not statistically significant (p = 0.143). - The intraoral scanner showed significantly smaller mean occlusal clearance (51.32 ± 16.04 µm) compared with the conventional method (68.20 ± 18.15 µm; p = 0.024), indicating tighter occlusal contact. - Minimum occlusal clearance was substantially lower in the digital method (−61.74 ± 35.38 µm) than in the conventional method (4.09 ± 27.15 µm; p < 0.001).

No.	Author(s) (Year)	Title of the Study	Study Objectives	Study Design	Methodology	Country, Study Setting, and Sample Characteristics	Journal Source	Type of Digital Technology	Reported Advantages	Reported Limitations	Key Findings
2.	Karthika Krishnakumar, Ritesh Kalaskar (2025)	*Comparative evaluation of digital and tray impression technique as a method of recording anatomical details of cleft lip and palate in neonates A randomized controlled clinical trial*	To evaluate the effectiveness of digital impression techniques in recording anatomical details of cleft lip and palate (CLP) in neonates and to compare them with conventional tray impression methods.	Randomized controlled clinical trial	Thirty-two neonates aged 1–15 days with cleft lip and palate were randomly allocated into two groups: conventional tray impression and digital impression technique (DIT). Evaluated parameters included anatomical detail accuracy, feeding plate adaptation, and deviations of the sulcus, ridge, and palate. Three-dimensional superimposition between the feeding plate and the maxillary arch was performed using dedicated software. Intergroup comparisons were conducted using independent t-tests.	India; Government Dental College and Hospital; 32 neonates aged 1–15 days diagnosed with cleft lip and palate, randomly assigned to conventional and digital groups.	*Journal of Indian Society of Pedodontics and Preventive Dentistry*	Medit i500 Intraoral Scanner	The digital approach demonstrated high accuracy in reproducing anatomical details and improved safety for neonates by eliminating impression materials that pose aspiration risk. Digital records allow long-term storage without dimensional changes and enable objective, quantitative analysis through software-based superimposition.	Scanning accuracy depends on device performance and operator skill. Patient movement may introduce distortion. The requirement for specialized equipment and software, along with associated costs, may limit accessibility and reliability if not properly managed.	- The majority of neonates were male (75%) with predominantly unilateral left-sided CLP (81.3%). - Measurement reliability was excellent (Kappa = 1). - APLC ($p = 0.001$) and SDMR ($p = 0.032$) were significantly higher in the tray impression technique (TIT) group. - Overextension parameters (LFLSA, BFBSM, BFBSP) were significantly higher in the TIT group ($p < 0.05$). - Superimposition analysis revealed significantly greater deviations of the sulcus, ridge, and palate in the TIT group ($p \leq 0.001$). - The digital impression technique demonstrated lower overall deviation and superior feeding plate adaptation compared with the tray impression method. - Significant intergroup differences were observed in anteroposterior cleft length ($p = 0.001$) and mid-sulcus depth ($p = 0.032$). - Overall, the digital technique provided improved surface detail reproduction, higher impression accuracy, and more optimal feeding plate adaptation.

No.	Author(s) (Year)	Title of the Study	Study Objectives	Study Design	Methodology	Country, Study Setting, and Sample Characteristics	Journal Source	Type of Digital Technology	Reported Advantages	Reported Limitations	Key Findings
3.	Mohamed M. Dohiem1, Medhat Sameh Abdelaziz, Mohamed Farouk Abdalla and Aya Mohamed Fawzy (2022)	*Digital assessment of the accuracy of implant impression techniques in free end saddle partially edentulous patients. A controlled clinical trial*	To evaluate and compare the accuracy of digital intraoral implant impressions, conventional closed-tray impressions, and conventional open-tray impressions in vivo using standardized data segmentation and best-fit algorithms, in order to address inconsistencies in previous implant impression studies.	*Controlled clinical trial (in vivo study)*	Sixteen implants placed in eight partially edentulous patients with free-end saddle cases were evaluated using four impression techniques: direct intraoral scanning (IOS) on stock abutments, IOS with scan body, conventional closed-tray, and conventional open-tray techniques. Conventional impressions were poured into stone casts and subsequently digitized using a desktop scanner. For the scan body group, CAD software was used to replace the scan body with an identical abutment. Implant positional deviations were analyzed using three-dimensional metrology software and compared using one-way ANOVA with post hoc analysis.	Sharqia, Egypt; Zagazig University; eight patients with 16 dental implants in free-end saddle partially edentulous cases.	*BMC Oral Health*	Intraoral scanner (Medit i700); scan body system (Neo Biotech IS scan body); CAD software; three-dimensional metrology analysis software.	Intraoral scanning with a scan body demonstrated superior implant impression accuracy. The digital workflow eliminates tray selection, impression disinfection, and laboratory transfer steps, while reducing material-related distortion. IOS also enhances patient comfort and enables secure long-term electronic storage of digital records.	The study was limited to free-end saddle partially edentulous cases and cannot be generalized to fully edentulous or other partially edentulous configurations. The sample size was relatively small.	- Significant differences in trueness values (RMS) were observed among impression techniques ($p < 0.001$). - Mean total deviation values were as follows: • IOS with scan body: 21.45 ± 3.3 µm (lowest deviation, highest accuracy) • Closed-tray technique: 40.04 ± 4.1 µm • Open-tray technique: 47.79 ± 4.6 µm (highest deviation) - Post hoc analysis demonstrated statistically significant differences between all groups. - Horizontal inter-abutment distance measurements differed significantly among groups ($p = 0.006$). - No significant difference was observed between IOS and the closed-tray technique in horizontal measurements ($p = 0.629$). - The open-tray technique showed the greatest horizontal deviation (267.5 ± 21.213 µm). - Incorporation of a scan body significantly improved trueness and overall dimensional accuracy. - Despite statistically significant differences, all deviations remained within clinically acceptable thresholds.

No.	Author(s) (Year)	Title of the Study	Study Objectives	Study Design	Methodology	Country, Study Setting, and Sample Characteristics	Journal Source	Type of Digital Technology	Reported Advantages	Reported Limitations	Key Findings
4.	Sinem Kahya Karaca and Kıvanc Akca (2024)	*Comparison of conventional and digital impression approaches for edentulous maxilla: clinical study*	To compare conventional and digital impression techniques used for tissue-supported complete dentures (TCSD) in edentulous maxillary patients.	*In-vivo clinical study*	Edentulous maxillary patients with healthy oral mucosa were included. In the digital group, three impression protocols were performed using an intraoral scanner (Trios 4): digital scanning without artificial intelligence (D1), digital scanning with AI-assisted scanning (D2), and a modified two-step digital protocol including occlusal rim recording (D3). In the conventional group, two impression techniques were applied: a two-step technique using a custom tray with zinc oxide eugenol (C1) and a simplified one-step technique using a stock tray with irreversible hydrocolloid (C2). Deviations between techniques were analyzed across predefined anatomical regions.	Turkey; Department of Prosthodontics, Faculty of Dentistry, Hacettepe University, Ankara; 15 edentulous maxillary patients (mean age 59.6 years) with healthy oral mucosa.	*BMC Oral Health*	Intraoral scanner (Trios 4); artificial intelligence-assisted scanning (AI-Scan)	Digital impressions demonstrated results comparable to the conventional two-step technique, considered the clinical gold standard for edentulous cases. The digital workflow produced consistent outcomes, and protocol modifications improved clinical efficiency by facilitating maxillomandibular relationship recording and reducing chairside time.	The study was limited to edentulous maxilla without long-term clinical evaluation of tissue-supported complete denture outcomes. The sample size was small and did not represent variations in ridge anatomy such as severe resorption. Only one intraoral scanner system was evaluated, limiting generalizability to other IOS systems and protocols.	- Fifteen edentulous maxillary patients were evaluated, with normally distributed deviation data. - The highest deviations were observed in the border areas. - Comparison between conventional two-step and one-step techniques (C1–C2) showed a significant difference only in the border region ($p = 0.01$). - No significant differences were found between the conventional two-step technique and digital scanning without AI (C1–D1) across all regions ($p > 0.05$). - Digital scanning with and without AI (D1–D2) showed comparable results, except for the palatal region, where a statistically significant but clinically minimal deviation was observed ($p = 0.03$). - No significant differences were observed between the standard digital protocol and the modified two-step digital protocol (D1–D3) in right and left matching areas. - Overall, digital impressions for edentulous maxilla demonstrated accuracy comparable to conventional methods and showed promising potential for clinical application.

Inclusion and exclusion criteria

Inclusion and exclusion criteria were strictly defined to ensure that the studies analyzed were relevant to the objectives and research questions of this review. Articles were included if they met the following criteria: (1) Original research presenting primary empirical data; (2) Studies evaluating digital dental records generated through intraoral scanners, CAD/CAM systems, or artificial intelligence–based technologies; (3) Studies relevant to forensic human identification, particularly those addressing ante-mortem dental record acquisition, morphometric analysis, digital reproducibility, or data comparison methods with potential forensic applicability; (4) Articles published in English; and (5) Available in full-text format.

Articles were excluded if they were narrative or systematic reviews, editorials, conference abstracts without complete datasets, non-human studies, or did not present findings that could be analytically compared with conventional gypsum-based dental models in a forensic context.

Article selection

The study selection process was conducted in accordance with the PRISMA framework. A structured literature search was performed in major international scientific databases in the fields of dentistry and forensic science using combinations of keywords related to forensic odontology, human identification, dental records, conventional impression techniques, intraoral scanning, CAD/CAM systems, and artificial intelligence.

All retrieved records were screened for duplication prior to eligibility assessment. Title and abstract screening were conducted to exclude studies that were not aligned with the research objectives. Articles deemed potentially eligible underwent full-text evaluation based on the predefined inclusion and exclusion criteria.

Two reviewers independently screened the titles, abstracts, and full-texts of articles based on the predefined eligibility criteria. Any discrepancies during the study selection process were resolved through discussion. If consensus could not be reached, a third reviewer served as the adjudicator. This selection process resulted in four studies that fulfilled the eligibility criteria and were included in the final synthesis.

Data mapping and analysis

Data from each included study were systematically extracted and organized into a synthesis table. Data extraction was independently performed by two reviewers using a standardized data extraction form. Any disagreements were resolved through discussion, with arbitration by a third reviewer if necessary. The extracted variables comprised the author and year of publication, study design, type of digital technology, reported forensic applications, comparative aspects with conventional casts, and the advantages and limitations of each digital modality.

Data were analyzed using a narrative comparative framework. Findings were categorized according to technology groups, namely intraoral scanners, CAD/CAM systems, and AI-assisted technologies. This framework facilitated a structured evaluation of technical performance, operational constraints, and forensic applicability of digital dental records in comparison with conventional casts.

Quality assessment

Methodological quality and risk of bias were evaluated to determine the strength and reliability of the evidence provided by the included studies. The methodological quality assessment was conducted independently by two reviewers using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist.[8] Any disagreements were resolved through discussion, and unresolved differences were adjudicated by a third reviewer

The assessment addressed the appropriateness of the study design, the transparency and reproducibility of digital data acquisition procedures, the validity of comparisons with conventional casts, and the relevance of reported outcomes to individual forensic identification.

The results of the quality appraisal were presented descriptively and were incorporated into the interpretation of findings. Studies were not excluded solely on the basis of quality scores, considering the limited number of available publications in the field of digital forensic odontology.

Table 2. Methodological quality assessment using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist

No.	Checklist item	Sinem Kahya Karaca (2024)	Mohamed M. Dohiem (2022)	Donghao Wei (2024)	Karthika Krishnakumar (2025)
1.	Were the criteria for inclusion in the sample clearly defined?	🟢	🟢	🟢	🟢
2.	Were the study subjects and the setting described in detail?	🟢	🟢	🟢	🟢
3.	Was the exposure measured in a valid and reliable way?	🟢	🟢	🟢	🟢
4.	Were objective, standard criteria used for measurement of the condition?	🟢	🟢	🟢	🟢
5.	Were confounding factors identified?	🟡	🟢	🟢	🟢
6.	Were the strategies to deal with confounding factors stated?	🟡	🟢	🟢	🟢
7.	Were the outcomes measured in a valid and reliable way?	🟢	🟢	🟢	🟢
8.	Was an appropriate statistical analysis used?	🟢	🟢	🟢	🟢

9.	Is it clear in the study what the cause is and what the effect is?	🟢	🟢	🟢	🟢
10.	Were the participants included in any comparisons similar?	🟢	🟢	🟢	🟢
11.	Were the participants included in any comparisons similar?	🟢	🟢	🟢	🟢
12.	Were the participants included in any comparisons receiving similiar treatmant/care, other than the exposure or intervention of interest?	🟢	🟢	🟢	🟢
13.	Was there a control group?	🟢	🟡	🟢	🟡
14.	Were there multiple measurements of the outcome both pre- and post-the intervention/exposure?	🟡	🟢	🟢	🟢
15	Was follow-up complete, and if not, were differences between groups in terms of their follow-up adequately described and analyzed?	🟢	🟢	🟢	🟢
16.	Were the outcomes of participants included in any comparisons measured in the same way?	🟢	🟢	🟢	🟢
17.	Were outcomes measured in a reliable way?	🟢	🟢	🟢	🟢
18.	Was appropiate statistical analysis used?	🟢	🟢	🟢	🟢

🟢 = Low Risk 🔴 = Unclear Risk 🟡 = High Risk

RESULTS

Search results

The literature search was conducted in two international databases, PubMed and Google Scholar. Eligibility criteria were established using the SPIDER framework, encompassing Sample, Phenomenon of Interest, Design, Evaluation, and Research type. The literature search was conducted between December 2025 and January 2026.

The inclusion criteria were defined to ensure methodological relevance and evidentiary quality. Eligible studies were original research articles presenting primary data, focused on digital dental records for forensic identification, addressing dental record acquisition processes, and employing technologies such as intraoral scanners, CAD/CAM systems, or artificial intelligence (AI).

In the initial stage of the literature search, 88 articles were identified from PubMed and 67 articles from Google Scholar, published between 2021 and 2026, using the keywords: “forensic dentistry,” “forensic odontology,” “human identification,” “dental identification,” “dental record,” “dental cast,” “conventional impression,” “study model,” “digital,” “intraoral scanner,” “CAD CAM,” and “digital impression.”

The initial search identified 155 records, comprising 88 from PubMed and 67 from Google Scholar, published between 2021 and 2026. The search strategy incorporated the following keywords: forensic dentistry, forensic odontology, human identification, dental identification, dental record, dental cast, conventional impression, study model, digital, intraoral scanner, CAD/CAM, and digital impression.

Following title and abstract screening, irrelevant publications were excluded. The remaining articles underwent full-text assessment to determine their alignment with the research objectives, methodological rigor, and availability of relevant primary data. After the final selection process, four studies met all eligibility criteria and were included in the qualitative analysis.

Article characteristics

The four included studies were published between 2021 and 2025 and were conducted in controlled clinical settings. The study designs comprised one randomized controlled trial and three prospective comparative clinical studies.

All studies evaluated the accuracy of digital models using three-dimensional analytical techniques, including surface superimposition, best-fit alignment algorithms, and deviation analysis based on root mean square (RMS) values. The assessed parameters included occlusal morphology, implant spatial positioning, palatal surface adaptation, and overall surface deviation.

Although none of the studies were conducted explicitly within a forensic setting, all provided morphometric data relevant to dental record-based human identification.

Risk of bias

The risk of bias assessment indicated that the included studies demonstrated generally acceptable methodological rigor, supported by the use of standardized measurement protocols and three-dimensional software-based analytical techniques. These methodological features reduced the likelihood of measurement bias and enhanced internal validity.

However, several limitations were identified. All studies were conducted in controlled clinical settings and were not specifically designed for forensic applications, and none simulated postmortem or extreme environmental conditions. These factors restrict the external validity and real-world applicability of the findings. Overall, the risk of bias was considered low to moderate, primarily due to contextual limitations rather than methodological weaknesses.

Digital Dental Records for Forensic Identification from an Intraoral Scanner

Intraoral scanners (IOS) facilitate the acquisition of high-resolution three-dimensional

(3D) digital representations of dental arches and maxillomandibular relationships.[9,10] These digital datasets are routinely employed in clinical dentistry for diagnostic assessment, treatment planning, and prosthodontic fabrication. Beyond their clinical utility, IOS's ability to capture precise anatomical morphology has substantial implications for forensic odontology.[11,12]

Empirical studies have demonstrated that digital impressions generated through IOS exhibit deviation levels comparable to, and in certain contexts lower than, those obtained through conventional elastomeric impression techniques.[13] The trueness and precision of digital impressions are considered clinically acceptable, particularly in single-unit restorations and short-span prostheses. Moreover, digital workflows reduce operator-dependent variability and enhance reproducibility, thereby contributing to standardized data acquisition.[14]

From a forensic perspective, the permanent digital storage of dental morphology constitutes a significant advantage. Unlike conventional casts, digital files can be archived indefinitely without risk of physical degradation, dimensional instability, or loss.[15,5] Consequently, intraoral scanning provides a reliable antemortem data source that can be retrieved and reanalyzed for comparative identification procedures.[16]

Digital Dental Records for Forensic Identification from CAD/CAM Model

Digital datasets obtained from intraoral scanners can be further processed using Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) systems.[17] These systems convert scan data into standardized file formats, such as Standard Tessellation Language (STL), enabling digital model generation and prosthetic fabrication.[18]

CAD/CAM-derived digital models preserve fine anatomical details, including cusp morphology, occlusal relationships, and interdental spacing. The high geometric fidelity of STL files enables accurate reproduction of dental structures, which is critical in forensic comparison, particularly in cases involving bite-mark analysis or fragmented remains.[19]

Importantly, digital CAD/CAM records eliminate the limitations inherent in physical storage systems. Conventional gypsum casts are susceptible to fracture, distortion, and storage constraints, whereas digital models can be stored securely in cloud-based or institutional databases.[5] The permanence, portability, and reproducibility of CAD/CAM digital records significantly strengthen their value as long-term forensic reference material.[20]

Digital Dental Records for Forensic Identification from AI-Assisted Technologies

The integration of artificial intelligence (AI) into digital dentistry represents a further advancement in data acquisition and interpretation.[21] AI-assisted intraoral scanning systems incorporate machine learning algorithms to optimize image stitching, reduce motion artifacts, and enhance margin detection during scanning procedures.[22]

By minimizing operator-related errors and improving real-time feedback, AI algorithms enhance both trueness and precision of digital impressions. Furthermore, AI-based post-processing can assist in pattern recognition, occlusal analysis, and automated comparison of dental datasets. These capabilities are particularly relevant in forensic identification, where accuracy and objectivity are paramount.[10,23]

The application of AI in digital dental record systems also supports large-scale data management and automated matching processes[24]. When integrated with forensic databases, AI technologies may facilitate rapid comparisons between antemortem and postmortem records, thereby improving identification efficiency in mass-disaster scenarios.[25,26]

Collectively, intraoral scanners, CAD/CAM systems, and AI-assisted technologies establish a robust digital ecosystem capable of generating high-quality, reproducible, and permanently stored dental data. These advancements substantiate the growing role of digital dental records as reliable alternatives to conventional plaster models in forensic identification.[27]

DISCUSSION

This review identifies a coherent digital ecosystem underpinning contemporary dental documentation: intraoral scanning (IOS) as the acquisition modality, CAD/CAM as the standardization and manufacturing framework, and artificial intelligence (AI) as the analytical layer. Recent reviews emphasize that digital dentistry should be understood as an integrated system (IOS, CAD/CAM, AI) that enhances interoperability, data storage durability, and analytical accuracy across various fields such as prosthodontics, orthodontics, and forensics.[28,29,30,31] When examined collectively rather than independently, these three components form a structurally integrated pathway that strengthens the feasibility of digital dental records for forensic identification. This systemic integration is not merely a technological progression, but a paradigm shift from material-based documentation to data-driven forensic reproducibility.[32,33] Cloud-based STL archiving systems have been shown to maintain geometric integrity over time without the dimensional degradation associated with gypsum casts, supporting the permanence required for forensic record retention.[34,35,36]

Across heterogeneous clinical scenarios, IOS has demonstrated reproducible dimensional accuracy. Wei et al. (2024) reported significantly higher OCR consistency rates and lower occlusal clearance values in IOS-derived models compared with conventional impressions, indicating greater accuracy in recording occlusal contact regions.[37]

Recent studies report that intraoral scanner trueness and precision fall within clinically acceptable ranges for full-arch, fixed prosthetic, and partially edentulous cases, confirming the reliability of IOS compared with conventional methods.[38,39] Importantly, these accuracy outcomes are not isolated findings but have been replicated across different scanner generations and clinical settings, suggesting methodological robustness. Dohiem et al. (2022) observed reduced distortion in implant-supported restorations fabricated through digital impressions, reinforcing spatial fidelity in rigid prosthetic frameworks.[40] Karaca et al. (2024) confirmed clinically acceptable trueness in edentulous maxillae, while Krishnakumar et al.

(2025) demonstrated accurate capture of complex cleft lip and palate morphology in neonates.[41,42]

Synthesized together, these findings indicate a consistent trend: IOS provides equal or superior dimensional stability compared with conventional impressions across dentate, edentulous, prosthetic, and anatomically complex cases. This convergence across structurally diverse oral conditions enhances the external validity of digital models as reliable antemortem records. From a forensic perspective, such cross-condition consistency is critical, as antemortem records often originate from diverse clinical scenarios rather than standardized research environments.[43] Quantitative comparative studies demonstrate that full-arch digital impressions consistently exhibit acceptable trueness and reduced deviation relative to conventional elastomeric impressions, particularly when recent hardware and software updates are applied.[41,44]

While IOS establishes geometric accuracy at the acquisition stage, forensic applicability ultimately depends on whether the acquired data are structurally standardized, reproducible, and legally defensible within downstream workflows. The reproducibility of STL-based superimposition allows precise three-dimensional comparison between antemortem and postmortem datasets, a fundamental requirement in forensic identification.[45] CAD/CAM technology transforms raw scan data into standardized STL files, enabling precise 3D reconstruction, landmark segmentation, and deviation analysis. Unlike plaster casts, which are susceptible to material expansion, environmental degradation, and storage limitations, CAD-generated models maintain geometric stability over time.

In implant-supported cases, the precision reported by Dohiem et al. gains additional forensic relevance when considered within CAD/CAM fabrication accuracy. Implant position, angulation, and prosthetic interfaces can be digitally preserved with micrometric fidelity, strengthening prosthesis-based identification. Similarly, the ability to segment occlusal regions (Wei et al.) within CAD software supports standardized superimposition protocols, thereby enhancing reproducibility, an essential requirement in comparative forensic assessment.

Once digital datasets are standardized and reproducible, the next critical step is to enhance analytical objectivity. The third layer, AI, further extends the analytical capacity of digital records. Although the reviewed studies primarily focused on scanning accuracy and CAD/CAM precision, emerging literature demonstrates that AI-assisted algorithms can automate landmark detection, deviation mapping, and pattern recognition in 3D dental models. When applied to IOS-derived STL datasets, AI has the potential to reduce operator-dependent variability and improve inter-examiner reliability. Emerging open-access research highlights AI augmentation in IOS workflows, including automated mesh defect correction and improved accuracy of complete-arch impressions through intelligent post-processing[46]. In forensic contexts, this may translate into objective similarity scoring systems rather than purely visual comparison, thereby enhancing methodological transparency, quantitative threshold definition, and evidentiary defensibility.

The translational implications from clinical dentistry to forensic odontology are therefore multidimensional. Wei's high consistency rate strengthens the evidentiary reliability of digital arch comparison protocols. Dohiem's implant-accuracy findings reinforce the reliability of prosthesis-based identification. Krishnakumar's documentation of complex craniofacial morphology demonstrates that IOS can capture individualizing anatomical features beyond those of the conventional dentition. When these datasets are processed within CAD/CAM systems and analyzed using AI-assisted tools, the digital workflow evolves from a clinical convenience into a potentially standardized forensic identification platform.

Despite these promising findings, the overall quality and generalizability of the available evidence remain limited. All four included studies were conducted under controlled clinical conditions rather than authentic forensic settings. Sample sizes were relatively small (8–32 participants), reducing statistical power and limiting the generalizability of the findings. Each study focused on highly selected clinical populations, including healthy dentate individuals, implant-supported cases, edentulous maxillae, or neonates with cleft lip and palate. Furthermore, none of the studies evaluated postmortem changes, thermal damage, decomposition, or disaster victim identification (DVI) scenarios. Consequently, although the available evidence consistently supports the technical accuracy of digital dental technologies, their direct applicability to forensic human identification remains indirect and should be interpreted with caution pending validation under authentic forensic conditions.

Nevertheless, the term "replacing" must be critically interpreted. Technologically, IOS integrated with CAD/CAM and potentially enhanced by AI has demonstrated sufficient precision, stability, and reproducibility to replace conventional impressions in routine clinical documentation. Digital workflows not only reduce material distortion but also streamline prosthesis fabrication with predictable outcomes, supporting a shift from analog to digital models in clinical documentation.[47] The elimination of material distortion, improved long-term archiving, and enhanced quantitative comparison collectively support this transition. Therefore, the debate no longer centers on technical feasibility, but on regulatory validation and forensic admissibility.

However, full forensic replacement requires additional validation. Forensic validity testing, including the simulation of post-mortem conditions and the legal admissibility of AI tools, remains insufficiently standardized across jurisdictions.[28,48] Most available evidence derives from clinical accuracy studies rather than simulated disaster victim identification (DVI) conditions involving fragmentation, thermal damage, or postmortem alteration. Furthermore, there is no internationally agreed deviation threshold defining a positive digital match, nor standardized AI validation protocols for forensic admissibility. Without harmonized deviation thresholds and validated AI protocols, legal acceptance of digital matches may vary across jurisdictions and face evidentiary challenges in court proceedings.

Taken together, the integration of acquisition accuracy, digital standardization, and analytical automation defines the structural foundation of a modern forensic-ready dental documentation system. Thus, digital dental records should currently be regarded as a technologically robust and logistically advantageous alternative to conventional impressions, with strong potential for forensic integration. Yet universal replacement in forensic identification remains contingent upon (1) internationally standardized deviation cut-off values, (2) validation of CAD/CAM-derived STL models under postmortem simulation, and (3) regulatory frameworks governing AI-assisted comparative analysis.

Study Limitations

The primary limitation of this review is the small number of eligible studies, with only four meeting the predefined inclusion criteria. This reflects the limited body of literature directly addressing the forensic applicability of digital dental models. Most available evidence comes from prosthodontic or orthodontic accuracy studies conducted in clinical settings rather than from investigations conducted in authentic forensic identification contexts. Consequently, the current evidence base remains indirect, and extrapolation to medico-legal casework should be undertaken with caution.

Methodological heterogeneity represents an additional constraint. The included studies employed different deviation metrics, measurement landmarks, and region-of-interest definitions. Some investigations quantified global surface deviation across full-arch datasets, whereas others assessed localized anatomical features such as cuspal morphology, occlusal contact relationships, or implant positioning accuracy. These inconsistencies in analytical endpoints limit direct quantitative comparison and prevent formal meta-analytic synthesis.

Technological variability further complicates interpretation. Different generations of intraoral scanners, optical acquisition systems, calibration protocols, and proprietary data-processing algorithms were utilized across studies. Because trueness and precision are partially device-dependent, inter-study variation in hardware and software configurations may have influenced the reported magnitudes of deviation. As a result, generalized conclusions regarding digital accuracy must be interpreted within the context of device-specific performance characteristics.

A further limitation concerns environmental validity. All included studies were conducted under controlled laboratory or ideal clinical conditions. None simulated postmortem scenarios involving thermal exposure, fragmentation, mechanical trauma, or decomposition-related tissue alteration. Such conditions may introduce distortions in dental structures or digital datasets, potentially affecting the reliability of superimposition and identification thresholds. Therefore, the translational applicability of clinical accuracy findings to disaster victim identification and forensic casework remains insufficiently validated.

Taken together, these limitations indicate that although current evidence supports the technical feasibility of digital dental records, further validation studies incorporating postmortem simulation models, standardized deviation thresholds, and cross-device calibration protocols are necessary before definitive conclusions about a universal forensic replacement can be reached.

CONCLUSION

This systematic review synthesized current evidence on digital dental records, including intraoral scanners, CAD/CAM-generated models, and artificial intelligence applications, as alternatives to conventional gypsum casts in forensic identification. Available studies consistently demonstrate high morphometric accuracy, with three-dimensional deviations generally within clinically acceptable thresholds. STL-based superimposition and surface deviation mapping provide objective analytical frameworks aligned with forensic identification principles.

Digital models offer additional structural advantages, including elimination of material distortion, reproducible duplication without physical degradation, long-term digital storage, and compatibility with analytical software systems. These features support the feasibility of transitioning from material-based documentation to standardized digital workflows.

However, existing evidence is primarily derived from controlled clinical settings rather than forensic validation studies. No included research directly evaluated ante-mortem and post-mortem comparisons, resistance to extreme environmental conditions, long-term retention stability under forensic standards, or medico-legal admissibility. Therefore, although digital dental records demonstrate strong technological capability, full forensic replacement of gypsum models remains insufficiently validated.

Future research should focus on postmortem simulation models, standardized deviation thresholds, cross-device calibration, and regulatory frameworks governing AI-assisted comparative analysis to ensure scientific reliability and legal defensibility.

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