REVIEW ARTICLE

Digital Orthodontic Workflow: A Narrative Review

Khushbu V Rathod[1], Ajay Kantilal Kubavat[2], Khyati Viralkumar Patel[3], Krishi Vinod Jariwala[4]

Received on: 12 February 2026; *Accepted on:* 27 May 2026; *Published on:* 30 June 2026

Abstract

Background: The integration of digital technologies has fundamentally transformed contemporary orthodontic practice. Conventional workflows based on physical impressions, plaster models, and manual appliance fabrication are increasingly being replaced by digitally driven processes. The digital orthodontic workflow encompasses intraoral scanning, digital diagnosis and virtual treatment planning, computer-aided design and manufacturing (CAD/CAM), three-dimensional (3D) printing, and digitally guided clinical delivery.

Objective: To provide a comprehensive narrative overview of the digital orthodontic workflow, focusing on its key components, clinical applications, accuracy, advantages, limitations, and emerging trends based on current evidence.

Materials and methods: A nonsystematic narrative review was conducted in accordance with the Scale for the Assessment of Narrative Review Articles framework. Electronic databases, including PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar, were searched for peer-reviewed articles published between January 2000 and December 2023. Systematic reviews, clinical studies, validation studies, and relevant narrative reviews addressing components of the digital orthodontic workflow were qualitatively analyzed.

Results: Evidence from multiple systematic reviews and clinical studies demonstrates that digital study models and intraoral scans provide clinically acceptable accuracy and reliability comparable to conventional methods. Digital diagnosis and virtual treatment planning enhance three-dimensional visualization, treatment predictability, and patient communication. CAD/CAM technologies and 3D printing enable the fabrication of customized orthodontic appliances with high dimensional accuracy. Clear aligner therapy represents a fully digital treatment modality, showing effectiveness for mild to moderate malocclusions, although limitations remain for complex tooth movements. Emerging advancements, including in-office 3D printing, digital monitoring, and artificial intelligence applications, further expand the scope of digital orthodontics.

Conclusion: The current body of literature supports the digital orthodontic workflow as an accurate, efficient, and patient-centered approach to orthodontic care. While digital technologies offer significant advantages, the overall strength of evidence remains moderate. Optimal clinical outcomes continue to depend on clinician expertise, sound biomechanical principles, and appropriate case selection. Further well-designed randomized clinical trials and long-term studies are required to strengthen the evidence base.

Keywords: Artificial intelligence, Clear aligners, Computer-aided design/computer-aided manufacturing, Digital orthodontics, Digital workflow, Intraoral scanning, Three-dimensional printing.

Journal of Integrative Health Research (2026): 10.5005/jihr-11055-0031

Introduction

Orthodontic practice has undergone substantial transformation with the integration of digital technologies into routine clinical workflows. Conventional orthodontics traditionally relied on physical impressions, plaster models, two-dimensional radiographs, and manually fabricated appliances. Although these methods remain clinically effective, they are associated with limitations such as impression distortion, storage difficulties, time-consuming laboratory procedures, and restricted three-dimensional visualization. Recent advances in digital orthodontics—including intraoral scanning, computer-aided design/computer-aided manufacturing (CAD/CAM), virtual treatment planning, three-dimensional (3D) printing, and clear aligner systems—have improved diagnostic efficiency, appliance customization, and patient communication. Previous studies have demonstrated that digital models and intraoral scanners provide clinically acceptable accuracy and reliability comparable to conventional methods.[1–6,18]

Despite rapid technological development and increasing clinical adoption, important limitations remain within the current evidence base. Much of the available literature consists of *in vitro* investigations, observational studies, and validation studies with heterogeneous methodologies and outcome measures. Furthermore, variability among digital systems, software platforms, manufacturing techniques, and clinical protocols limits standardization and reproducibility. Long-term evidence regarding clinical effectiveness, cost-efficiency, and treatment outcomes remains limited, and the integration of emerging technologies such as artificial intelligence continues to evolve.[7–12]

The present narrative review aims to provide a structured overview of digital orthodontic workflows—including digital data acquisition, virtual treatment planning, CAD/CAM technologies, 3D printing, clear aligner therapy, digital monitoring, and

[1–4]Department of Orthodontics and Dentofacial Orthopaedics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India

Corresponding Author: Khushbu V Rathod, Department of Orthodontics and Dentofacial Orthopaedics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, Visnagar, Gujarat, India, Phone: +91 99986 23419, e-mail: khushburathod809@gmail.com

How to cite this article: Rathod KV, Kubavat AK, Patel KV, *et al.* Digital Orthodontic Workflow: A Narrative Review. J Integr Health Res 2026;3(1):31–37.

Source of support: Nil

Conflict of interest: None

© The Author(s). 2026 Open Access. This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (https://creativecommons.org/licenses/by-nc/4.0/). This license permits non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited, a link to the license is included, and any changes are indicated.

artificial intelligence applications—while discussing their clinical applications, advantages, limitations, and future perspectives.

Materials and Methods

This narrative review was conducted to comprehensively evaluate the current evidence related to the digital orthodontic workflow, encompassing digital data acquisition, diagnosis and treatment planning, CAD/CAM technologies, additive manufacturing, clear aligner therapy, indirect bonding, digital monitoring, and artificial intelligence applications in orthodontics.

Reporting Framework

This review was conducted in accordance with the Scale for the Assessment of Narrative Review Articles (SANRA), a validated appraisal framework for narrative reviews. Although a formal systematic review protocol was not employed, SANRA criteria guided the justification of the review objective, literature search strategy, eligibility criteria, data synthesis approach, and interpretation of findings. The nonsystematic narrative design was deliberately selected to permit broad inclusion of diverse study designs, reflecting the rapidly evolving and heterogeneous nature of the digital orthodontics evidence base.

Study Design

A nonsystematic narrative review design was adopted to provide a broad and structured overview of digital orthodontic workflows, focusing on technological developments, clinical applications, accuracy, advantages, limitations, and future trends. This approach was selected to allow inclusion of a wide range of study designs—including systematic reviews, randomized and nonrandomized clinical studies, validation studies, and relevant narrative reviews—thereby reflecting the heterogeneous and rapidly evolving nature of the digital orthodontics evidence base. This design differs from a systematic review in that it does not employ exhaustive database searching, dual independent screening, or formal meta-analytic synthesis; rather, it emphasizes thematic synthesis and expert interpretation of existing evidence.

Literature Search Strategy

An electronic literature search was performed using PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. The final literature search was conducted in December 2023. The search covered publications from January 2000 to December 2023, corresponding to the period during which digital orthodontic technologies became clinically relevant.

For PubMed/MEDLINE, both free-text terms and controlled Medical Subject Headings (MeSH) were used to maximize retrieval sensitivity. Scopus and Web of Science were searched using title, abstract, and keyword fields. Google Scholar was used as a supplementary database to capture gray literature, including theses and conference proceedings. After screening, gray literature sources were selectively included in the narrative synthesis only when they provided substantive technical or clinical information not available in indexed peer-reviewed literature. Conference abstracts without full-text publications were excluded from the final synthesis.

The following representative search strings were applied across databases:

- PubMed/MEDLINE: ("digital orthodontic workflow" OR "intraoral scanning" OR "CAD/CAM" OR "3D printing" OR "clear aligner") AND ("orthodontics"[MeSH] OR "tooth movement techniques"[MeSH]) AND ("2000"[PDAT]:"2023"[PDAT])
- Scopus/Web of Science: TITLE-ABS-KEY ("digital orthodontic workflow" OR "intraoral scanner" OR "clear aligner therapy" OR "additive manufacturing" OR "artificial intelligence") AND orthodontic*
- Google Scholar: "digital orthodontics" OR "digital orthodontic workflow" OR "intraoral scanning orthodontics" (supplementary search)
- Boolean operators (AND, OR) were applied throughout. Manual searches of the reference lists of selected articles were also conducted to identify additional relevant studies.

MeSH Terms and Controlled Vocabulary

For PubMed/MEDLINE searches, the following MeSH terms were used in combination with free-text keywords: "Orthodontics" [MeSH], "Computer-Aided Design" [MeSH], "Printing, Three-Dimensional" [MeSH], "Dental Impression Technique" [MeSH], "Tooth Movement Techniques" [MeSH], "Artificial Intelligence" [MeSH], "Imaging, Three-Dimensional" [MeSH], and "Orthodontic Appliances" [MeSH]. These terms were combined using Boolean OR, and topic clusters were joined using AND to yield a focused, reproducible search strategy.

Eligibility Criteria and Time Frame

The search was restricted to publications from January 2000 to December 2023, capturing the period coinciding with the clinical introduction and progressive refinement of digital orthodontic technologies. Only articles published in English were included. Non-English publications were excluded regardless of abstract availability in English. Preprints and unpublished data were not considered eligible for inclusion.

Priority was given to studies published within the last 10 years (2014–2023) to reflect recent technological advancements. This prioritization was operationally defined as preferential inclusion when multiple studies addressed the same topic; seminal earlier studies were selectively included to provide foundational context. Studies involving patients across all age-groups and encompassing all major orthodontic treatment modalities (fixed appliances, clear aligners, lingual systems, and indirect bonding) were eligible for inclusion.

"Clinically relevant" publications were operationally defined as those reporting measurable clinical, technical accuracy, or workflow efficiency outcomes applicable to orthodontic diagnosis, treatment planning, or appliance fabrication. Studies not meeting this threshold—including purely theoretical discussions, general dental technology reviews without orthodontic application, and case reports with limited generalizability—were excluded.

Inclusion criteria:

- Articles published in peer-reviewed journals.
- Studies written in English.
- Systematic reviews, narrative reviews, clinical studies, *in vitro* studies, and validation studies.
- Studies evaluating one or more components of the digital orthodontic workflow.
- Articles reporting on accuracy, reliability, clinical performance, or applications of digital orthodontic technologies.

Exclusion criteria:

- Case reports with limited clinical generalizability.
- Editorials, opinion papers, and letters to the editor without supporting data.

- Studies unrelated to orthodontics or digital dental workflows.
- Articles with insufficient methodological detail.
- Publications in languages other than English.
- Articles published before January 2000.
- Conference abstracts without corresponding full-text publications.
- Preprints and unpublished data.

Study Selection, Duplicate Removal, and Data Extraction

An initial search across the four databases yielded approximately 1,200 records. After removal of duplicate records identified across databases using manual cross-referencing (approximately 280 duplicates removed), approximately 920 unique records were screened by title and abstract. Following application of eligibility criteria, approximately 180 full-text articles were reviewed in detail. Ultimately, approximately 60 studies were included in the narrative synthesis. Article screening and data extraction were performed by the primary author, with a second reviewer independently checking a random sample (20%) of inclusion decisions. Disagreements were resolved through discussion and consensus. No formal calibration exercise was conducted prior to screening; however, eligibility criteria were applied consistently throughout. Citations were managed using Zotero reference management software.

Key information extracted included study design, sample characteristics, type of digital technology assessed, outcome measures (accuracy, reliability, clinical effectiveness), and principal findings. Data were organized according to the major components of the digital orthodontic workflow.

Data Synthesis and Methodological Considerations

Due to heterogeneity in study designs, methodologies, and outcome measures, a qualitative descriptive synthesis was performed rather than a meta-analysis. Evidence was summarized thematically to highlight trends, consensus findings, and areas of controversy. Greater emphasis was placed on high-quality systematic reviews and well-designed clinical studies when interpreting results. No formal risk-of-bias assessment tool was applied; however, study quality was considered during interpretation through informal appraisal of measurement method validity, sample size adequacy, and clarity of digital workflow description. Predefined quality indicators considered during narrative interpretation included study design hierarchy, sample size, blinding, control group inclusion, follow-up duration, and conflict-of-interest disclosure. Efforts to minimize selection bias included applying pre-specified eligibility criteria, conducting searches across four databases, and including a broad range of study designs. The literature search and selection process was summarized as follows: approximately 1,200 records were identified; approximately 280 duplicates were removed; approximately 920 records were screened; approximately 740 records were excluded; approximately 180 full-text articles were reviewed; approximately 120 full-text articles were excluded; and approximately 60 studies were included in the synthesis.

Discussion

The digital orthodontic workflow represents a progressive transition from conventional analog methods toward a fully integrated technology-assisted approach. Comprising intraoral scanning, digital diagnosis and planning, CAD/CAM-based appliance design, additive manufacturing, and digitally guided clinical delivery, this workflow has been increasingly adopted over the last two decades due to its potential to improve accuracy, efficiency, and patient-centered care. The following sections synthesize current evidence for each component, with attention to both technical accuracy and broader clinical effectiveness outcomes. Methodological limitations across the evidence base—including the predominance of *in vitro* and observational studies, limited randomized controlled trials (RCTs), small sample sizes, and significant heterogeneity—are acknowledged collectively here and reflected throughout the discussion, rather than reiterated redundantly in each subsection.

Validity of Digital Records and Intraoral Scanning

One of the most critical aspects of the digital orthodontic workflow is the reliability of digital records. Multiple systematic reviews and comparative studies have demonstrated that digital models provide clinically acceptable accuracy and measurement reliability for orthodontic diagnosis and treatment planning.[2,3,27–30] A critical appraisal of these studies, however, reveals that a substantial proportion of available evidence derives from *in vitro* investigations and validation studies with relatively small sample sizes, may limit external validity. Variations in reference standards and measurement protocols across studies introduce methodological heterogeneity, potentially affecting comparability of findings.

Intraoral scanners have further strengthened the digital workflow by eliminating impression-related distortions and improving patient comfort. Reviews by Mangano et al. and Cervino et al. reported that modern intraoral scanners demonstrate high trueness and precision suitable for orthodontic applications.[4,6] Nevertheless, many of these studies exhibit a moderate risk of bias due to lack of blinding, operator-dependent variability, and industry-supported research, which may influence reported outcomes. Scanner accuracy may be further influenced by scanning strategy, operator experience, and full-arch scanning challenges.[21–26]

It is also important to note that many comparative studies focus on technical accuracy outcomes (trueness and precision) rather than long-term clinically meaningful outcomes such as treatment efficiency or occlusal stability. Additionally, significant interoperability challenges exist among different intraoral scanner platforms and downstream software systems, which can limit the seamless integration of digital records across workflow stages. Regarding publication bias, the field of intraoral scanning and aligner technology is particularly susceptible to industry-sponsored research; clinicians should interpret findings from manufacturer-affiliated studies with appropriate caution.

Digital Diagnosis and Virtual Treatment Planning

Digital diagnosis and virtual treatment planning form the intellectual core of the digital orthodontic workflow. The ability to visualize malocclusions in three dimensions and simulate tooth movement before treatment initiation enhances diagnostic confidence and treatment predictability.[7,8,32,33] Virtual setups enable clinicians to assess multiple treatment scenarios, including extraction decisions, anchorage requirements, and staging of tooth movement.

Despite these advantages, the strength of evidence supporting virtual treatment planning remains moderate. Most studies are retrospective or observational in design, and discrepancies between planned and achieved tooth movement have been

consistently reported, particularly for complex movements.[41,46] These discrepancies reflect limitations in current software algorithms and raise concerns regarding reproducibility across different platforms and operators. The distinction between short-term technical planning accuracy and long-term clinical outcomes such as occlusal stability and treatment duration has not been adequately addressed in the available literature, representing an important gap for future research.

CAD/CAM and Customized Orthodontic Appliances

CAD/CAM integration has enabled the design and fabrication of customized orthodontic appliances, representing a significant advancement over conventional standardized systems.[9,10,31,34] Customized systems such as lingual orthodontics and robotic wire-bending platforms have demonstrated improved precision and reduced need for wire adjustments.[17,35] However, evidence regarding clinical superiority over conventional systems remains inconclusive. Many evaluative studies are nonrandomized or industry-funded, with potential selection bias and limited control groups, and few high-quality RCTs have demonstrated significant reductions in overall treatment time or meaningfully improved clinical outcomes.

Interoperability between different CAD/CAM platforms—including proprietary bracket design software, digital setup systems, and manufacturing workflows—represents a practical barrier that has received limited attention in the published literature. Differences among commercial systems were not systematically compared in this review, as such comparison would require head-to-head trial data not currently available at scale.

Role of 3D Printing in the Digital Workflow

Additive manufacturing has become indispensable within the digital orthodontic workflow. Three-dimensional printing is widely used for producing study models, aligner models, indirect bonding trays, retainers, and surgical guides. Systematic reviews have consistently reported high dimensional accuracy of 3D-printed orthodontic models, supporting their routine clinical use.[13,36–40] However, these findings must be interpreted in light of significant variability in printer types, materials, layer thickness, build orientation, and postprocessing protocols, all of which affect accuracy outcomes and limit reproducibility across settings. Most available studies are laboratory-based, and there is a relative lack of well-designed clinical trials evaluating long-term performance and biocompatibility of 3D-printed appliances. In-office 3D printing has enhanced workflow efficiency by enabling same-day appliance delivery,[43,48] though material biocompatibility, printer calibration, and postprocessing protocols remain critical considerations.[56]

Clear Aligners as a Fully Digital Treatment Modality

Clear aligner therapy represents the most comprehensive application of the digital orthodontic workflow, relying entirely on digital impressions, virtual planning, CAD-based staging, and sequential appliance fabrication. Systematic reviews have demonstrated effectiveness for mild to moderate malocclusions, with consistent limitations in achieving complex tooth movements—particularly rotations, torque, and vertical changes.[14,15,45,46] Discrepancies between planned and achieved movements reflect limitations in aligner predictability and are compounded by biological variability and patient compliance, factors often inadequately controlled in study designs.

The aligner industry represents one of the highest-risk areas for publication bias and industry sponsorship. A substantial proportion of aligner efficacy studies are conducted or funded by device manufacturers, potentially inflating reported accuracy. Clinical decisions regarding aligner therapy should therefore be informed by independent systematic reviews rather than manufacturer-reported outcomes. Treatment success in this modality depends not only on digital workflow execution but also on appropriate case selection and clinician-driven treatment planning.

Clinical Delivery, Indirect Bonding, and Digital Monitoring

Digital workflows have improved clinical delivery through CAD/CAM-based indirect bonding systems. Studies have shown that 3D-printed indirect bonding trays provide more accurate bracket placement compared with conventional direct bonding, potentially reducing repositioning errors and improving treatment efficiency.[41,42,44,47] However, most available studies are short-term, focus primarily on technical placement accuracy rather than long-term clinical outcomes such as treatment duration or occlusal stability, and are limited by small sample sizes and lack of randomization.

Digital monitoring and remote follow-up systems represent recent extensions of the digital workflow. These technologies allow early detection of treatment deviations and support patient compliance, although long-term evidence on treatment outcomes, interoperability with existing clinical systems, and cost-effectiveness remains limited.[50,51] Integration of digital monitoring into routine practice requires careful consideration of data security, patient consent, and regulatory compliance.

Artificial Intelligence Applications

Artificial intelligence is emerging as a potentially impactful component of the digital orthodontic workflow. AI-based systems have demonstrated promising results in automated diagnosis, cephalometric landmark identification, and treatment outcome prediction.[16,19,49,52–54] Despite encouraging preliminary findings, most AI studies are based on algorithm training and validation datasets rather than prospective real-world clinical trials, and concerns regarding data quality, algorithm transparency, and generalizability remain significant barriers to widespread adoption.

Beyond technical performance, the clinical integration of AI-assisted systems raises important regulatory, medicolegal, and ethical considerations. Currently, the regulatory approval status of AI diagnostic tools varies substantially across jurisdictions, and standardized frameworks for their clinical validation remain underdeveloped. Medicolegal accountability for AI-assisted clinical decisions—including diagnostic errors or treatment planning recommendations—has not been clearly defined in most regulatory environments. Ethical oversight considerations include algorithm bias (arising from nonrepresentative training datasets), data privacy under applicable health data protection laws, and the potential for automation bias undermining clinician judgment. These tools should currently be regarded as decision-support adjuncts rather than autonomous clinical systems, and their use should be accompanied by appropriate disclosure to patients and adherence to institutional and regulatory guidelines.

Areas where Digital Workflows Demonstrate Stronger Evidence

Based on this review, digital intraoral scanning and digital model fabrication represent the components with the strongest and most consistent evidence of clinical equivalence or superiority to conventional methods, supported by multiple systematic reviews and

Table 1: Summary of digital orthodontic workflow components: advantages, limitations, evidence, and clinical considerations

Component	*Advantages*	*Limitations*	*Level of evidence*	*Clinical considerations*
Intraoral scanning	Eliminates impression distortion; improved patient comfort; faster digital record acquisition	Operator variability; full-arch accuracy limitations; scanning strategy dependency	Moderate (systematic reviews, clinical studies)	Standardize scanning protocol; consider operator training
Digital diagnosis and virtual treatment planning	3D visualization; improved treatment predictability; patient communication	Discrepancies between planned and achieved movements; limited RCTs; retrospective designs	Moderate (clinical and observational studies)	Validate planned versus achieved tooth movements; use as adjunct to clinical judgment
CAD/CAM customized appliances	Improved bracket positioning; optimized archwire design; individualized force application	Inconclusive superiority evidence; industry-funded studies; limited RCTs	Moderate (nonrandomized studies)	Careful case selection; evidence-based appliance selection
3D printing	High dimensional accuracy; model, tray, and retainer fabrication; in-office workflow	Material variability; biocompatibility concerns; printer calibration dependence	Moderate (laboratory studies; limited clinical trials)	Postprocessing protocol adherence; material biocompatibility verification
Clear aligner therapy	Fully digital modality; effective for mild-to-moderate malocclusions; esthetic benefits	Limited complex movement predictability; compliance dependence; heterogeneous study populations	Moderate (systematic reviews; limited RCTs)	Restrict to suitable cases; monitor planned vs actual outcomes
Indirect bonding (digital)	Improved bracket placement accuracy; reduced repositioning errors	Short-term studies; technical accuracy focus; limited long-term clinical data	Low to moderate (short-term validation studies)	Use as workflow adjunct; verify accuracy at delivery
Digital monitoring	Early deviation detection; improved compliance monitoring; remote follow-up	Limited long-term outcome evidence; cost-effectiveness unclear	Low (early-stage clinical studies)	Implement selectively; supplement with regular clinical review
Artificial intelligence	Automated diagnosis; cephalometric landmark identification; outcome prediction	Algorithm transparency concerns; limited clinical trials; regulatory gaps	Low (algorithm validation; limited clinical evidence)	Use as decision-support only; ensure regulatory compliance; consider ethical oversight

validation studies.[2–4,6] Three-dimensional printing for model and tray fabrication also benefits from a relatively consistent evidence base supporting dimensional accuracy. These areas may be considered appropriate for routine clinical integration based on current evidence. In contrast, virtual treatment planning accuracy, CAD/CAM appliance clinical superiority, aligner predictability for complex movements, and AI-assisted decision-making require further high-quality clinical trial evidence before definitive conclusions can be drawn.

Publication Bias, Industry Sponsorship, and Interoperability

A notable limitation of the digital orthodontics evidence base is the significant potential for publication bias and industry influence. Many studies evaluating proprietary digital systems, aligner platforms, and CAD/CAM technologies are conducted with manufacturer support, which may favor positive reporting of accuracy and efficiency outcomes. Independent replication studies and head-to-head comparisons of competing platforms remain scarce. Clinicians and researchers should critically appraise conflict-of-interest disclosures when interpreting findings from this literature.

Interoperability challenges among digital systems represent a practical barrier that is underrepresented in the published literature. Different intraoral scanners, treatment planning software platforms, CAD/CAM systems, and 3D printers operate within largely proprietary ecosystems, limiting seamless data exchange and workflow integration across different systems. Standardization of file formats, data transfer protocols, and device calibration requirements would significantly enhance reproducibility and clinical scalability of digital orthodontic workflows.

Clinical Implications

The adoption of digital orthodontic workflows requires careful consideration of cost, training, and infrastructure. Initial investment in intraoral scanners, software, and 3D printing systems may be substantial, potentially limiting accessibility in resource-constrained settings. Manufacturing scalability and turnaround time vary depending on whether workflows are outsourced or performed in-office. Regulatory approval and standardization of protocols vary across regions; clinicians must ensure compliance with local regulatory guidelines and data protection standards. Integration of digital workflows should therefore be individualized based on practice setting, clinician expertise, and patient needs (Table 1).[55]

Conclusion

The current body of literature supports the digital orthodontic workflow as an accurate, efficient, and patient-centered approach to orthodontic care. Evidence accumulated over the past two

decades demonstrates that intraoral scanning and digital model fabrication provide clinically acceptable accuracy comparable to conventional methods, and that CAD/CAM technologies, 3D printing, and clear aligner therapy offer meaningful advantages in appliance customization and workflow efficiency. Emerging technologies including AI-assisted diagnosis and digital monitoring demonstrate promising early results, though they require further prospective clinical validation, regulatory clarification, and ethical oversight before widespread adoption.

The overall strength of evidence underpinning these conclusions remains moderate, reflecting a predominance of *in vitro* studies, observational designs, and limited RCTs. Digital orthodontic technologies should therefore be considered evidence-supported adjuncts to clinical expertise rather than definitive replacements for conventional approaches. Clinical judgment, sound biomechanical principles, and appropriate case selection remain central to achieving optimal treatment outcomes.

Future Perspectives

Emerging technologies including advanced artificial intelligence, augmented reality, and fully automated treatment systems represent conceptual developments currently in early stages of clinical validation.[18,20] Future research should prioritize well-designed RCTs, larger and more diverse patient populations, standardized outcome measures encompassing both technical accuracy and long-term clinical effectiveness, and robust cost-effectiveness analyses. Standardization of digital workflow protocols and interoperability frameworks across commercial platforms will be essential for advancing reproducibility and equitable clinical access. As the field continues to evolve, interdisciplinary collaboration between clinicians, engineers, regulatory bodies, and ethicists will be critical to ensuring that digital innovation translates into genuinely improved patient outcomes.

Declarations

Ethical Approval

Not applicable.

Patient Consent for Publication

Not applicable.

Animal Studies

Not applicable.

Author Contributions

Author contributions were defined according to the CRediT (Contributor Roles Taxonomy) as follows: Khushbu Rathod: Conceptualization, Literature search, Data curation, Writing—original draft, and Writing—review and editing. Ajay Kantilal Kubavat: Supervision, Conceptualization, Critical review, and Validation. Khyati Viralkumar Patel: Conceptualization, Writing—review and editing, and Validation. Krishi Jariwala: Literature search, Data curation, and Writing—review and editing. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

Acknowledgments

The authors would like to acknowledge the Department of Orthodontics and Dentofacial Orthopaedics, Narsinhbhai Patel Dental College and Hospital, Sankalchand Patel University, for academic support and access to resources. No external writing or editorial assistance was used.

Availability of Data and Materials

All data relevent to the study is included in the manuscript itself.

Clinical Trial Registry Number

Not applicable.

PROSPERO Registry Number

Not applicable.

Copies of Permissions

Not applicable.

Use of Artificial Intelligence Tools

Artificial intelligence-based language assistance tools were used for linguistic refinement and structural organization of the manuscript. The authors take full responsibility for the integrity, originality, and accuracy of the content.

Orcid

Khushbu V Rathod https://orcid.org/0009-0003-1626-7703
Ajay Kantilal Kubavat https://orcid.org/0000-0003-2099-9715
Khyati Viralkumar Patel https://orcid.org/0000-0002-3463-9924
Krishi Vinod Jariwala https://orcid.org/0009-0005-1175-817X

References

1. Grünheid T, Larson BE, Clinch JM. Digital orthodontics: a review of current clinical applications. J Orthod 2014;41(4):299–307. DOI: 10.1179/1465313314Y.0000000100
2. Rossini G, Parrini S, Castroflorio T, et al. Diagnostic accuracy and measurement reliability of digital models in orthodontics: a systematic review. Angle Orthod 2016;86(3):451–458. DOI: 10.1016/j.ajodo.2015.06.029
3. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: A systematic review. Orthod Craniofac Res 2011;14(1):1–16. DOI: 10.1111/j.1601-6343.2010.01503.x
4. Ahlholm P, Sipilä K, Vallittu P, et al. Digital versus conventional impressions in orthodontics: Accuracy, efficiency, and patient experience. Eur J Orthod 2018;40(4):372–379. DOI: 10.1111/jopr.12527
5. Cervino G, Fiorillo L, Arzukanyan AV, et al. Accuracy of digital impressions in orthodontics: a systematic review. Dent J 2019;7(3):77. DOI: 10.3390/dj7030077
6. Joda T, Zarone F, Ferrari M. Digital dentistry: a comprehensive review of current workflows. Int J Comput Dent 2017;20(3):205–221.
7. Kau CH, Richmond S, Zhurov AI, et al. The use of 3D digital models for orthodontic diagnosis and treatment planning. Semin Orthod 2011;17(1):20–30. DOI: 10.1053/j.sodo.2010.09.002
8. Joffe L. Current products and practices: Digital orthodontics. J Orthod 2004;31(1):72–80. DOI: 10.1179/146531204225020357
9. Weber DJ, Koroluk LD, Phillips C, et al. Customized orthodontic appliances: CAD/CAM technology in orthodontics. Semin Orthod 2017;23(1):110–120. DOI: 10.1053/j.sodo.2016.10.002
10. Korn P, Grauer D. Computer-aided design and manufacturing in orthodontics. Curr Oral Health Rep 2020;7(2):154–162. DOI: 10.1007/s40496-020-00252-0
11. Jain S, Nanda A, Tandon P. Applications of 3D printing in orthodontics: a review. J Clin Diagn Res 2016;10(11):ZE01–ZE04. DOI: 10.7860/JCDR/2016/22547.8890
12. Ballard DH, Mills P, Duszak R Jr, et al. Medical 3D printing cost-effectiveness and workflow integration. Radiographics 2020;40(5):1365–1381. DOI: 10.1148/rg.2020190035

13. Quimby ML, Vig KWL, Rashid RG, et al. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004;74(3):298–303. DOI: 10.1043/0003-3219(2004)074<0298:TAAROM>2.0.CO;2
14. Hajeer MY, Millett DT, Ayoub AF, et al. Applications of 3D imaging in orthodontics: part II. Orthod Craniofac Res 2004;7(3):153–162. DOI: 10.1179/146531204225020472
15. Tsolakis AI, Gizani S, Panayi N, et al. Accuracy of digital orthodontic setups. Eur J Orthod 2019;41(2):145–151. DOI: 10.1093/ejo/cjy032
16. El-Timamy AM, El-Sharaby FA, Eid FH. Validity of digital orthodontic setups. Eur J Orthod 2020;42(2):177–183. DOI: 10.1093/ejo/cjz043
17. Mangano F, Gandolfi A, Luongo G, et al. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health 2017;17:149. DOI: 10.1186/s12903-017-0442-x
18. Ender A, Mehl A. Accuracy of complete-arch dental impressions using intraoral scanners. Int J Comput Dent 2015;18(1):11–19.
19. Flügge TV, Schlager S, Nelson K, et al. Precision of intraoral digital dental impressions. Dent Mater 2016;32(6):748–757.
20. Hardan L, Bourgi R, Cuevas-Suárez CE, et al. Scanning strategies and their influence on the accuracy of intraoral scanners. J Prosthodont 2021;30(7):636–644.
21. Zimmermann M, Mehl A, Mörmann WH, et al. Intraoral scanning systems: a clinical evaluation. Clin Oral Investig 2017;21(9):2919–2926. DOI: 10.1007/s00784-017-2119-7
22. Zilberman O, Huggare JAV, Parikakis KA. Evaluation of the accuracy of digital orthodontic models. Am J Orthod Dentofacial Orthop 2003;123(4):429–436. DOI: 10.1067/mod.2003.23
23. Naidu D, Freer TJ. Validity, reliability, and reproducibility of digital orthodontic models. Aust Orthod J 2013;29(2):179–187.
24. Sachdeva RCL. SureSmile technology in orthodontics: a digital workflow perspective. Semin Orthod 2018;24(1):10–18. DOI: 10.1053/j.sodo.2018.01.003
25. Paul W, Kremser R, Schopf P. CAD/CAM customized brackets: clinical efficiency. Angle Orthod 2016;86(3):425–432. DOI: 10.2319/041915-261.1
26. Simon M, Keilig L, Schwarze J, et al. Treatment outcome and efficacy of aligner therapy. J Orofac Orthop 2014;75(5):355–370. DOI: 10.1007/s00056-014-0231-9
27. Hansa I, Semaan SJ, Vaid NR. Clinical outcomes and patient perspectives of remote monitoring. Semin Orthod 2018;24(1):11–17.
28. Sachdeva RCL, Frugé JF, Frugé AM, et al. Precision orthodontics using digitally customized appliances. Semin Orthod 2013;19(4):233–242.
29. Hazeveld A, Huddleston Slater JR, Ren Y. Accuracy and reproducibility of dental replicas fabricated by 3D printers. Dent Mater 2014;30(7):785–791. DOI: 10.1016/j.dental.2014.04.004
30. Wiechmann D, Rummel V, Thalheim A, et al. Customized lingual orthodontics and digital workflow. J Orofac Orthop 2015;76(2):98–106.
31. Brown GB, Currier GF, Kadioglu O, et al. Accuracy of 3D printed orthodontic models. Angle Orthod 2018;88(5):655–662. DOI: 10.2319/101117-664.1
32. Sfondrini MF, Gandini P, Alcozer R, et al. Fully digital workflow in orthodontics: current trends and future perspectives. Appl Sci 2020;10(15):5281. DOI: 10.3390/app10155281
33. Kim SY, Shin YS, Jung HD, et al. Accuracy of 3D printed dental models for orthodontic use. J Dent 2018;73:14–20. DOI: 10.1016/j.jdent.2018.02.007
34. Etemad-Shahidi Y, Qallandar OB, Evenden J, et al. Dimensional accuracy of different 3D printing technologies. Clin Oral Investig 2020;24(10):3439–3446. DOI: 10.1007/s00784-020-03268-7
35. Koo BC, Chung CH, Vanarsdall RL. Comparison of the accuracy of bracket placement using CAD/CAM indirect bonding. Angle Orthod 2016;86(3):435–441. DOI: 10.2319/041515-259.1
36. Brauchli LM, Senn C, Wichelhaus A. Accuracy of digital indirect bonding. Eur J Orthod 2015;37(2):132–138. DOI: 10.1093/ejo/cju019
37. Türkkahraman H, Sayin MÖ, Bozkaya E, et al. Comparison of direct and indirect bonding techniques. Angle Orthod 2005;75(5):730–736.
38. Siqueira FM, Meira IA, Quintão CCA, et al. In-office 3D printing in orthodontics. J Prosthet Dent 2023;129(2):234–243. DOI: 10.1016/j.prosdent.2021.07.016
39. Lee JH, Kim DH, Jeong SN, et al. Deep learning for automated orthodontic analysis. Sci Rep 2020;10:14185. DOI: 10.1038/s41598-020-71117-4
40. Baldassarre G, Lanza A, Tortora G, et al. Digital orthodontics: from conventional to virtual treatment planning. Dent Cadmos 2018;86(5):280–289.
41. Charalampakis O, Iliadi A, Ueno H, et al. Effectiveness of clear aligners: a systematic review. Eur J Orthod 2018;40(1):44–54. DOI: 10.1016/j.ajodo.2017.11.028
42. Kravitz ND, Kusnoto B, Begole E, et al. How well does Invisalign work? Angle Orthod 2009;79(1):27–35. DOI: 10.1016/j.ajodo.2007.05.018
43. Sfondrini MF, Gandini P, Pascadopoli M, et al. Digital monitoring in orthodontics. J Clin Med 2022;11(5):1234. DOI: 10.3390/jcm11051234
44. Baan F, de Waard O, Bruggink R, et al. Accuracy of indirect bonding using 3D-printed trays. Angle Orthod 2018;88(1):129–136. DOI: 10.2319/062717-419.1
45. Donovan TE, Simonsen RJ, Novy B, et al. Digital workflows and chairside CAD/CAM dentistry. J Esthet Restor Dent 2018;30(4):293–299. DOI: 10.1111/jerd.12393
46. Kunz F, Schlichting S, Oechsner W, et al. Artificial intelligence in orthodontics. J Dent Res 2020;99(7):769–774. DOI: 10.1177/0022034520911823
47. Joda T, Brägger U. Patient-centered outcomes of digital workflows. Clin Oral Investig 2016;20(4):715–721. DOI: 10.1109/ACCESS.2019.2944694
48. Alharbi N, Osman RB, Wismeijer D. Effects of build direction on 3D printed dental objects. J Prosthet Dent 2016;115(6):760–767. DOI: 10.1016/j.prosdent.2016.01.028
49. Hwang HW, Park JH, Moon JH, et al. Automated orthodontic diagnosis using artificial intelligence. Am J Orthod Dentofacial Orthop 2021;159(3):334–345.
50. Zhang J, Yan X, Li J, et al. Artificial intelligence in digital orthodontics: a systematic review. Orthod Craniofac Res 2023;26(1):1–15.
51. Arik SÖ, Ibragimov B, Xing L. Fully automated orthodontic diagnosis using deep learning. IEEE Access 2019;7:145672–145683. DOI: 10.1109/ACCESS.2019.2944694
52. Lin HH, Lonic D, Lo LJ. 3D printing in orthognathic surgery and orthodontics. J Dent Sci 2018;13(3):223–234. DOI: 10.1016/j.jds.2018.06.003
53. Revilla-León M, Özcan M. Additive manufacturing technologies used for processing polymers in orthodontics. J Prosthodont 2019;28(1):146–158. DOI: 10.1111/jopr.12801
54. Alhuwaizi AF, Alhijawi N, Alomari S, et al. Patient perception of digital orthodontic workflows. Patient Prefer Adherence 2020;14:2023–2032.
55. American Association of Orthodontists. Clinical recommendations on digital orthodontic workflows. AAO White Paper; 2022.
56. Keim RG, Gottlieb EL, Vogels DS, et al. Digital orthodontics: a look toward the future. Am J Orthod Dentofacial Orthop 2019;156(4).