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Intraoral Scanners in Contemporary Dental Practice: Recent Advances, Diagnostic Capabilities, and Clinical Integration

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ABSTRACT

Intraoral scanners (IOSs) are central to the digital transformation of dentistry. Their evolution from impression tools to multifunctional platforms reflects advancements in hardware, software, and clinical integration. This review aims to present recent technological developments in IOSs, evaluate their expanding diagnostic capabilities, and examine their integration into clinical workflows across various dental specialties.A narrative review of peer-reviewed literature published within the last three years was conducted, focusing on technological innovations, clinical applications, and user experience associated with IOSs. Advancements in scanning speed, wireless functionality, and real-time image processing have significantly improved clinical efficiency and patient comfort. IOSs now support diagnostic tools for caries detection, tooth wear analysis, oral hygiene monitoring, and soft-tissue evaluation. Integration with CBCT and facial scanning technologies enables creation of digital twins for comprehensive treatment planning. Despite these innovations, challenges persist in scanning edentulous regions, achieving consistent segmentation accuracy, and integrating IOSs into large institutional settings.

Conclusion: IOSs are redefining modern dentistry by streamlining workflows, enhancing diagnostic precision, and personalizing patient care. Continued innovation and research are

needed to address existing limitations and unlock their full potential across all areas of dental and maxillofacial practice.

Keywords: Intraoral scanner, Digital dentistry, Diagnostic imaging, CAD-CAM, Oral diagnosis, Prosthodontics, orthodontics, Teledentistry, Digital workflow

INTRODUCTION

Intraoral scanners (IOSs) have become an essential component of digital dentistry, transforming how clinicians capture and process intraoral impressions. By generating high-resolution, three-dimensional virtual models, these devices have redefined workflows traditionally reliant on physical molds. Over the past decade, significant innovations in both hardware and software have dramatically enhanced the speed, precision, and clinical utility of IOSs—particularly in computer-aided design and computer-aided manufacturing (CAD-CAM) applications, where they are most commonly utilized [1].

Beyond their foundational role in impression-taking, intraoral scanners now integrate with complementary digital imaging tools such as cone-beam computed tomography (CBCT) and facial scanning systems. This synergy has broadened their clinical application into areas such as diagnosis, treatment planning, and patient monitoring. As digital technology continues to evolve, the relevance and capabilities of IOSs are poised to expand across various disciplines within dentistry and oral-maxillofacial surgery.

This review aims to provide an overview of recent advancements in IOS technologies and their diverse clinical applications. It examines key innovations in scanner hardware and software, explores diagnostic utilities, and evaluates user and patient experiences. The discussion draws upon findings from the past three years of published literature to offer a focused analysis of trends and challenges in IOS integration. The article concludes by identifying current limitations and highlighting future directions for research and development aimed at optimizing IOS use in clinical practice.

Advancements in Intraoral Scanner (IOS) Technology

Hardware Innovations

Although detailed data on the internal mechanics of IOS hardware remains limited—largely due to proprietary restrictions maintained by manufacturers—ongoing hardware improvements continue to influence clinical performance and user adoption. 1powder, and the integration of full-color imaging. These upgrades collectively contribute to enhanced efficiency, greater patient comfort, and improved visualization for clinicians.

The evolution of IOS hardware has become more incremental in recent years, with manufacturers refining existing models rather than introducing radical redesigns. Competition in the market has intensified, prompting both established companies and new entrants to differentiate themselves through ergonomic enhancements, pricing strategies, and software integration features [2].

One of the most impactful recent trends is the transition from corded to wireless, battery-powered devices. While this shift improves mobility and convenience, it also introduces concerns regarding battery life and potential connectivity issues. Some modern devices incorporate haptic feedback, offering tactile cues to assist in capturing accurate scans. Additionally, many scanners are equipped with built-in heating elements within the scanning heads to prevent condensation during extended use.

Autocalibration features in certain models further enhance usability by reducing the frequency of manual adjustments required. IOS devices are now available as standalone scanners or as components of comprehensive CAD-CAM systems, enabling efficient chairside restoration workflows [1].

Despite these advances, challenges remain. Maintaining a dry field during scanning is critical, as the presence of saliva or blood can interfere with data acquisition. Furthermore, accurately capturing subgingival margins—particularly in complex restorative cases—continues to be a technical limitation of current IOS hardware. [3]

Software Innovations

Software development has been a driving force in the advancement of intraoral scanner technology, often outpacing hardware in expanding clinical capabilities. Contemporary IOSs are equipped with algorithms that allow for continuous image capture and real-time processing, enabling smooth and seamless stitching of data into high-fidelity three-dimensional models.

These software enhancements have been pivotal in transforming intraoral scanners from simple data acquisition tools into multifunctional platforms. Modern IOS software supports a wide array of clinical applications, including computer-aided design and manufacturing (CAD-CAM), implant planning, orthodontic simulations, digital smile design, and comprehensive treatment planning. These platforms also facilitate enhanced communication with patients through visual tools that improve understanding of treatment options.

One of the key innovations in IOS software is the use of intelligent filtering techniques. These help eliminate redundant or irrelevant data—such as portions of the buccal mucosa or the tongue—thereby improving scan clarity and reducing file size. Moreover, the shift from closed, proprietary systems to open data architectures has significantly improved interoperability. Most current IOSs now support standard export formats like STL, OBJ, and PLY, each offering unique advantages. While STL files remain the most commonly used due to their simplicity, OBJ and PLY formats offer richer data by preserving texture and color information, at the cost of larger file sizes [4].

A major area of software development has been the segmentation of individual teeth from digital models. Accurate tooth segmentation is fundamental for applications in orthodontics, prosthodontics, and surgical planning. However, due to anatomical variability and challenges in distinguishing tooth-gingiva boundaries, achieving high precision in automated segmentation has proven difficult. Traditional methods require extensive labeled datasets and manual annotation, which are time-intensive and limit scalability [5]. For example, a fully automated, fault-aware system based on deep learning achieved impressive results in tooth segmentations, with 94% of cases being deemed clinically viable by experts without the need for additional corrections [6].

Emerging approaches leveraging deep neural networks now offer promising solutions. These systems utilize self-supervised learning during pretraining, followed by supervised fine-tuning, allowing them to deliver clinically viable results with reduced dependence on manually labeled data. Such technologies are improving the feasibility of automated, high-accuracy segmentation and advancing the diagnostic potential of IOSs [7].

In addition, software tools are being developed for automated landmark recognition, essential for orthodontic analysis and outcome prediction. By combining machine learning and linear programming, these systems can identify and label tooth landmarks, speeding up routine evaluations [8]. While human oversight remains necessary, these advancements mark a significant step toward reliable, reproducible, and time-efficient digital model analysis [4].

Collectively, these software innovations are expanding the role of IOSs well beyond impression capture—positioning them as integral tools in modern digital diagnostics, treatment planning, and patient communication.

Diagnostic Capabilities of Intraoral Scanners

The evolution of intraoral scanner technology has significantly extended its utility beyond impression-taking. Modern IOS systems now contribute meaningfully to diagnostics, offering tools for detecting dental caries, monitoring tooth wear, assessing oral hygiene, evaluating soft-tissue conditions, and determining tooth shade. These capabilities have the potential to improve clinical decision-making while enhancing patient engagement in their own care.

Caries Detection

Several intraoral scanners are now equipped with adjunctive diagnostic features aimed at early caries detection. These systems typically employ fluorescence-based methods using violet light (around 415 nm) or near-infrared imaging (727–850 nm) to identify demineralized tooth structures. Depending on the technology used, scanners can detect proximal, occlusal, or both types of lesions [9].

Comparative studies have demonstrated that fluorescence-enabled IOSs can perform on par with visual examinations for detecting occlusal caries in permanent molars [10]. In both laboratory and clinical settings, the diagnostic accuracy of these scanners was consistent. However, the presence of biofilm can increase the likelihood of false positives, underscoring the importance of appropriate scan preparation.

Further research has shown that IOSs equipped with near-infrared imaging can offer diagnostic performance comparable to bitewing radiography in certain clinical contexts [11]. Nevertheless, outcomes vary depending on clinician experience, with more accurate diagnoses achieved by practitioners familiar with interpreting IOS-generated images.

Despite promising evidence, the reliability of near-infrared imaging for caries detection remains mixed, particularly in pediatric populations. Some studies indicate high sensitivity for enamel lesions, while others suggest limited diagnostic value without complementary radiographic data [12].

In addition to caries detection, IOSs can visualize developmental enamel defects. However, features like color enhancement and digital magnification may exaggerate the perceived severity of these anomalies, such as fluorosis or molar-incisor hypomineralization [12].

Tooth Wear Monitoring

Intraoral scanners offer a noninvasive and quantitative approach to tracking tooth surface loss over time. Using best-fit alignment algorithms, IOS software can superimpose sequential scans to assess changes with an accuracy margin of approximately ±15 µm in controlled conditions [13]. Although this level of precision is insufficient to detect very early wear, it is effective in identifying and monitoring clinically relevant changes.

Clinical studies suggest that changes exceeding 70 µm can be reliably detected, making periodic scans every 1 to 3 years a practical strategy for monitoring tooth wear [14]. However, the absence of stable intraoral reference points may introduce variability. Improved alignment algorithms or designated anatomical landmarks could enhance scan consistency in future iterations.

Oral Hygiene Assessment

Digital planimetry using IOS-acquired images has shown promise for accurately assessing plaque accumulation [15]. By applying disclosing agents and analyzing the color images, clinicians can perform comprehensive evaluations of dental plaque distribution across all tooth surfaces. This method has proven more precise than conventional photographic assessments [16].

Moreover, smartphone-enabled intraoral scanning has been tested for home-based plaque monitoring. In one randomized controlled trial, patients received automated feedback based on machine-learning evaluations of visible plaque, leading to measurable improvements in periodontal health [17]. These findings highlight the potential for IOSs—and by extension, patient-operated imaging—to support behavior modification and personalized oral hygiene strategies.

Soft-Tissue Evaluation

Intraoral scanners are increasingly used for the quantitative analysis of gingival recession and peri-implant soft-tissue contours [18,19]. Superimposition of sequential scans enables clinicians to track soft-tissue changes with greater accuracy than conventional methods. However, scan precision is influenced by the operator's skill, scanner type, and the anatomical region being assessed. Posterior and interproximal regions remain particularly challenging due to limited accessibility and lighting conditions [18-21].

Tooth Shade Determination

Certain IOSs equipped with color scanning technology offer tools for estimating tooth shade. While some studies report comparable accuracy to traditional visual methods, systematic reviews indicate that IOS-based shade matching is still inferior to spectrophotometry [22]. The limitations are primarily attributed to inconsistent lighting and the inability to maintain optimal angulation during scanning. As a result, IOSs are currently best suited for supporting, rather than replacing, other shade determination methods [23].

Clinical Integration of Intraoral Scanners

Patient and Clinician Experience: Benefits and Challenges

While the adoption of intraoral scanners has been most prominent in digital prosthodontics and restorative workflows, their integration into broader diagnostic routines is steadily increasing. One of the primary advantages of IOSs is the enhanced comfort they provide for patients. Unlike traditional impression techniques, which can provoke gag reflexes or discomfort, digital impressions are generally better tolerated and often preferred by patients.

From a clinical perspective, IOSs improve workflow efficiency and reduce the turnaround time for prosthetic fabrication [4,24]. Surveys have shown growing interest among dental practitioners in incorporating IOSs into their practices, particularly for single-unit restorations [2,25]. Among current users, the perceived benefits include increased accuracy, time savings, and improved communication with dental laboratories. However, high initial costs remain a significant barrier to adoption, especially for smaller clinics.

Large institutional settings face additional hurdles. The integration of IOS systems with existing electronic health records can be technically complex, requiring robust data management protocols and adequate training for clinicians and support staff. Furthermore, secure handling of large imaging datasets and concerns about data storage can hinder seamless implementation. As a result, the pace of IOS adoption tends to be slower in academic or hospital-based dental centers compared to private practices [26].

Accuracy Considerations: Trueness and Precision

For IOSs to be reliable in clinical practice, both trueness (how closely a scan represents the actual anatomy) and precision (the consistency of repeated scans) must meet acceptable standards. These parameters are commonly assessed using root mean square error (RMSE) values, which quantify the deviation between a reference model and the IOS-acquired scan. Lower RMSE values indicate higher accuracy [27].

Recent studies have shown that many current-generation IOSs can achieve clinically acceptable accuracy for capturing full-arch scans in dentate patients. However, their performance is often less reliable in edentulous areas due to the absence of anatomical landmarks[2]. In such cases, conventional impressions may still be necessary—particularly when recording soft-tissue dynamics or fabricating complete dentures.

In implant dentistry, where passive fit is critical, IOSs have demonstrated acceptable accuracy for single and short-span implant-supported restorations [28]. However, challenges remain when capturing full-arch implant configurations [29]. Innovations such as horizontally oriented scan gauges—which reduce the need for scanner rotation—are being developed to improve spatial accuracy by minimizing stitching errors during scan acquisition [30].

For conventional fixed prosthetics, IOSs provide marginal and internal fit results that are comparable to those of traditional impressions. Systematic reviews confirm that, across various clinical studies, IOSs offer reliable results for crowns and fixed partial dentures. Nevertheless, significant variability persists among different IOS models and even between successive generations of the same device, underscoring the importance of device selection and clinician training [31].

Digital Twin Integration for Enhanced Treatment Planning

The convergence of intraoral scanning technology with cone-beam computed tomography (CBCT) and 3D facial imaging has enabled the creation of highly accurate "digital twins"—virtual representations that replicate patients' anatomical structures with remarkable detail. These integrated models allow for comprehensive treatment planning by providing a holistic view of dental, skeletal, and soft-tissue components.

Digital twins play a pivotal role in procedures that require precise spatial visualization, such as implant placement, orthodontic planning, and endodontic navigation [32]. For instance, the fusion of IOS data with CBCT scans facilitates static and dynamic guidance systems for placing orthodontic mini-implants or performing guided endodontic access in calcified canals [33]. Similarly, overlaying IOS and facial scan data enables more individualized aesthetic planning through digital smile design.

Prosthodontics: Addressing Complexities with IOSs

In complex prosthodontic cases, particularly those involving edentulous zones or free-end saddles, capturing accurate maxillomandibular relationships remains a clinical challenge. Evidence suggests that quadrant scans focused on buccal surfaces during intercuspation yield higher accuracy than full-arch scans when recording occlusal relationships in dentate patients [34]. However, for extensive implant-supported restorations, digital bite registration still presents limitations due to alignment errors introduced during mesh merging [35].

Efforts are underway to develop virtual articulators that simulate mandibular movements using patient-specific IOS data. Although promising, minor translational discrepancies between aligned digital meshes can distort occlusal relationships, thus limiting the clinical application of these systems for now [36].

For full-arch implant impressions, alternative techniques such as photogrammetry are gaining traction. This method uses high-resolution photographs of scan bodies with fixed reference markers to calculate implant positions with minimal stitching. While early results show high accuracy, especially in fully edentulous arches, supporting data remain limited and mostly derived from controlled or case-based studies [37].

Orthodontics: Enabling Digital-First Workflows

Intraoral scanners have transformed modern orthodontic practice, enabling virtual diagnostics and aligner-based treatment planning. While some studies report inconsistent accuracy when comparing IOS-derived measurements to traditional models, especially in cases involving crowding or appliances, recent evidence supports the feasibility of obtaining accurate digital impressions—even with multibracket appliances in place [38].

Furthermore, combining IOS data with CBCT imaging allows for real-time prediction of root positions during or after orthodontic treatment. This approach reduces the need for multiple radiographic exposures while enhancing treatment precision [33,39].

Oral and Maxillofacial Surgery: Versatile Utility Across Age Groups

IOSs have demonstrated clinical utility in oral and maxillofacial surgery, particularly for managing congenital anomalies such as cleft lip and palate. Studies from specialized care centers show that IOSs can be effectively used across various age groups—from neonates to preschoolers—whether patients are awake or under general anesthesia [29,40,41].

The benefits extend beyond patient safety by reducing the risks associated with conventional impression materials, especially in airway-compromised individuals. IOSs also enable digital workflows for fabricating nasoalveolar molding appliances, speech prostheses, and surgical plates [42,43]. Additionally, these digital scans can be used to assess facial symmetry, monitor postoperative healing, and assist in presurgical planning for craniofacial reconstruction.

In maxillofacial prosthetics, IOSs have been used experimentally to capture extraoral defects such as auricular or orbital voids. Although they may not yet match the accuracy of high-end facial scanners, IOSs offer a cost-effective and accessible alternative for clinical environments lacking advanced imaging resources [44].

Teledentistry: Expanding Access Through Remote Scanning

Intraoral scanners are increasingly being utilized in teledentistry workflows to facilitate remote consultations and triage. The ability to transmit high-quality, true-color 3D images allows clinicians to assess dental conditions from afar, supporting early diagnosis and treatment planning without requiring in-person visits. Preliminary studies suggest that remote evaluations based on IOS-generated images can accurately detect a range of dental findings, although assessments of periodontal conditions remain inconsistent [45].

Further innovation involves patient-operated intraoral imaging using smartphones. When combined with artificial intelligence–powered feedback systems, this approach can support remote monitoring of treatments such as clear aligner therapy or post-periodontal care. However, the technology is still maturing. Studies have indicated that while such systems may assist with detecting issues like aligner misfits, they currently cannot replace in-person supervision and are best viewed as supplemental tools [46].

Forensic Dentistry: A Novel Application of IOS Technology

Beyond clinical use, intraoral scanners are being explored in forensic dentistry. Unique anatomical structures, such as the anterior palate, can serve as biometric identifiers, and IOS-acquired records may expedite identification efforts when pre-existing digital data is available [47,48]. The potential for highly reproducible and detailed digital dental records makes IOSs a valuable asset for forensic investigations, particularly in mass disaster or missing persons scenarios [48].

CONCLUSION AND FUTURE DIRECTIONS

Intraoral scanners have revolutionized digital dentistry, enabling streamlined workflows, enhanced diagnostics, and improved patient comfort. While their primary applications lie in CAD-CAM fabrication and restorative dentistry, their integration into orthodontics, oral surgery, diagnostics, and even remote care illustrates their expanding role across dental specialties.

The rise of machine learning—especially deep learning—has empowered new capabilities such as automated tooth segmentation, landmark detection, and predictive modeling. However, several limitations still need to be addressed: ensuring scanning accuracy in edentulous regions, improving diagnostic reliability for conditions such as caries or gingival recession, and integrating IOSs into large institutional systems remain critical areas for improvement.

Future research should focus on optimizing the cost-effectiveness and interoperability of IOSs, especially for use in high-volume practices and educational institutions. Enhancements in user-friendly interfaces, data security, and cloud-based storage solutions will further streamline adoption. There is also strong potential in extending IOS functionality into areas such as teledentistry, augmented reality, and robotic-assisted interventions.

With continued innovation and validation, intraoral scanners are well-positioned to serve not only as impression tools but as comprehensive digital platforms for personalized diagnostics, treatment planning, and patient-centered care.

REFERENCES

1. Baan F, Bruggink R, Nijsink J, Maal TJJ, Ongkosuwito EM. Fusion of intra-oral scans in cone-beam computed tomography scans. *Clinical oral investigations* 2021;*25*:77-85.
2. Al-Hassiny A, Végh D, Bányai D, Végh Á, Géczi Z, Borbély J, et al. User experience of intraoral scanners in dentistry: transnational questionnaire study. Int Dent J. 2023;73(5):754–759.
3. Tabesh M, Nejatidanesh F, Savabi G, Davoudi A, Savabi O. Marginal accuracy of lithium disilicate full-coverage single crowns made by direct and indirect digital or conventional workflows: a systematic review and meta-analysis. J Prosthodont. 2022;31(9).
4. Bandiaky ON, Le Bars P, Gaudin A, Hardouin JB, Cheraud-Carpentier M, Mbodj EB, Soueidan A. Comparative assessment of complete-coverage, fixed tooth-supported prostheses fabricated from digital scans or conventional impressions: a systematic review and meta-analysis. J Prosthet Dent. 2022;127(1):71–79.
5. Vinayahalingam S, Kempers S, Schoep J, Hsu T-MH, Moin DA, van Ginneken B, Flügge T, Hanisch M, Xi T. Intra-oral scan segmentation using deep learning. BMC Oral Health. 2023;23(1):643.
6. Hao J, Liao W, Zhang YL, Peng J, Zhao Z, Chen Z, Zhou BW, et al. Toward clinically applicable 3-dimensional tooth segmentation via deep learning. J Dent Res. 2022;101(3):304–311.
7. Liu Z, He X, Wang H, Xiong H, Zhang Y, Wang G, et al. Hierarchical self-supervised learning for 3D tooth segmentation in intra-oral mesh scans. IEEE Trans Med Imaging. 2023;42(2):467–480.
8. Woodsend B, Koufoudaki E, Mossey PA, Lin P. Automatic recognition of landmarks on digital dental models. Comput Biol Med. 2021;137:104819.

9. Cuenin K, Chen J, Tai SK, Lee D, Gerges G, Oh H. Caries detection and characterization in pediatric patients using iTero 5D near-infrared technology. Am J Orthod Dentofacial Orthop. 2023;165(1):54–63.
10. Michou S, Lambach MS, Ntovas P, Benetti AR, Bakhshandeh A, et al. Automated caries detection in vivo using a 3D intraoral scanner. Sci Rep. 2021;11(1):21276.
11. Metzger Z, Colson DG, Bown P, Weihard T, Baresel I, Nolting T. Reflected near-infrared light versus bite-wing radiography for the detection of proximal caries: a multicenter prospective clinical study conducted in private practices. J Dent. 2022;116:103861.
12. Cardoso-Silva L, Vicioni-Marques F, de Paula-Silva, Francisco Wanderley, et al. Comparison between intraoral scanning and direct visual analysis for the assessment of developmental defects of enamel. J Dent. 2023;137:104677.
13. Witecy C, Ganss C, Wöstmann B, Schlenz MB, Schlenz MA. Monitoring of erosive tooth wear with intraoral scanners in vitro. Caries Res. 2021;55(3):215–224.
14. Bronkhorst H, Bronkhorst E, Kalaykova S, Pereira-Cenci T, Huysmans M-C, Loomans B. Inter- and intra-variability in tooth wear progression at surface-, tooth- and patient-level over a period of three years: a cohort study: inter- and intra-variation in tooth wear progression. J Dent. 2023;138:104693.
15. Doi K, Yoshiga C, Kobatake R, Kawagoe M, Wakamatsu K, Tsuga KUse of an intraoral scanner to evaluate oral health. J Oral Sci. 2021;63(3):292–294.
16. Jung K, Giese-Kraft K, Fischer M, Schulze K, Schlueter N, Ganss C. Visualization of dental plaque with a 3D-intraoral-scanner - a tool for whole mouth planimetry. PLoS One. 2022;17(10):e0276686.
17. Shen K-L, Huang C-L, Lin Y-C, Du J-K, Chen F-L, et al. Effects of artificial intelligence-assisted dental monitoring intervention in patients with periodontitis: a randomized controlled trial. J Clin Periodontol. 2022;49(10):988–998.
18. Kuralt M, Fidler A. A novel computer-aided method for direct measurements and visualization of gingival margin changes. J Clin Periodontol. 2022;49(2):153–163.
19. Kuralt M, Gašperšič R, Fidler A. Methods and parameters for digital evaluation of gingival recession: a critical review. J Dent. 2022;118:103793.
20. Dritsas K, Halazonetis D, Ghamri M, Sculean A, Katsaros C, Gkantidis N. Accurate gingival recession quantification using 3D digital dental models. Clin Oral Investig. 2023;27(4):1697–1705.
21. Song YW, Bienz SP, Benic GI, Cha J-K, Hämmerle CHF, Jung U-W, Jung RE. Soft-tissue dimensional change following guided bone regeneration on peri-implant defects using soft-type block or particulate bone substitutes: 1-year outcomes of a randomized controlled clinical trial. J Clin Periodontol. 2023;50(2):147–157.

22. Tabatabaian F, Namdari M, Mahshid M, Vora SR, Mirabbasi S. Accuracy and precision of intraoral scanners for shade matching: a systematic review. J Prosthet Dent. 2022;S0022-3913(22)00565-0.
23. Akl MA, Mansour DE, Zheng F. The role of intraoral scanners in the shade matching process: a systematic review. J Prosthodont. 2023;32(3):196–203.
24. Serrano-Velasco D, Martín-Vacas A, Paz-Cortés MM, et al. Intraoral scanners in children: evaluation of the patient perception, reliability and reproducibility, and chairside time - a systematic review. Front Pediatr. 2023;11:1213072.
25. Revilla-Leon M, Frazier K, Da Costa JB, et al. Intraoral scanners: an American Dental Association Clinical Evaluators Panel survey. J Am Dent Assoc. 2021;152(8):669–670.e2.
26. Jahangiri L, Akiva G, Lakhia S, Turkyilmaz I. Understanding the complexities of digital dentistry integration in high-volume dental institutions. Br Dent J. 2020;229(3):166–168.
27. Vitai V, Németh A, Sólyom E, Czumbel LM, Szabó B, Fazekas R, Gerber G, Hegyi P, Hermann P, Borbély J. Evaluation of the accuracy of intraoral scanners for complete-arch scanning: a systematic review and network meta-analysis. J Dent. 2023;137:104636.
28. Schmidt A, Wöstmann B, Schlenz MA. Accuracy of digital implant impressions in clinical studies: a systematic review. Clin Oral Implants Res. 2022;33(6):573–585.
29. Ayoub A, Khan A, Aldhanhani A, Alnaser H, Naudi K, Ju X, Gillgrass T, Mossey P. The validation of an innovative method for 3D capture and analysis of the nasolabial region in cleft cases. Cleft Palate Craniofac J. 2021;58(1):98–104.
30. Giglio GD, Giglio AB, Tarnow DP. A paradigm shift using scan bodies to record the position of a complete-arch of implants in a digital workflow. Int J Periodontics Restorative Dent. 2023;44(1):115–126.
31. Mahat NS, Shetty NY, Kohli S, Jamayet NB, Patil P. Clinical outcomes of implant-supported and tooth-supported fixed prostheses fabricated from digital versus analogue impression: a systematic review and meta-analysis. Evid Based Dent. 2023;24(3):142.
32. Lee J-H, Lee H-L, Park I-Y, On S-W, Byun S-H, Yang B-E. Effectiveness of creating digital twins with different digital dentition models and conebeam computed tomography. Sci Rep. 2023;13(1):10603.
33. Christopoulou I, Kaklamanos EG, Makrygiannakis MA, Bitsanis I, Perlea P, Tsolakis AI. Intraoral scanners in orthodontics: a critical review. Int J Environ Res Public Health. 2022;19(3):1407.
34. Morsy N, El Kateb M. In vivo precision of digital static interocclusal registration for full arch and quadrant arch scans: a randomized controlled clinical trial. BMC Oral Health. 2022;22(1):559.

35. Joda T, Gintaute A, Brägger U, Ferrari M, Weber K, Zitzmann NU. Time-efficiency and cost-analysis comparing three digital workflows for treatment with monolithic zirconia implant fixed dental prostheses: a double-blinded RCT. J Dent. 2021;113:103779.
36. Schlenz MA, Schupp B, Schmidt A, Wöstmann B, Baresel I, Krämer N, SchulzWeidner N. New caries diagnostic tools in intraoral scanners: a comparative in vitro study to established methods in permanent and primary teeth. Sensors (Basel). 2022;22(6):2156.
37. Gómez-Polo M, Barmak AB, Ortega R, Rutkunas V, Kois JC, Revilla-León M. Accuracy, scanning time, and patient satisfaction of stereophotogrammetry systems for acquiring 3D dental implant positions: a systematic review. J Prosthodont. 2023;32(S2):208–224.
38. Palone M, Bellavia M, Floris M, Rombolà A, Cremonini F, Albertini P, Lombardo L. Evaluation of effects of brackets and orthodontic wires on intraoral scans: a prospective in-vivo study. Orthod Craniofac Res. 2023;27(1):44–54.
39. Lee S-C, Hwang H-S, Lee KC.. Accuracy of deep learning-based integrated tooth models by merging intraoral scans and CBCT scans for 3D evaluation of root position during orthodontic treatment. Prog Orthod. 2022;23(1):15.
40. Benitez BK, Brudnicki A, Surowiec Z, Wieprzowski Ł, Rasadurai A, Nalabothu P, Lill Y, Mueller AA. Digital impressions from newborns to preschoolers with cleft lip and palate: a two-centers experience. J Plast Reconstr Aesthet Surg. 2022;75(11):4233–4242.
41. Weise C, Frank K, Wiechers C, Weise H, Reinert S, Koos B, Xepapadeas AB. Intraoral scanning of neonates and infants with craniofacial disorders: feasibility, scanning duration, and clinical experience. Eur J Orthod. 2022;44(3):279–286.
42. Abreu A, Lima MH, Hatten E, Klein L, Levy-Bercowski D. Intraoral digital impression for speech aid/obturator in children: report of 2 Cases. Cleft Palate Craniofac J. 2022;59(2):262–267.
43. Shanbhag G, Pandey S, Mehta N, Kini Y, Kini A. A virtual noninvasive way of constructing a nasoalveolar molding plate for cleft babies, using intraoral scanners, CAD, and prosthetic milling. Cleft Palate Craniofac J. 2020;57(2):263–266.
44. Unkovskiy A, Spintzyk S, Beuer F, Huettig F, Röhler A, Kraemer-Fernandez P. Accuracy of capturing nasal, orbital, and auricular defects with extra- and intraoral optical scanners and smartphone: an in vitro study. J Dent. 2022;117:103916.
45. Steinmeier S, Wiedemeier D, Hämmerle CHF, Mühlemann S. Accuracy of remote diagnoses using intraoral scans captured in approximate true color: a pilot and validation study in teledentistry. BMC Oral Health. 2020;20(1):266.

46. Ferlito T, Hsiou D, Hargett K, Herzog C, Bachour P, Katebi N, Tokede O, et al. Assessment of artificial intelligence-based remote monitoring of clear aligner therapy: a prospective study. Am J Orthod Dentofacial Orthop. 2023;164(2):194–200.
47. Simon B, Aschheim K, Vág J. The discriminative potential of palatal geometric analysis for sex discrimination and human identification. J Forensic Sci. 2022;67(6):2334–2342.
48. Mikolicz A, Simon B, Gáspár O, Shahbazi A, Vag J. Reproducibility of the digital palate in forensic investigations: a two-year retrospective cohort study on twins. J Dent. 2023;135:104562.