# "Advancements in Intraoral Scanning: Accuracy, Clinical Performance, and the Future of Digital Dentistry"

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**KEYWORDS**

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**ABSTRACT**

Intraoral scanners (IOS) have revolutionized digital dentistry by providing highly accurate, real-time 3D impressions, eliminating the need for conventional impression techniques. These devices enhance workflow efficiency, improve patient comfort, and integrate seamlessly with CAD/CAM systems, AI-driven software, and cloud-based storage for interdisciplinary collaboration. This review explores the evolution, types, accuracy, clinical applications, advantages, limitations, and future innovations of intraoral scanners, highlighting their transformative role in modern dental practice. Various IOS technologies, including structured-light scanning, laser-based imaging, confocal microscopy, and stereophotogrammetry, have been analyzed. Studies assessing accuracy, precision, and clinical performance indicate that while IOS demonstrates high accuracy for single-unit and short-span restorations, full-arch scanning remains challenging due to cumulative distortion errors. Recent advancements, such as AI-driven image stitching, real-time error correction, and multi-wavelength scanning, are helping to overcome these limitations. Clinically, IOS has shown significant benefits in prosthodontics, orthodontics, implantology, caries detection, and restorative dentistry. Although IOS technology improves chairside efficiency, patient experience, and digital workflow optimization, challenges such as high costs, learning curves, and limitations in complex cases persist. With ongoing technological innovations and increasing regulatory approvals (FDA, CE marking), intraoral scanners are rapidly becoming the gold standard in digital dentistry. Future research should focus on enhancing full-arch scan accuracy, expanding AI integration, and making IOS more accessible for broader clinical adoption. As digital workflows continue to evolve, intraoral scanners are set to redefine modern dentistry, improving precision, efficiency, and patient outcomes.

## Introduction & History of intraoral scanners :

Intraoral scanners (IOS) emerged in the late 1980s as a digital alternative to traditional dental impressions. The first scanner, developed by CEREC (Sirona), was primarily for chairside CAD/CAM restorations. Early devices were bulky and had limited accuracy, but optics, software, and processing power advancements improved their precision and usability. By the 2000s, second- and third-generation scanners had become widely adopted in dentistry, enabling seamless integration with 3D imaging and CAD/CAM workflows. Today, IOS technology is pivotal in modern dentistry. These devices capture highly accurate 3D digital impressions of teeth and oral tissues, enhancing precision in prosthodontics, orthodontics, implantology, and forensic odontology. IOS systems integrate with software for treatment planning, virtual smile design, and digital workflows for fabricating crowns, bridges, aligners, and surgical guides. They also improve patient comfort, reduce errors, and enable faster turnaround times for restorations. The ongoing development of AI-powered tools and cloud-based platforms continues to expand their functionality. [1]

Recent studies emphasize the ability of intraoral scanners to enhance interdisciplinary collaboration. By generating shareable digital files, IOS systems streamline communication between dental professionals, laboratories, and specialists, improving workflow efficiency and treatment outcomes [1]. This feature also facilitates remote consultations and second opinions, aligning with the growing trend of tele-dentistry. Furthermore, intraoral scanners play a crucial role in patient education and engagement by providing real-time visualizations of oral conditions, which improve understanding and compliance with treatment plans. This review discusses the types of intra-oral scanners, the application of intra-oral scanners in dentistry, accuracy, precision and clinical performance, advantages and limitations, future direction, and innovation.

Over the years, intraoral scanner technology has evolved significantly, transitioning from powder-based scanning systems—which required titanium dioxide powder for accurate imaging—to powder-free scanners, improving ease of use and patient comfort. Modern scanners now feature AI-driven auto-matching algorithms, enhancing precision by automatically aligning scans and reducing errors. Adopting cloud-based data storage and real-time collaboration tools has further streamlined dental workflows, facilitating seamless communication between clinicians and dental laboratories. With continuous improvements in scanning speed, resolution, and user-friendly interfaces, IOS has become an essential tool in digital dentistry.

The global adoption of intraoral scanners has surged due to increased accessibility, reduced costs, and the growing demand for digital workflows in dentistry. Advances in AI-powered diagnostics and automation have made IOS more efficient, further encouraging their widespread implementation in clinics and teaching institutions. The market is primarily driven by major manufacturers such as 3Shape, iTero (Align Technology), Medit, Carestream, and Planmeca, which continue introducing innovations to improve scanning accuracy and workflow integration. Regulatory approvals, including FDA clearance in the U.S. and CE marking in Europe, have further validated the reliability of these devices, boosting their credibility and market penetration. Intraoral scanners are expected to become the standard for impression-taking and diagnostic imaging worldwide as the industry moves toward fully digitalized workflows.

**Technologies of intra-oral Scanners**:

An intraoral scanner operates using a combination of sophisticated optics, imaging sensors, and software algorithms to capture an accurate and detailed three-dimensional representation of an object [2]. The fundamental concept of digital scanning relies on optical phenomena such as optical triangulation, parallel confocal imaging, and other technologies for capturing three-dimensional motion videos [3].

**Light projection technology:**

Many intraoral scanners use structured or natural light to project light patterns onto scanned surfaces. By examining the distortions in these patterns as they interact with dental structures, the scanner generates highly accurate 3D surface maps [4]. Passive techniques rely solely on ambient light to illuminate intraoral tissues, depending on the object's texture for imaging. In contrast, active techniques project structured white, red, or blue light from the scanner onto the object, making them less dependent on tissue's natural texture and color for reconstruction [3].

Additionally, multi-wavelength scanning technology is being integrated into advanced intraoral scanners, enabling improved color differentiation, soft tissue visualization, and enhanced depth perception. This advancement further refines the precision of prosthetic and orthodontic planning, ensuring better adaptation of restorations and aligners in clinical practice.

**Distance to object technologies [5,6,7]:**

a. Triangulation—The triangulation principle in oral scanners involves projecting a light source onto the surface of the teeth and capturing the reflected light using a camera or sensor from two different points of view. By measuring the angles of the reflected light and using the scanner's fixed geometry, the system calculates the precise position of each point on the surface. This process is repeated from multiple angles to create a detailed 3D digital model of the scanned area, allowing for accurate representations of the teeth and oral structures.

b. Confocal - Confocal imaging in oral scanners works by directing a focused beam of light at the dental surface and capturing only the reflected light that is in focus at specific depths. The scanner captures sequential images from different focal planes and angles, ensuring that only sharp, in-focus data is recorded. By combining this information from multiple depths and perspectives, the scanner reconstructs a highly detailed 3D model of the tooth or oral structure.

c. Active wavefront Sampling (AWS) - Active Wavefront Sampling (AWS) in oral scanners involves an off-axis aperture module that moves in a circular path around the optical axis, causing the point of interest (e.g., a tooth) to rotate. This movement generates wavefront distortions, which are captured by a camera. By analyzing these distortions, the scanner calculates distance and depth information for each point on the surface, allowing it to reconstruct a highly accurate 3D model.

d. Stereophotogrammetry- Stereophotogrammetry estimates all coordinates (x, y, and z) through algorithmic analysis of images. This method uses passive light projection and software, rather than active projection and hardware, making the camera small, easy to handle, and cost-effective. Multiple cameras capture images of the same object from slightly different viewpoints, which are then used to form the basis of the 3D model.

**Reconstruction technology:**

Reconstruction technology involves creating a 3D model by analyzing and merging data from multiple images or scans. It often utilizes an accelerometer built into the camera and uses similarity calculations to determine the image's viewpoint. Algorithms are then applied to identify matching points of interest (POI) across different images. These points are used to reconstruct the object's surface, resulting in a precise and detailed 3D representation [1, 8].

Types of Image Reconstruction Techniques:

- Point Cloud Processing: Converts raw scan data into a dense point cloud, which is then processed into a smooth, high-resolution model.
- Mesh Reconstruction: Uses triangulation techniques to convert the point cloud into a polygonal mesh for enhanced surface detailing.
- Surface Texture Mapping: Integrates color and texture data to improve visual realism in final 3D renderings.

Recent advancements include machine learning-enhanced reconstruction, where AI algorithms refine the alignment and noise reduction in the 3D model, making the process faster and more accurate. Additionally, real-time adaptive scanning allows intraoral scanners to auto-correct for motion artifacts, ensuring optimal scan fidelity even in dynamic clinical settings.

With ongoing developments in cloud-based processing, scanned data can now be remotely processed and stored, enabling seamless collaboration between clinicians, dental labs, and orthodontic specialists. This technology plays a crucial role in CAD/CAM dentistry, prosthetic fabrication, and digital treatment planning, allowing for precise, patient-specific restorations with minimal adjustments.

**Types of intra-oral scanners:**

Between 2015 and 2020, significant advancements were made in intraoral 3D scanning technology, leading to the development of faster, more precise, and AI-powered scanners. Notable scanners introduced during this period include the Trios 3 and Trios 4 (both available in normal and high-resolution modes) by 3Shape Trios A/S (Copenhagen, Denmark), the iTero Element series (iTero Element, iTero 2, and iTero 5D Element) by Align Technologies (San Jose, California, USA), and the Dental Wings scanner by Dental Wings (Montreal, QC, Canada).

Other innovations included the Panda 2 from Pengtum Technologies (Shanghai, China), the Medit i500 and Medit i700 from Medit Corp. (Seoul, South Korea), the Planmeca Emerald™ by Planmeca (Helsinki, Finland), and the Aoralscan from Shining 3D Tech. Co., Ltd. (Hangzhou, China) [9].

More recently, AI-assisted intraoral scanners have emerged, with features like real-time error correction, automated occlusion detection, and enhanced scan stitching. Additionally, wireless scanners such as Trios 5 and Medit i700 Wireless have improved maneuverability and reduced clutter in dental operatory settings. The iTero Element 5D further integrates Near-Infrared Imaging (NIRI) technology for non-invasive caries detection, making it a multi-functional diagnostic tool.

As the field of digital dentistry continues to evolve, new intraoral scanners are being designed with improved processing speeds, better color rendering, and enhanced AI-driven automation, leading to more efficient clinical workflows and higher patient comfort [9].

**Applications of Intraoral Scanners in Dentistry**

In prosthodontics, intraoral scanners (IOS) have significantly improved the fabrication of prosthetic restorations, such as crowns and bridges. The high-quality and detailed accuracy of digital impressions ensure a more precise fit of the prosthesis while eliminating the distortions commonly associated with traditional impression materials. IOS can be seamlessly integrated with computer-aided design (CAD) and computer-aided manufacturing (CAM) systems, enabling a three-dimensional previsualization of the area of interest and allowing the creation of restorations tailored to the teeth's unique anatomy [10].

This combination of CAD/CAM systems and IOS accelerates the fabrication process, reduces the need for adjustments, and enhances the quality of the final restoration. Furthermore, the improved fit achieved through accurate digital impressions leads to better functionality and esthetics, minimizing complications and increasing patient satisfaction. By reducing chairside time and eliminating the discomfort associated with traditional impressions, IOS contributes to a more efficient and patient-friendly treatment experience.

**Applications of Intraoral Scanners in Orthodontics**

Intraoral scanners have become indispensable in orthodontics, offering numerous advantages such as enhanced patient comfort, streamlined workflows, and precise digital impressions [11]. These scanners are crucial for full-arch scanning, indirect bonding, and the digital fabrication of orthodontic appliances. They also improve diagnosis and treatment planning by providing highly accurate measurements of arch width, tooth size, overjet, and overbite [12].

The ability to digitally simulate treatment plans and create diagnostic setups [13] strengthens communication between patients and orthodontists, fostering better collaboration [14]. Additionally, IOS technology simplifies the transfer of digital data to dental laboratories, eliminating shipping delays, reducing costs, and improving the accuracy of appliance fabrication [15]. By incorporating IOS, orthodontists can enhance both clinical efficiency and patient outcomes.

**Applications in Oral Surgery and Implants**

Intraoral scanners have revolutionized implant dentistry by improving precision, efficiency, and patient outcomes in various aspects of care. They play a critical role in guided implant surgery by accurately capturing implant positions and enabling the creation of precise surgical guides through digital integration. This enhances implant placement accuracy while reducing the risk of prosthetic misfit.

Additionally, IOS streamlines surgical planning by facilitating the design and fabrication of customized guides and prostheses, addressing many of the limitations associated with traditional impression techniques. The digital workflow enabled by IOS improves clinical efficiency by reducing patient discomfort, expediting data capture, and ensuring seamless communication with dental laboratories. This not only saves time but also delivers predictable, high-quality outcomes for both surgical and prosthetic procedures.

Caries Detection

Intraoral scanners (IOS) utilize advanced optical technologies, such as fluorescence and near-infrared imaging (NIR), to detect caries noninvasively. Fluorescence-based IOSs, operating at a wavelength of 415 nm, effectively identify occlusal caries, while NIR imaging, using wavelengths between 727–850 nm, enables the detection of both proximal and occlusal carious lesions [3]. Studies show that IOSs provide diagnostic accuracy comparable to traditional methods, such as visual-tactile examinations and radiographs [16]. However, false positives can occur due to external factors like biofilm accumulation. Combining IOS-based assessments with bitewing radiography has been shown to improve diagnostic reliability in certain cases [17].

**Tooth Wear Monitoring**

IOSs are equipped with image superimposition software that allows for the quantitative monitoring of tooth wear over time. These systems achieve accuracy margins as low as ±15 µm, making them reliable tools for detecting significant surface changes [18]. In vitro studies have demonstrated that IOSs can accurately measure wear caused by mechanical or chemical factors, while clinical studies suggest a threshold of 73 µm, beyond which wear can be reliably tracked [19]. Periodic scans every 1–3 years are recommended for effective monitoring, particularly for patients with high wear rates [20].

Oral Hygiene Assessment

IOSs facilitate detailed oral hygiene assessments by enabling accurate quantification of plaque levels. When combined with plaque-disclosing agents, the 3D planimetric imaging generated by IOSs provides a superior method for monitoring dental plaque compared to traditional visual evaluations [21]. Furthermore, patient-operated intraoral scans integrated with machine learning-supported feedback systems have been shown to improve periodontal and plaque indices, highlighting the potential of IOSs for personalized oral health management [22].

Tooth Shade Determination

IOSs equipped with color imaging can assist in tooth shade determination, offering a noninvasive alternative to traditional visual matching techniques. However, limitations such as inconsistent lighting and variations in reading angles can impact accuracy, making IOSs less precise than spectrophotometers, which provide quantitative color measurements [23]. While useful as supplementary tools, IOSs are not recommended as the primary method for shade matching in cases requiring high precision [7].

Pediatric Applications

Intraoral scanners (IOS) are increasingly utilized in pediatric dentistry to improve patient experience, accuracy, and efficiency compared to traditional impression techniques. Children, who are often sensitive to discomfort and gag reflexes associated with conventional alginate impressions, generally find IOS more comfortable and less stressful. Studies report significant improvements in patient perception, including reduced nausea and greater acceptance of the procedure. However, evidence regarding the accuracy and reproducibility of IOS in pediatric applications remains inconclusive.

While chairside time can vary depending on the device, the long-term advantages of digital workflows—such as eliminating the need for physical storage and enabling easier model retrieval—outweigh the higher initial costs. These benefits make IOS a favorable choice for pediatric patients, though further research is needed to standardize and compare performance across devices and clinical conditions [24].

Applications of Intraoral Scanners in Restorative Dentistry

In restorative dentistry, the integration of 3D intraoral scanners has significantly enhanced the accuracy and efficiency of procedures, such as fillings, inlays, and onlays. Unlike traditional methods that rely on impression trays and plaster models, digital impressions utilize advanced optical technologies to generate highly precise three-dimensional models of the dentition. This precision improves the fit and functionality of restorations, particularly in complex cases where accuracy is critical.

Additionally, intraoral scanners streamline workflows by enabling chairside design and fabrication of dental prostheses through CAD/CAM systems. This eliminates the need for multiple visits and labor-intensive steps, such as mold pouring and physical adjustments. For example, rapid digital workflows allow clinicians to capture digital impressions, design restorations, and produce them onsite using an integrated milling unit, often completing the entire process within a single visit. These advancements reduce procedural time and enhance patient comfort and satisfaction by eliminating the discomfort associated with traditional impression methods [6].

**Accuracy, Precision, and Clinical Performance of Intraoral Scanners**

Intraoral scanners (IOS) have revolutionized impression-making in dentistry, emerging as essential tools where accuracy and precision are critical for clinical success. Accuracy refers to how closely a measurement corresponds to the true value, whereas precision pertains to repeatability and consistency in obtaining the same measurements over multiple scans [3]. These two parameters determine IOS reliability in restorative and prosthetic workflows.

Defining Accuracy and Precision in IOS Technology

- Trueness (Accuracy): This is assessed by superimposing IOS scans onto a high-precision reference scan, such as one acquired using coordinate measuring machines (CMMs) or industrial laser scanners. The differences in measurements at a micrometric level indicate the degree of accuracy.
- Precision (Reproducibility): This is evaluated by overlaying multiple scans taken at different times and analyzing consistency in data capture. The smaller the variation, the higher the precision [5].

Factors Influencing IOS Accuracy & Precision

**Accuracy is influenced by several intrinsic and extrinsic factors:**

- Operator Skill: The scanning technique, angulation, and speed can significantly impact scan quality. Interrupted or improper scanning paths may introduce stitching errors.
- Scanner Calibration & Software Algorithms: Variability exists between different scanner brands, as each uses proprietary software algorithms for reconstruction. Proper calibration and software updates improve measurement fidelity.
- Scan Length & Arch Size: Studies suggest that single-tooth and short-span scans exhibit higher accuracy than full-arch scans, where minor distortions accumulate over distance.
- Environmental Factors: Temperature, humidity, and intraoral conditions (saliva, soft tissue movement, and reflections) may affect scan accuracy. Dry-field isolation improves results [26].

Clinical Performance & Limitations of IOS Systems

**Studies evaluating IOS accuracy in various dental procedures report:**

- Single-Unit Restorations: IOS delivers excellent trueness and precision, making it ideal for crowns, inlays, and onlays [27].
- Short-Span Bridges: IOS achieves comparable accuracy to traditional impressions, though marginal fit and occlusal adjustments may sometimes be needed [1].

- Full-Arch Scans: Accuracy declines over larger scanning areas, making desktop scanners more reliable for complete-arch restorations, dentures, and implant-supported prostheses [26].

A study by Renne et al. compared sextant vs. full-arch scanning across seven IOS devices, confirming that while intraoral scanners are highly accurate, no single scanner perfectly balances speed and precision [27]. Additionally, Aswani K et al. found that IOS performs well for short-span scanning, but deviations may appear in larger restorations due to cumulative distortion errors. Nedulco et al. and Wesemann et al. similarly concluded that desktop scanners outperform IOS in full-arch accuracy, making indirect digitalization preferable for extensive restorations [1,26].

**Technological Advancements Improving IOS Accuracy**

- AI-Driven Error Correction: Machine-learning algorithms now detect scanning errors in real time, automatically correcting distortions and missing data points.
- Multi-Wavelength Scanning: The use of variable light wavelengths enhances contrast and depth accuracy, improving tissue differentiation.
- Automated Margin Detection: New software enhancements now allow for real-time margin detection and auto-adjustments, reducing manual post-processing time.
- Adaptive Scan Stitching: Some modern IOS systems integrate adaptive data stitching, ensuring better overlap and alignment in full-arch scans.

With ongoing technological advancements, intraoral scanners continue to narrow the gap between traditional and digital impressions, bringing greater efficiency, accuracy, and predictability to modern dentistry.

**Clinical Performance of IOS**

Beyond accuracy and precision, factors such as scanning time, the learning curve, and the size of the intraoral camera significantly impact the clinical performance of IOS devices. Modern digital impressions achieve micrometer-level accuracy, providing clinically acceptable results for single-tooth restorations and fixed partial prostheses involving up to 4–5 units [24].

Intraoral scanners eliminate common errors associated with conventional impression materials, such as distortions and voids, ensuring better-fitting restorations and improved treatment outcomes [3]. However, challenges remain in detecting deep margin lines on prepared teeth and managing situations involving bleeding [1]. As digital scanners become more affordable and widely adopted, they are poised to become standard tools in modern dentistry [6].

**Advantages and Limitations of Intraoral Scanners (IOS)**

**Advantages**

1. Patient Comfort :

One of the key advantages of optical impressions is the ability to directly capture all dental arch information without the need for traditional physical impressions. This noninvasive process is especially beneficial for patients who may have difficulty with conventional impressions, such as the elderly, pediatric patients, and individuals with strong gag reflexes. The improved patient experience makes dental visits more pleasant.[1]

2. Time Efficiency:

Despite technological advancements in IOS, enabling full-arch scans in under three minutes, the primary time savings occur in subsequent steps rather than during the scanning itself (which takes a comparable 3–5 minutes to traditional impressions).[1,24] Digital impressions eliminate the need for tray selection, substance mixing, and setting time, reducing overall chair time. Further efficiencies are gained as digital impressions can be emailed directly to dental labs, bypassing traditional processes like pouring impressions and mailing physical models.

3. Workflow Optimization:

Intraoral scanners enhance operational efficiency by providing real-time visualization, which minimizes the need for repeat scans by promptly identifying and correcting errors. When integrated with CAD/CAM technologies, IOS facilitates on-site production of dental restorations, eliminating intermediary steps and streamlining workflows.[1]

Additionally, digital impressions improve collaboration among dental professionals by enabling better consultations and treatment planning through electronic data sharing. Practitioners can leverage 3D models for diagnostics, virtual treatment simulations, early prosthetic approvals, and quick diagnostics, enhancing treatment outcomes and patient satisfaction.

4. Real-Time Feedback and Capture :

IOS devices provide real-time feedback through live images displayed on a computer screen as the scanner moves within the oral cavity. This mechanism ensures comprehensive coverage and high-quality data capture, offering immediate visual confirmation to the operator.[3]

5. Reduced Material and Environmental Impact:

By eliminating the need for disposable materials such as alginate and impression trays, IOS contributes to sustainable dental practices. The digital workflow minimizes material waste, reduces reliance on physical models, and is more environmentally friendly and economical.

**Limitations**

1. Initial Investment Costs

The high cost of intraoral scanners can pose a barrier, particularly for smaller practices with limited budgets. Software updates, maintenance, and training add to the overall expense, potentially widening the gap between resource-rich and resource-limited practices.

2. Learning Curve and Operator Dependency

Operating IOS effectively requires proper training, and the quality of the impressions depends significantly on the operator's expertise. Dental practitioners and support staff need time to become proficient with the technology. Operator-related errors, such as poor scanning technique or incomplete coverage, can compromise scan quality.[25]

3. Learning Curve for Patients

While generally patient-friendly, some individuals may require additional explanation about the scanning process to feel at ease.

4. Software and Hardware Limitations

- Compatibility issues may arise during full-arch scans, and frequent software updates can create integration challenges.
- IOS devices rely on a robust digital infrastructure, which can be difficult for some practices to maintain.
- Software glitches or scanner malfunctions can disrupt workflows, delay treatment, and increase costs.
- Dependable internet access is crucial for communication with dental labs; disruptions can lead to workflow interruptions and treatment delays.
- Scanning efficiency may decrease if patient movement, moisture, or specific materials (e.g., temporary restorations) interfere with the process.

5. Complex Cases

Certain clinical scenarios, such as extensive restorations, significantly impaired dentition, or soft tissue interference, may still require traditional impression methods. Challenges include:

Detecting deep marginal lines on prepared teeth, especially in cases involving bleeding or excessive moisture. [1]

Reflection caused by saliva or powder application, which can impact the accuracy of impressions. [6]

Scanning highly reflective or translucent materials may also reduce efficiency and precision.[25]

6. Clinical Limitations

IOS technology may not be suitable for all cases, such as those involving extensive edentulous spans or conditions with significant bleeding. While IOS performs well for many procedures, traditional impressions remain necessary for certain complex treatments where comprehensive data capture is critical.

**Future Directions and Innovations in Intraoral Scanners (IOS)**

1. Improved Scanning Speed and Accuracy
   - Faster Scanning: Future intraoral scanners will significantly reduce scan times while maintaining or improving data quality. For example, the iTero Lumina scanner operates at twice the speed of earlier models, enhancing efficiency and reducing chair time. These advancements will increase patient satisfaction and streamline workflows.
   - Higher Resolution and Precision: Enhanced resolution will provide more detailed and precise digital impressions, leading to better-fitting restorations, reduced retakes, and improved clinical outcomes.
2. AI Integration
   - AI-Assisted Diagnostics: Advanced AI algorithms integrated into intraoral scanners will detect early signs of dental issues, such as cavities, periodontal disease, and even oral cancer. For instance, AI systems have already demonstrated the ability to categorize teeth based on restoration data from scan images.
3. Enhanced Patient Comfort
   - Compact and Ergonomic Designs: Next-generation scanners will feature smaller, lighter, and more ergonomic designs. For example, the iTero Lumina scanner has a wand that is 50% smaller and 45% lighter, making it more comfortable for patients during procedures. [28]
4. Improved Data Management and Storage
   - Cloud-Based Platforms: Digital impressions will be automatically uploaded to cloud-based storage systems, simplifying data retrieval, sharing, and secure collaboration with dental labs, specialists, and other healthcare providers. [30]
5. Multi-Functional Devices
   - Beyond Impressions: Future IOS devices may incorporate additional functionalities, such as measuring occlusion, monitoring gingival changes, and assessing soft tissue health—all within a single tool.
   - Augmented Reality (AR) Integration: Intraoral scanners could use AR to provide real-time overlays during scans, enabling practitioners to better visualize the oral cavity, detect abnormalities, and guide restorative procedures. [28]
6. Increased Accessibility and Affordability
   - Affordable Solutions: Advances in technology and widespread adoption will lower costs, making intraoral scanners accessible to smaller practices, community health centers, and underserved populations.
   - Portable Designs: Enhanced portability will enable IOS use in remote locations, mobile dental vans, and in-home care, improving access to care for disadvantaged groups.
7. Smarter Restorations and Implants
   - Real-Time Implant Assistance: Integration with surgical planning software will allow intraoral scanners to provide real-time data for implant placement, facilitating precise adjustments during procedures.
   - Customized Implants: High-resolution 3D scanning data will enable the creation of personalized implants and restorations, resulting in better patient outcomes and satisfaction. [29]
8. Environmental Sustainability
   - Reduced Waste: By eliminating traditional impression materials such as alginate and silicone, IOS technology contributes to reduced clinical waste. Future innovations are likely to focus on further minimizing environmental impact.
   - Energy Efficiency: Next-generation scanners will prioritize energy-efficient designs, aligning with the growing emphasis on sustainable dental practices. [30]

## Conclusion

Intraoral scanners (IOS) have transformed digital dentistry, offering high-precision, real-time alternatives to conventional impression techniques. Their ability to capture detailed 3D models with high accuracy and precision has significantly improved workflows in prosthodontics, orthodontics, restorative dentistry, and implantology. While IOS technology continues to advance in speed, usability, and AI-driven automation, challenges remain—particularly in full-arch accuracy and environmental variability.

Despite these limitations, ongoing technological developments such as multi-wavelength scanning, AI-powered auto-correction, adaptive stitching, and real-time margin detection are narrowing the gap between IOS and conventional impression methods. As the industry moves towards fully digitalized workflows, intraoral scanning is expected to become the gold standard for impression-making in dentistry.

Future research should focus on enhancing full-arch scan accuracy, refining software integration for treatment planning, and improving accessibility by making IOS more cost-effective for smaller dental practices. With increasing global adoption and regulatory support (FDA, CE approvals), intraoral scanners are poised to redefine patient care, efficiency, and clinical precision in modern dentistry.

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