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Scanning Technology and Its Future Prospects in Prosthetic Dentistry: A Comprehensive review

(Intraoral Scanners in Prosthetic dentistry: A Digital Revolution)

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ABSTRACT:

The advent of intraoral scanners (IOS) has revolutionized the field of prosthetic dentistry, offering digital alternatives to traditional impression techniques. This review provides a comprehensive narrative overview of IOS technology, its clinical applications in prosthetic workflows, accuracy compared to conventional methods, benefits, limitations, and future prospects.

Background

Prosthetic dentistry is fundamentally reliant on precise impressions to replicate intraoral conditions accurately for the fabrication of fixed and removable prostheses[1]. Traditionally, elastomeric impression materials such as polyvinyl siloxane and polyether have been widely used for this purpose [1]. However, these methods are often associated with various drawbacks, including patient discomfort, susceptibility to dimensional changes during setting, potential for voids or bubbles, and the need for multiple steps involving tray selection, material mixing, setting time, and disinfection[1].

In response to these challenges, the digital revolution in dentistry has led to the development and growing adoption of intraoral scanners (IOS)[2]. These devices use optical scanning technologies to digitally capture the geometry of dental arches, providing real-time, high-resolution 3D data that can be used directly for prosthetic planning and fabrication through computer-aided design/computer-aided manufacturing (CAD/CAM) systems[2].

The use of intraoral scanners in prosthetic dentistry has evolved rapidly over the past decade, transitioning from a novel adjunct to an increasingly essential tool in restorative procedures [3]. In particular, IOS has shown promise in improving clinical outcomes and efficiency in

procedures ranging from single-unit crowns to more complex restorations like multi-unit fixed partial dentures and implant-supported prostheses [3].

However, despite their many benefits, intraoral scanners are not without limitations. Factors such as cost, learning curve, and limitations in capturing subgingival or reflective surfaces continue to pose challenges [4]. Furthermore, while IOS accuracy is well established for small restorations, their reliability for full-arch scans remains under active investigation due to potential errors introduced during image stitching and software limitations[4].

This review aims to provide a comprehensive narrative overview of intraoral scanners in prosthetic dentistry, highlighting their principles of operation, clinical applications, advantages, limitations, and future directions, based on current evidence and expert consensus.

1.1 **Principles of Operation of Intraoral Scanners**

Intraoral scanners (IOS) are advanced digital devices developed to capture direct optical impressions of the patient's dentition and adjacent oral structures with high precision. Unlike conventional impression techniques that depend on physical impression materials — which are prone to dimensional changes and technique sensitivity — IOS employs light-based scanning technologies to generate accurate three-dimensional (3D) digital models. These digital impressions not only streamline the diagnostic and treatment planning processes but also facilitate the fabrication of prosthetic restorations through computer-aided design and computer-aided manufacturing (CAD/CAM) systems, thereby potentially improving clinical outcomes and patient comfort. However, the accuracy and clinical applicability of IOS can vary based on factors such as operator skill, scanning strategy, and intraoral conditions, warranting critical evaluation of their limitations alongside their advantages [5].

The operation of IOS is based on several **core principles and technologies**:

1.1.1 **Optical Scanning and Image Acquisition**

IOS employs optical technologies to capture the geometry of the teeth and soft tissues. The scanner projects light (visible, laser, or structured) onto the surface of the oral tissues and captures the reflected light using sensors. The captured data is processed in real-time to generate a 3D digital image[6].

1.1.2 Image Reconstruction Techniques

Various methods are used by different scanner brands to reconstruct the 3D image from the captured data:

- **Triangulation[7]**
  This technique uses the angles between a light source, the scanned object, and a camera sensor to calculate distances. When the scanner projects a light beam onto a surface, its reflection is captured from a different angle. Based on the geometric triangulation principle, the system determines the exact location of each point on the object's surface.
- **ConfocalMicroscopy**
  This method captures focused images at different depths by using a pinhole aperture to filter out-of-focus light. It allows for the collection of sharp images from various focal planes and then stacks them to produce a precise 3D model. TRIOS scanners (3Shape) commonly use this method.
- **Active Wave front Sampling(AWS)**
  Used in some iTero scanners, AWS captures images at different angles by rotating optical elements within the scanner. This allows the system to build a detailed 3D model based on variations in light reflection.
- **Structured Light Scanning**
  This technique projects a known light pattern (such as stripes or grids) onto the object. Distortion of the pattern caused by surface

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contours is captured by the sensor, and software algorithms reconstruct the 3D surface from this distortion[7].

- **Photogrammetry** (used especially in implant scanning)
  This method takes multiple images from various angles to create a 3D model. It is highly accurate for capturing spatial relationships, especially of scanned bodies and implant positions[6].

1.1.3 Software Algorithms and Data Processing [8]

The raw image data collected by the scanner is processed using advanced software algorithms. These algorithms perform

- **Surface matching** (also called stitching): aligns multiple images into a continuous 3D model.
- **Noise reduction**: filters out irrelevant data (e.g., reflections, saliva).
- **Color rendering**: some scanners provide color images to help identify margin lines and tissue types.

1.1.4 **Output and Integration**[8]

The final digital impression is typically exported in open file formats such as

- **STL (Standard Tessellation Language)**—widely used in CAD/CAM workflows.
- **PLY (Polygon File Format)**—includes color and texture data.
- **OBJ (Object File)**—another format supporting color and texture.

Summary Table: Common Technologies in IOS

Technology	Description	Example Scanners
Triangulation	Measures angles of reflected light	CEREC (Dentsply Sirona)
Confocal Microscopy	Captures focused images at multiple depths	TRIOS (3Shape)
Active Wavefront Sampling	Captures multiple angles using rotating mirrors	iTero (Align Technology)
Structured Light	Projects light patterns to detect surface contours	Medit, Planmeca Emerald
Photogrammetry	Captures images from multiple positions for 3D mapping	PIC dental, True Definition

1.2 Clinical Applications of IOS

Intraoral scanners (IOS) are digital devices used to capture direct optical impressions of the oral cavity. They have a wide range of clinical applications in dentistry due to their accuracy, efficiency, and patient comfort. Here are the main clinical applications of intraoral scanners [6,7].

In prosthetic dentistry, intraoral scanning (IOS) technology plays a pivotal role in a variety of restorative procedures. For crown and bridge restorations, digital impressions are utilized for both single units and full-arch cases, providing high accuracy and reducing the need for multiple appointments. IOS is also instrumental in minimally invasive procedures such as veneers and inlays/onlays, where high-precision scans are essential

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for ensuring optimal fit and aesthetics. Additionally, IOS has become increasingly valuable in the fabrication of removable prostheses, particularly when integrated with CAD/CAM systems. This digital workflow enhances the efficiency, accuracy, and reproducibility of complete and partial dentures, representing a significant advancement over conventional impression techniques [6].

In the domain of implant dentistry, intraoral scanning (IOS) offers several critical advantages that enhance clinical precision and efficiency. During implant planning and placement, IOS enables accurate data capture, which is essential for guided surgery and precise implant positioning. For implant prosthetics, digital impressions allow for the scanning of scan bodies rather than relying on conventional impression materials, resulting in improved accuracy and patient comfort. This approach not only simplifies the clinical procedure but also enhances communication between the clinic and laboratory. Furthermore, IOS facilitates the fabrication of immediate loading prostheses by enabling rapid data acquisition [7].

1.3 Advantages

Intraoral scanners (IOS) offer several advantages over traditional impression techniques, making them increasingly popular in modern dental practice [8]. Here are the key advantages:

Intraoral scanners (IOS) provide significant advantages in modern dentistry, notably improving patient comfort by eliminating messy impression materials that can cause gagging or discomfort. The digital process is faster, less invasive, and particularly helpful for pediatric, geriatric, or anxious patients. Critically, IOS offers superior accuracy by minimizing human error and material distortion, resulting in precise 3D data and better marginal fit of restorations, which ultimately enhances clinical outcomes and reduces the need for adjustments [8].

In terms of **time efficiency**, intraoral scanners allow for quicker data acquisition and immediate visualization of the scanned area. This eliminates several steps involved in traditional impressions, such as pouring, trimming, or shipping stone models, ultimately reducing chair time and the number of appointments—particularly helpful in same-day restorative procedures. **Enhanced communication** is also a major benefit; real-time visuals enable clearer discussions with patients and allow digital files to be instantly shared with dental labs, specialists, or insurance providers.

Furthermore, intraoral scanners are well-suited for **integration with digital workflows**, making them compatible with CAD/CAM systems for same-day crowns, orthodontic aligners, and surgical guides. They also work seamlessly with 3D printing and milling technologies. From an environmental and economic standpoint, scanners are **eco-friendly and cost-effective in the long term**, as they reduce the need for impression materials, shipping, and physical model storage—thereby minimizing waste and associated costs [9].

Another advantage is **improved record keeping**, as digital files are easy to store, retrieve, duplicate, and back up, allowing clinicians to monitor changes over time, such as wear, gingival recession, or orthodontic movement. Lastly, intraoral scanners support **better patient education and case acceptance**. Visual aids help patients better understand their treatment needs, and real-time images of their oral conditions often increase their willingness to proceed with recommended procedure[9].

1.4 Limitations of Intraoral scanners

Intraoral scanners, while offering numerous benefits, do have certain limitations that must be considered in clinical practice. One of the primary drawbacks is the high initial cost, which includes the price of the scanner itself, software licenses, and any necessary hardware upgrades. This financial barrier may be significant, especially for small practices. Additionally, there is a learning curve associated with using intraoral scanners effectively. Dentists and their teams must invest time in training to master proper scanning techniques, as poor technique can lead to inaccurate impressions [10].

Another challenge is the reduced accuracy in capturing full-arch impressions or long-span prosthetic cases. Some scanners may struggle with stitching errors or image distortion when scanning large areas, which can impact the fit of restorations. Scanning subgingival margins, deep cavities, or areas with saliva or bleeding can also be problematic, as these conditions can interfere with the scanner's ability to capture detailed images. Access to posterior areas in patients with limited mouth opening can further complicate the process.

Intraoral scanners also require a robust digital infrastructure, including reliable power, internet connectivity, and compatibility with lab systems. Some dental laboratories still prefer or require traditional impressions, limiting the universal adoption of IOS. Furthermore, issues with proprietary file formats and software interoperability can arise, creating workflow disruptions. Regular software updates are essential to maintain functionality and performance, and hardware can become obsolete quickly due to rapid advancements in digital dentistry. Despite these limitations, with proper implementation and training, intraoral scanners remain a highly valuable tool in modern dental care [11].

1.5 Future of intraoral scanners (IOS) [12]

Some of the most promising future developments in IOS technology include:

1.5.1 Increased Accuracy and Precision

Future IOS devices are expected to offer even higher accuracy and precision, especially in capturing details of complex dental anatomy. Improved optics, advanced scanning technologies, and real-time error correction algorithms will enhance the precision of digital impressions, minimizing the need for re-scanning or adjustments.

1.5.2. Artificial Intelligence (AI) Integration

AI will play a critical role in future IOS systems. By integrating machine learning algorithms, future scanners will be able to automatically identify anomalies such as cavities, fractures, or malocclusions, assisting clinicians in early detection. AI could also be used to predict the most appropriate treatment options based on scanned data, further streamlining the decision-making process.

1.5.3 **Enhanced 3D Imaging and Real-Time Visualization**[12].

The future of IOS will include enhanced 3D imaging capabilities, providing more detailed, lifelike renderings of dental structures. Real-time visualization of scans will become even more intuitive, allowing practitioners to manipulate and examine 3D models on-screen, offering greater clarity in treatment planning and patient education [11].

1.5.4 **Integration with Other Digital Technologies**

As digital dentistry evolves, IOS devices will increasingly integrate with other technologies such as Cone Beam Computed Tomography (CBCT) and Digital Radiography. This convergence will offer a comprehensive view of both hard and soft tissues, enabling more accurate diagnosis and treatment planning, especially in implantology, orthodontics, and prosthodontics [12].

1.5.5 Miniaturization and Portability

Advances in miniaturization will lead to smaller, more portable intraoral scanners that are easier to handle and more convenient for use in various clinical settings. These compact devices will be more accessible, potentially allowing for mobile dental practices and tele-dentistry applications.

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1.5.6. Faster Scanning and Data Processing

Speed is a significant area of improvement. Future IOS devices will likely offer faster scanning capabilities, with real-time processing of large amounts of data. The reduction in scanning and processing time will improve patient throughput and reduce the overall time required for restorative or orthodontic procedures.

1.5.7. Cloud-Based Data Storage and Sharing

Cloud-based integration will allow for the storage, sharing, and collaboration of digital scans across different platforms and dental offices. This will enable better coordination between general practitioners, specialists, and dental labs, making workflows more efficient and patient care more integrated

1.5.8. Enhanced Patient Comfort and Experience

Future IOS systems will continue to enhance patient comfort by being even more ergonomic and non-invasive. With advancements in sensor technology, devices will be capable of scanning larger areas without discomfort, reducing the need for multiple scans or patient repositioning

1.5.9. Automated Treatment Planning and CAD/CAM Integration

In the future, IOS will become an integral part of automated treatment planning and CAD/CAM systems. Scanned data will be directly fed into design software to create prosthetics such as crowns, bridges, and dentures with minimal human intervention, reducing errors and optimizing treatment time.

1.5.10. Cost Reduction and Accessibility

As the technology matures, it is expected that the cost of intraoral scanners will decrease, making them more affordable for small dental practices. Wider access to this technology will likely increase its adoption, helping more patients benefit from digital workflows.

1.5.11. Smart Materials for Improved Accuracy

Advances in materials science may lead to the development of more advanced, high-fidelity scanning tips and materials that can capture even more intricate details with greater accuracy. These innovations could help IOS devices scan through various types of dental restorations, ensuring consistent and precise impressions.

Conclusion

The future of intraoral scanning technology holds exciting prospects for the dental profession. These advancements will lead to more precise, faster, and patient-friendly workflows, ultimately improving the quality of care and accessibility of digital dentistry. As technology continues to progress, intraoral scanners will be even more integral to a wide range of dental procedures, from diagnostics to restorative treatments, and play a central role in the growing field of digital dentistry.

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