Accuracy of intraoral and extraoral scanners in fixed prosthodontics

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ACCURACY OF INTRAORAL AND EXTRAORAL SCANNERS IN FIXED PROSTHODONTICS

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ACCURACY OF INTRAORAL AND EXTRAORAL SCANNERS IN FIXED PROSTHODONTICS

Summary

Intraoral and extraoral scanners have revolutionized dental practice by providing high-precision digital impressions, transforming how dental procedures are performed. Scanners create detailed digital models of a patient's dental anatomy, allowing for more precise diagnostics and treatment planning. Precision and accuracy are crucial in dental scanning, as they directly impact the quality and dependability of digital impressions. Accuracy encompasses two key concepts: precision and trueness. Precision refers to the consistency and repeatability of measurements, ensuring that the digital model maintains loyalty to the original scan. Trueness relates to the degree of agreement between the digital scan and the actual anatomical structure, ensuring accurate representation without distortion. Intraoral scanners offer real-time data capture directly from the patient's mouth. Digital impressions created with intraoral scanners reduce the need for traditional impression materials, lowering the risk of mistakes associated with analog impressions. Extraoral scanners handle larger and more complex models with high precision, ensuring efficient workflows and accurate restorations. New scanners on the market are introducing modern software and artificial intelligence, dramatically increasing the quality and usability of these scanners, reducing mistakes, and improving the scanning process. The choice between intraoral and extraoral scanners depends on specific accuracy, precision, and workflow requirements. Intraoral scanners are ideal for immediate, chairside use, while extraoral scanners excel in laboratory environments where large-scale, detailed models are necessary. Both types of scanners are crucial in advancing digital dentistry, ensuring high-quality outcomes, and enhancing the overall patient experience.

Keywords: intraoral scanner; accuracy; digital impression; extraoral scanners; new scanners

TOČNOST RADA INTRAORALNIH I EKSTRAORALNIH SKENERA U FIKSNOJ PROTETICI

Sažetak

Intraoralni i ekstraoralni skeneri revolucionirali su stomatološku praksu pružajući visokoprecizne digitalne otiske, transformirajući način na koji se stomatološki postupci provode. Ovi skeneri stvaraju detaljne digitalne modele dentalne anatomije pacijenta, omogućujući precizniju dijagnostiku i planiranje liječenja. Točnost je ključan pojam u dentalnom skeniranju jer izravno utječe na kvalitetu i pouzdanost digitalnih otisaka. Točnost obuhvaća dva ključna koncepta: preciznost i istinitost. Preciznost se odnosi na dosljednost i ponovljivost mjerenja, osiguravajući da digitalni model ostane vjeran izvornom skenu. Istinitost se odnosi na stupanj podudarnosti između digitalnog skena i stvarne anatomske strukture, osiguravajući točno predstavljanje bez distorzije. Intraoralni skeneri nude prikupljanje podataka u stvarnom vremenu izravno iz usta pacijenta. Digitalni otisci stvoreni intraoralnim skenerima smanjuju potrebu za tradicionalnim materijalima za otiske, smanjujući rizik od pogrešaka povezanih s analognim otiscima. Ekstraoralni skeneri obrađuju veće i složenije modele s visokim stupnjem točnosti, osiguravajući učinkovite radne tokove i točne restauracije. Novi skeneri na tržištu uvode moderni softver i umjetnu inteligenciju, dramatično povećavajući kvalitetu i upotrebljivost ovih skenera, smanjujući pogreške i poboljšavajući proces skeniranja. Izbor između intraoralnih i ekstraoralnih skenera ovisi o specifičnim zahtjevima za točnost i radni tok. Intraoralni skeneri idealni su za trenutnu, stolnu upotrebu, dok se ekstraoralni skeneri ističu u laboratorijskim uvjetima gdje su potrebni velikih, detaljnih modela. Oba tipa skenera ključna su za napredak digitalne stomatologije, osiguravajući visokokvalitetne rezultate i poboljšavajući cjelokupno iskustvo pacijenata.

Ključne riječi: intraoralni skeneri; točnost; digitalni otisak; ekstraoralni skeneri; novi skeneri

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List of abbreviations

CAD/CAM - Computer-Aided Design/Computer-Aided Manufacturing

IOS - Intraoral scanner

EOS - Extraoral scanner

POI - points of interest

AWS - active wavefront sampling

STL - standard tessellation language

PYL - polygon format file

CEREC - Chairside Economical Restoration of Esthetic Ceramics

1. INTRODUCTION

The journey of digital dentistry began with integrating computer-aided design (CAD) and computer-aided manufacturing (CAM) into dental practices. These technologies, initially designed to enhance manufacturing processes in other industries, were modified to meet the particular requirements of dentistry. They have significantly increased accuracy and efficiency in how dental professionals create restorations, diagnose conditions, and plan treatments.

CAD/CAM technology is now an essential part of many dental procedures. It simplifies designing and producing surgical guides for dental implants, prosthodontic restorations such as crowns and bridges, and maxillofacial prostheses. Additionally, it facilitates the planning of orthodontic treatment (1).

Nearly 40 years ago, Dr. Warner Moorman and engineer Marco Brandestini developed the first CAD/CAM system, which marked the beginning of digital dentistry. The initial system in dental medicine employed CAD/CAM technology to create smaller restorations. This system, named CEREC (Chairside Economical Restoration of Esthetic Ceramics), initially stood for computer-assisted CERamic REConstruction. Over the years, the system improved, leading to the development of the CEREC inLab system for dental laboratories and the inEOS extraoral scanner. These advancements have significantly enhanced the efficiency and precision of dental restorations, making CEREC a cornerstone of modern dental practices. Ceramics was the first milled material, having better properties than composite materials regarding durability and aesthetics (2).

These advancements are not just about efficiency; they represent a leap towards greater patient satisfaction by reducing the time required for dental procedures and enhancing the comfort and aesthetics of dental solutions.

There are three types of CAD/CAM systems based on production:

1. In-office system (closed or partially closed): the prepared tooth is digitally scanned, and then the prosthetic replacement is fabricated within the dental office (chairside) and placed during the same visit (for example, Cerec)
2. In-lab system (open): impressions or models made from conventional impressions are scanned in the laboratory, and CAD/CAM is used to fabricate future work

3. Centralized production:Digital impressions are taken in the office and sent to the laboratory through a network. The laboratory then forwards them to a more prominent center for fabrication.

The transition from conventional impression materials to digital impressions is a significant step in the digital dental journey. Digital impressions allow accurate 3D digital casts to be produced by recording anatomical landmarks with a light source or laser beam from an optical camera. These digital models are crucial for creating restorations that fit perfectly without the discomfort and inaccuracies often associated with traditional molding materials.

Digitalization reduces the number of work phases, thereby decreasing the likelihood of errors. Digital techniques offer several benefits compared to traditional methods, such as quicker scanning times, better control during preparation, the ability to mark the preparation margins, scanning directly in the patient's mouth, online data transfer, the option to archive data, and significantly improved patient comfort (3).

Digital impressions can be obtained through two main types of systems: direct intraoral scanners (IOSs) and indirect extraoral scanners (EOSs). Each system has its specific applications, advantages, and challenges.

Intraoral scanners directly capture images of oral tissues, thereby preventing the necessity for conventional impression materials. Direct scanning reduces the risk of errors associated with manual impression-taking and improves the patient experience by eliminating the discomfort of traditional methods (4).

In contrast, extraoral scanners are used to scan physical impressions or stone casts located outside the mouth. Although they can be helpful in situations where intraoral scans are impossible, they have limitations due to potential inaccuracies arising from dimensional changes in impression materials or mechanical distortions in the scanning process.

Despite the advancements, the quest for accuracy and reliability in digital dental impressions continues. The expertise of the operator, the tools used, and the clinical environment all have

a significant impact on the outcomes' quality. The accuracy of these digital tools directly affects the efficiency of the final restorative work, emphasizing the necessity for continuous technological advancements and training (5, 6).
As digital dentistry continues to evolve, integrating these technologies presents opportunities and challenges. Thus, pursuing ever-greater precision and reliability remains a central theme in its development.

This thesis aims to focus on the accuracy of intraoral and extraoral digital dental scanners, a critical factor in the success of modern dental practices. The precision with which these scanners can advance the details of oral anatomy directly influences the effectiveness of treatment outcomes. Evaluating their accuracy provides insights into the current capabilities of dental technologies and highlights areas for potential improvement. Furthermore, this work will explore the latest scanners entering the market, assessing their technological innovations and their implications for dentistry in the future (1).

2. **ACCURACY IN DENTAL SCANNING**

2.1. Accuracy

Accuracy is crucial in dental scanning, as it directly impacts the quality and dependability of digital impressions. Accuracy encompasses two key concepts: precision and trueness.

These terms originated alongside digital scanners and are unique yet frequently misunderstood by dentists and technicians.

Precision refers to the consistency and repeatability of measurements, ensuring that the digital model maintains loyalty to the original scan.

Trueness relates to the degree of agreement between the digital scan and the actual anatomical structure, ensuring accurate representation without distortion.

Ideally, the scanner should achieve high values for both aspects, ensuring that the scan closely matches or is identical to the scanned object.

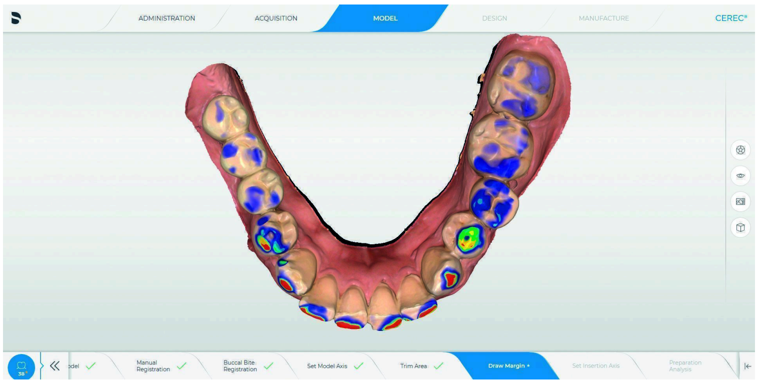
The most common causes of digital impression distortion are ambient light, the distance between the scanning tip and the object's surface, the scanning protocol, the surface's degree of wetness, and the material being scanned.

Several factors affect the accuracy of an intraoral scanner (IOS). Based on the dental arch, these factors can be divided into four groups: dentate, edentulous, completely edentulous with implants, and partially edentulous with implants. These factors include hardware variations and software algorithms (7).

Moreover, intraoral digital scanners have a defined tolerance threshold for accuracy. It is currently set at 50 micrometers, although most newer scanners surpass this mark, with some even achieving precision levels below 30 micrometers for precision and trueness. One big challenge for their use, and digital processes in general, has been ensuring the full arch scan is accurate (8).

2.2.Digital impression

A digital dental impression is a positive image of a patient's hard and soft oral tissues (Picture 1.). This method utilizes an intraoral scanner (IOS) instead of traditional impression materials and trays. The benefits of using an IOS include seeing the scan results immediately, the simplicity of repeating the scan if necessary, and the capability to focus selectively on specific areas of interest within the mouth. Once the scanning is complete, the data is transferred to a computer-aided design (CAD) program, which is used to create accurate dental restorations or prosthetics.



Picture 1. Digital impression

Taken with permission of prof .dr. sc. Marko Jakovac

Digital impressions revolutionize traditional dental procedures by enhancing the accuracy and efficiency of dental treatments.

Studies have shown that patients generally find the digital impression process faster and more convenient, leading to a more positive overall experience.

Digital impressions streamline the workflow in dental practices, reducing the turnaround time for creating and fitting dental prosthetics and ensuring higher precision. Scanning is faster than traditional clinic impressions.

Digitizing dental impressions can reduce the need for frequent patient visits and simplify the transmission of digital files to dental laboratories to create restorations. This eliminates the requirement of physically sending physical models. This is relevant because it reduces delivery time, the inconvenience of high shipping costs, and the possible destruction of model physical structures, which can sometimes occur. Moreover, information within digital records is more accessible to store and access than written documents, improving record-keeping in dental practices.

Some research shows that more than 89% of analog impressions sent to the laboratory contain errors such as margin issues, bubbles, or distortions. Digital scanners have a clear advantage as dentists can immediately view a positive image on the screen and quickly correct any scanning errors with additional scans, which take only seconds (1).

Digital impressions provide certain restrictions and difficulties. One of the main challenges, especially for smaller dental practices, is the initial cost of buying the necessary hardware and software, which can be high.

On the other hand, digital impressions can ultimately save dental practices money in the long term by eliminating the need for traditional impression materials, which can be costly and require regular replacement. Additionally, adequate training and practice are essential to achieving accurate and efficient digital impressions (6-9).

3. INTRAORAL SCANNERS

3.1.Mechanism and Technology

An intraoral scanner (IOS) is a dental device used by dentists to obtain accurate, three-dimensional images of patients' teeth and oral tissues.

In the past, scanners created images using powder. However, this method is now considered obsolete and is no longer used. Today, intraoral scanners predominantly opt for optical scanning, yet variations persist in their underlying technologies. Having a properly prepared tooth is essential for obtaining a high-quality optical impression.

The scanners generally consist of a probe movement control device, a measurement probe, a color or computing system, and measurement software.

The scanning varies, starting at 14x14mm and reaching an optimal size of 25x14mm. The scanning depth should be 14 mm to 20 mm for clarity and optimal scanner positioning. Additionally, the scanner should have a resolution of at least 25 micrometers (10).

Modern scanners achieve accuracy levels as fine as 10 micrometers, enabling them to fabricate bridges on implants and even entire jaw spans. While these claims require independent verification, it’s evident that highly accurate scanners are already on the market.

Each scanner operates by projecting light onto the subject, capturing it, and compiling the resulting images into either individual photographs or continuous videos. These images are then processed and assembled into a three-dimensional representation using specialized software.

This process relies on identifying points of interest (POI) and placing them programmatically in space according to their coordinates in width, length, and depth (x, y, and z).

In terms of light sources, scanners can be either passive or active. Passive scanners simply illuminate the object and recognize it based on texture differences, while active scanners project lines or grids of various colors and triangulate the object based on differences in their distance and shape.

Recording with scanners involves a high rate of multiple frames per second. While there are more advanced techniques like per-wave analysis, it’s sufficient for clinicians to understand the complex technology behind object capture, analysis, and assembly in the software's algorithm (1).

Finding the depth is especially difficult, but obtaining the third dimension is necessary. Triangulation, confocal scanning, active wavefront sampling (AWS), and stereophotogrammetry are some of the techniques used to do this.

Intraoral scanner recordings are saved in different formats, the most well-known being STL (Standard Tessellation Language). This format is based on triangulating each object's surface, typically employed in dental medicine and industry.

Three points define each triangle on the surface; smaller triangles result in more accurately scanned surfaces. Other formats, like PLY (Polygon File Format), store additional data to reproduce dental tissues' color, transparency, and texture.

When it comes to scanning speed, modern scanners are high-speed, with the quickest ones scanning an entire jaw in under 30 seconds. However, speed competitions are not particularly relevant in clinical practice for two main reasons.

First, the skill and knowledge of the person performing the scan play a significant role. Intraoral scans always take longer than demonstrations on models. Second, it makes no difference to the patient whether the scan takes 30 seconds or a few minutes. Today's scanners practically do not touch the teeth and cause no discomfort for the patient.

The accuracy of the scan and the technology used are significantly more important in preventing distortions and unnecessary repeated scans. Moreover, scanning the same areas multiple times because of poor technique poses challenges for the software and, at the very least, prolongs data processing time.

Several factors influence the accuracy of intraoral scanners (IOS). First, the usability of the scanning software is crucial. Second, the technology of the scanner itself, including its resolution and image quality, is vital. Third, applying powder material can affect accuracy; a too-thick layer can distort the scanned surface, which is rarely used today. Fourth, the presence of saliva and blood can reduce scan clarity. Lastly, the movement of soft tissue and limited space in the mouth can create challenges for accurate scanner positioning.

The ergonomics, weight, and size of the head are critical factors in the ease of use of scanners. A smaller head improves access to hard-to-reach areas and patients with smaller mouths, while a large head scans more expansive areas, enhancing speed and accuracy. Weight and balance help simplify techniques and avoid scanning direction or rotation difficulties. Technological limits currently restrict further size reduction of the scanner head.

It's important to note that scanners alone are not valuable without the accompanying image processing software. Certain scanners benefit from these programs and algorithms. For example, certain scanners, which have utilized similar technology for an extended period, demonstrate improved speed and accuracy through software updates, such as Primescan. Some scanners may incur subscription fees or additional upgrade costs, which should be considered in cost analyses.

Manufacturers now incorporate artificial intelligence into these programs to simplify scanning and image processing. The software identifies and removes unnecessary data, like scans of the cheek or mirror, retaining only relevant parts. This streamlines the cleanup process and reduces file size for quicker transmission.

The software performs many other calculations, offering features such as tooth color determination, caries detection, and fluorescence control.

Modern scanners also offer deep scanning capabilities, which help overlap images more efficiently and speed up the scanning process.

Scanners have become so advanced that they match the precision of traditional impressions. In addition, they provide various benefits, such as enhanced patient comfort, as patients tend to prefer scanning over conventional impressions. For doctors, it provides a clear view of the initial state or preparations and allows for convenient partial rescanning, which is notably simpler than traditional impressions (1, 10, 11).

3.2. Appliances

The following section will outline some of the most commonly used and newest devices on the market.

- Aoralscan 3 (Shining 3D)

Shining 3D's Aoralscan 3, developed in Hangzhou, China, is strategically positioned as a cost-effective option for dental practices. It prioritizes affordability without compromising quality. It features rapid scan speeds that enhance patient comfort and clinical efficiency.
Its high accuracy is vital for reliable dental diagnostics and treatment planning, while the integration of advanced AI simplifies the scanning process by automating tasks and optimizing data management.
It operates quickly and fluidly, allowing full arch scans to be completed in 30–40 seconds. The software stands out due to its polish and user-friendliness, which are uncommon in the more affordable segment of the market.
It features autoclavable and long, slim scanner tips suitable for adults and children, accommodating various patient needs. The scanner’s ergonomic design and lightweight construction enhance comfort during use. Additionally, it offers advanced capabilities like motion sensing, wireless connectivity, and a long-lasting battery, with a 30% more accurate design than its predecessor.
Applications include the orthodontic simulator and model builder. They are effectively implemented and provide practical, daily utility.
The Aoralscan 3 features an open architecture that allows for the easy export of scans in various file formats, including STL, PLY, OBJ, and Exocad. The software facilitates straightforward exporting of these scans directly from both the local software environment and cloud storage. The scanner software includes critical functionalities such as analyzing occlusion or reduction space, editing scans, and removing scan data. Additionally, it offers

features typically absent in other budget-friendly scanners, such as undercut analysis, margin line placement, and scan coordinate adjustment. (12-14).

- Medit i900 (Medit)

Over time, Medit has significantly expanded its product line. Following the introduction of the Medit i500, the company has developed newer models, including the i700 and its wireless version and the i600, the successor to the i500. Most recently, Medit introduced its premium model, the i900, which was developed in Seoul, South Korea.
The i900 weighs 165 grams and is 35 mm wide, nearly half the weight of the i700, which weighs 245 grams.
The i900 features real-time haptic feedback and an LED light on the back, providing immediate responses during scanning. Medit has upgraded the i900 with a third-generation optical engine, promising enhanced scanning speed, greater depth of field, and improved color accuracy. The device incorporates '10-bit imaging technology,' which Medit claims delivers a color depth that is 64 times richer than its previous models.
With its wholly redesigned optical engine, the scanner efficiently captures high-quality scans, minimizing blind spots and effectively detailing scans in challenging areas such as fluids and soft tissues. The Medit i900 is currently Medit's fastest scanner. The i900 features a larger field of view, enhancing the speed of scans and reducing stitching errors. Its scanner tip is the largest Medit model, allowing for more extensive capture with each scanner pass.
Medit is one of the few companies that offers export capabilities in STL, PLY, and OBJ formats for their intraoral scanners. The i900, launched in April 2024, and the older i500 from late 2018 both produce densely tessellated meshes, with the i900 showing a slight increase in mesh density. They have the largest file sizes.
Despite the technological advancements over six years, the difference in mesh density between the two models is minor, and its clinical relevance still needs to be explored. Notably, the i900 offers a superior scanning experience compared to earlier models like the i600 and i700 (15, 16).

- iTero Lumina (iTero)

The iTero LuminaTM scanner, equipped with iTero Multi-Direct CaptureTM (MDC) technology, revolutionizes intraoral scanning with enhanced capabilities and ergonomic design. It was developed in Israel and China.
The scanner's design incorporates the capture technology directly at the tip, eliminating the requirement for mirror tips that reflect light to a sensor at the back of the scanner.
The iTero Lumina scanner stands out for its significantly large field of view, which enhances the efficiency and speed of dental scans by minimizing stitching errors.
This compact wand offers a 50% smaller size for easier handling and an extended capture distance of 25 mm, simplifying the scanning of complex areas such as palates and crowded teeth.
The scanner delivers photorealistic scans. It eliminates the need for separate intraoral photos in patient records and Invisalign® cases, enhancing clinical decision-making and patient engagement with its high-quality 3D visualizations.
Interestingly, this scanner lacks wireless capabilities, a feature that has become common among other industry leaders like Medit and TRIOS (17, 18).

- TRIOS 5 (3Shape)

3Shape is a prominent player in digital dentistry. It is made in Copenhagen, Denmark, and is renowned for its leading-edge intraoral scanners and CAD/CAM software. The company solidified its market position with the launch of the TRIOS 3 around 2015/16. In late 2022, 3Shape introduced the TRIOS 5, its latest flagship intraoral scanner.
Although scanning speed is becoming less distinctive among high-end intraoral scanners, the TRIOS 5 stands out for its rapid performance. It typically completes full arch scans in 30 to 45 seconds, with the record fastest being 18 seconds. Regular users of the TRIOS 5 will appreciate its effectiveness, particularly in edentulous scans.

A critical aspect of the TRIOS 5 is its ScanAssist technology. It uses advanced AI algorithms to actively prevent stitching mistakes by rebuilding and improving the 3D model in real-time while it is being scanned. Dentists can now scan their patients from any angle, choosing a scanning path that best suits their techniques and preferences. This capability, not present in earlier TRIOS 3 and 4 models, distinctly sets the TRIOS 5 apart in the range of intraoral scanners. The TRIOS 5 from 3Shape is noted for its sleek, ergonomic design. It
boasts a modern, high-tech appearance with a two-tone black and white color scheme accented by 3Shape's signature red, a style continued from the Trios 4.
Despite being wireless and lighter, it has a strong build quality and feels balanced even after extended use. The scanner also features a new closed-tip design that improves hygiene by preventing fluid ingress and allowing for smoother, faster scans. Additional features, such as sleep mode, extend battery life, allowing for longer periods of operation without frequent battery changes.
3Shape is an open ecosystem that allows users to use STL and PLY files. This enables effortless incorporation with external dental laboratories that employ alternative computer-aided manufacturing (CAM) software (19–21).

- Primescan (Dentsply Sirona)

Primescan is a cornerstone for highly efficient digital workflows and was developed in Bensheim, Germany. It enhances internal and external collaboration in dental practices. This advanced system captures and processes data rapidly and in high resolution, and its intelligent data processing ensures optimal software integration by selectively transmitting essential data. The resulting scan outputs are immediately displayed on the Primescan touchscreen (Picture 2.).

Picture 2. Primescan intraoral scanner
Taken with permission of prof .dr. sc. Marko Jakovac

With the introduction of software generation 5.2, digital impression-taking using Primescan has become up to twice as quick as previously, with fewer interruptions during scanning. The enhanced scan accuracy of the device ensures the delivery of high-quality data for any type of dental indication, including those involving shiny materials.
Primescan's innovative Smart Pixel Sensor processes over one million 3D points per second, generating photorealistic and exact data. Its depth scan technology also ensures that images are clear and accurate, even at depths of up to 20 mm. This is especially helpful for scanning deeper indications, like subgingival preparations.
Its user-friendly design allows for quick, full-arch scans in less than a minute, offering powder-free, photorealistic color visualizations. Additionally, it supports a robust hygiene protocol with three types of sleeves, including single-use and autoclavable options, to meet diverse sanitation requirements.
Primescan supports a range of dental specialties, including restorative dentistry, prosthetics, implantology, and orthodontics. It has now extended its capabilities to include sleep appliances as well. It supports various data transfer options to your preferred partners,

ensuring that information is securely and encryptedly transmitted through the Connect Case Center Inbox.

Primescan offers easy upgradability to a complete chairside workflow and features a touch-enabled, intuitive user interface. This integration with the CEREC Primescan system revolutionizes the design and fabrication of dental restorations directly in the clinic, reducing the need for multiple patient visits and accelerating the completion of dental treatments (22, 23).

3.3 Difference in imaging

Table 1. Imaging modalities

Technology	**Scanners:**
Confocal imaging	3Shape , iTero
Structured light	Medit, Shining 3D
A mix of confocal imaging and stereo vision	Sirona Primescan

Intraoral scanner technologies are characterized by different imaging modalities, each with its representative brand (Table 1.). Comparing scanners within the same technology offers insights into which is superior, whereas comparisons across different technologies help delineate the specific advantages and limitations of each (24).

3.3. Scanning techniques

Several scanning techniques should be considered, and it's important to note that some scanners may show little difference between different techniques. It is always advisable to adhere to the manufacturer's instructions, so you should also take their advice on scanning techniques into account. There are three techniques and possibly their variations.

The first technique starts vestibulary or orally, transitions to occlusal, and ends on the opposite side, orally or vestibulary. The second technique starts occlusally, moves to the oral or vestibular surface, and ends on the opposite vestibular or oral side. The third technique is wavelike (S-type). The first two techniques for a complete set of teeth pass over the teeth and soft tissues three times per jaw (four times if the entire palate is desired), while the last technique passes only once in a wavelike manner.

It's essential to follow the manufacturer's instructions, although a common combination of techniques is starting posteriorly occlusal, with a preference to visualize part of the palatal and vestibular surfaces, as well as the gingiva, to facilitate easier image stitching. With digital impressions, particular attention should be paid to soft tissues.

Previously, scanners did not always include scanning of, for example, the palate. It's practically standard today because scans can overlap over soft tissues, and prosthetic indications are increasing (removable prosthetics). Keeping information in the designer's or technician's workflow is important. After grinding, the designer/technician has different information, especially if all teeth are ground down. They must now overlap their design onto the ground teeth, using information about soft tissue that does not change with grinding. In this process, the accuracy and precision of the scanner are crucial for overlapping scans (1).

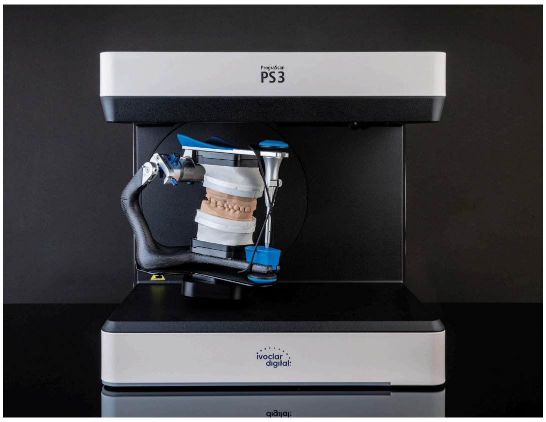
The scanning technique used to create full-arch digital scans significantly influences the scan's accuracy, and its effectiveness can vary depending on the scanner used (25).

Although studies generally indicate that operator experience affects the accuracy of clinical scanning techniques, this study shows otherwise. The findings suggest that these scanning methods are not significantly sensitive to the operator's experience, maintaining accuracy regardless of the operator's expertise level (26).

4. EXTRAORAL SCANNERS

Unlike intraoral scanners, laboratory scanners are integral to contemporary dental laboratories, boasting accuracy levels between 5 and 15 micrometers. Most CAD-CAM systems include a laboratory scanner. Today's market offers numerous laboratory scanners, which differ in their CAD-CAM systems, speed, scanning technology, and accuracy. Leading manufacturers offer scanners that are almost equivalent in quality.

A key feature is their ability to scan impressions and gypsum models. Gypsum models can be placed within an articulator. Previously, scanning positions in an articulator was challenging and involved using different aids and calibration blocks. However, modern scanners are now universally accessible and can effortlessly accommodate objects larger than the model (Picture 3.).



Picture 3. Extraoral scanner

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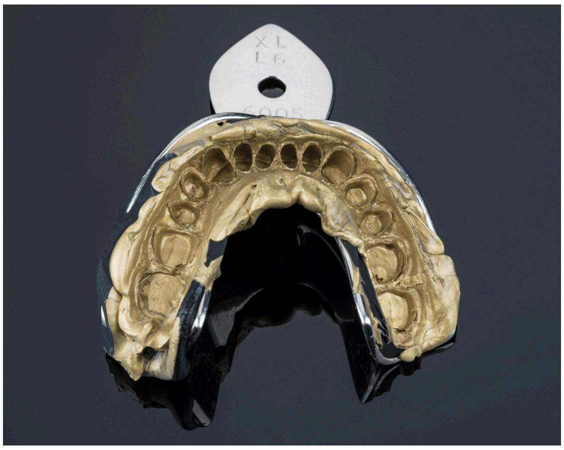
Extraoral scanners create images of the entire dental arch from various angles. Subsequently, these images are combined to create a comprehensive virtual three-dimensional model.

Most laboratory scanners employ blue light technology and vary in the number of lines utilized, resulting in increased scanning speed. However, the quality and precision of the scan are more critical than speed. The scanning software and the algorithm that assembles the scans into a final image are vital and improve speed and accuracy with each update.

The digital workflow comprises three key phases: data acquisition, design, and manufacturing. Digital scanners capture the surface topography with varying accuracy and precision during the data acquisition phase. The data is then transformed into a universal file format (STL, Standard Tessellation Language), regardless of the initial scanning system used. Ultimately, extraoral scanners will remain an essential part of the digital workflow for a long time. Despite laboratory scanners' high accuracy, analog impressions often have inaccuracies that are only sometimes visible, leading to errors that are not corrected (1, 27, 28).

4.1. Analog impression

An analog impression is a negative replica or reversed copy of the structure of an object, typically the teeth and surrounding tissues. This impression is sent to a dental laboratory, where technicians use it to craft plaster models. These models provide a clear view of the teeth and surrounding structures, significantly aiding diagnostic and treatment planning (Picture 4.).



Picture 4. Analog impression

Taken with permission of prof .dr. sc. Marko Jakovac

Careful attention must be paid to each step of the procedure to ensure the success of an analog impression. Dental materials and trays are crucial for this process. The most commonly used are elastic materials such as irreversible hydrocolloid, silicone, and polyether. Impressions can be made using stock trays and two types of addition silicone: putty consistency and light consistency. However, the highest-quality prosthetic impressions are taken with polyether in custom trays. Creating custom trays requires an initial impression made with alginate.

Several properties are crucial for impression materials, including precision, resistance to deformation and tearing, non-toxicity, working and setting time, patient comfort, and density.

Deformation issues mainly affect the addition silicones and polyethers during their

removal from the mouth, requiring a resting period before pouring to allow recovery. Impressions should rest for an hour before being poured.

For a precise alginate impression, attention must be paid to the details of mixing, such as the ratio of water to powder and the method of mixing (vacuum mixing compared to hand mixing), material quality, the angle at which the tray is inserted into the mouth, distortion during removal, storage method, and the time before pouring the model.

Machine mixing is recommended for better consistency.

Alginates are more prone to tearing, usually in interdental areas, which is less problematic for situational or anatomical impressions.

Non-toxicity is a crucial requirement, and modern impression materials generally do not cause toxic or allergic reactions, making them safe to use.

Regarding working time, manufacturers offer various setting speeds, but ultra-fast setting materials are generally not recommended as they often lead to errors.

While dentists often use fast-setting materials to minimize patient discomfort by shortening the time the impression is in the mouth, overly rapid setting can create more problems and future discomfort for the patient.

Therefore, it is essential to choose a material that allows sufficient time for mixing, application, and positioning in the mouth. Fast-setting materials are suitable for fewer teeth while slower-setting ones are better for more extensive procedures and provide enough working time.

A well-known in vivo study compared the accuracy of intraoral scanners with traditional alginate impressions in maxillae without teeth. The results showed that conventional methods are better at capturing the peripheral soft tissues needed for the marginal seals of removable prostheses. Digital systems may not perform as effectively as traditional methods when capturing subgingival preparation margins or when the gingival margin is bleeding (29).
Inspecting the impression before sending it to the laboratory to identify errors is essential. If errors are found, it is crucial to repeat the impression.
If the impression is repeated in such situations, significantly more time will be recovered later during the adjustment phase of the prosthetic work. This diminishes the quality of the work, as it cannot be ideally adjusted and is only acceptable with less precise margins, poorer aesthetics, and incorrect contacts. Repeating the impression helps maintain patient trust.
Mainly if it is explained that the process is complex and must be as precise as possible for the best, long-lasting results. Repeating the impression demonstrates the clinician's knowledge, experience, and professionalism, which is not a weakness (1).
The precision of an analog impression is crucial, as it influences the fit and quality of dental restorations. Each stage of the impression process is susceptible to potential errors, whether from human factors or material inconsistencies. Therefore, it is essential to do everything possible to maintain the highest accuracy at each stage and minimize errors (30).

4.2. Appliances

The following section will outline some of the most commonly used and newest devices on the market.

- Autoscan-DS-EX PRO(H) (Shining3D)

The AutoScan-DS-EX Pro (H) by Shining 3D is a versatile 3D dental scanner designed to meet various dental needs. Its headquarters are in Hangzhou, China.

It efficiently scans impressions, plaster models, articulators, and implant abutments. Equipped with high-resolution cameras and advanced algorithms, it ensures reliable data quality with an accuracy of ≤ 8 µm. The scanner captures details with dual 5.0 MP cameras. It offers fast scanning speeds, including 6.5 seconds for bite scans and 14 seconds for upper and lower jaw scans.
It integrates seamlessly into existing workflows and supports articulator transfer and output formats such as STL, PLY, and OBJ. Utilizing blue light as its light source enhances scanning accuracy (31).

- Medit T-Series (Medit)

The Medit T-Series lab scanners, developed in Seoul, South Korea, are engineered to meet the demands of dental laboratories. They offer speed and accuracy to elevate productivity in high-volume workflows while maintaining exceptional quality.
With its cutting-edge technology, the MEDiTEC T710 scanner can swiftly capture a full-arch scan in just 8 seconds. Advanced 5.0MP cameras power it, ensuring high-resolution, detailed scan data without blind spots. Notably, utilizing blue LED light technology, these scanners achieve an accuracy of < 4 microns according to ISO 12836 standards, upholding the highest precision standards.
The auto-elevation feature further enhances usability by eliminating the need for stacking jigs, effortlessly ensuring correct positioning. As an open system, the Medit T-Series scanners offer the flexibility to import and export files in STL format, facilitating seamless integration with other CAD/CAM systems. Additionally, flexible multi-die scanning and full-size articulator scanning optimize workflow efficiency, simplifying tasks and enhancing precision in dental lab work (32).

- F8 (3Shape)

The F8 lab scanner, made in Copenhagen, Denmark, provides accurate digital impressions for various dental restoration speeds. With its remarkable accuracy of 4 micrometers, it excels at creating detailed scans for complex cases, including dentures, crowns, bridges, and implant planning. The rapid scan speeds of 45 seconds for a complete arch impression allow technicians to process multiple cases quickly without sacrificing quality.

This scanner is adept at supporting the fabrication of removable prostheses and fixed restorations by capturing the details required for accurate fittings. Its compatibility with 3Shape software further extends its utility, enabling seamless workflow integration from scanning through dental restoration's design and manufacturing phases. Using non-contact blue light technology ensures precise data capture, which is crucial for designing restorations requiring meticulous attention to detail (33).

- inEos X5 (Dentsply Sirona)

The inEos X5 scanner was developed in Bensheim, Germany, meticulously designed for dental laboratories, and it upholds the highest quality standards for optical measuring systems, ensuring accuracy in all digitization tasks crucial to dental technicians. This scanner accommodates scans for nearly all dental indications, serving as a specialized tool for various digitization assignments in the lab.

Its open design fosters ease of operation and offers object-specific scanning strategies, providing unparalleled flexibility in application. Notably, the inEos X5 boasts a proven accuracy of 2.1 ± 2.8 µm on standard "bridge" test specimens and 1.3 ± 0.4 µm on standard "inlay" test specimens.

Equipped with unique 5-axis scanning technology and a large working area facilitated by its robot arm, this scanner combines intelligent scanning capabilities with user comfort, allowing efficient and unobstructed access to scan objects. One-piece scan bodies and specialized implant scanning strategies accurately determine implant positions, even in complex screw-retained restorations. It seamlessly scans both upper and lower jaws along with bite registrations, detecting marks for visual support in partial-denture design.

The scanner accommodates various impression tray shapes and sizes, making it ideal for capturing all relevant information for digital dentures. It can automatically scan up to four prepared dies and digitize a full-arch model in less than 60 seconds. It also offers efficient workflow integration and seamless inLab system compatibility, such as STL export and workflows tested with Exocad® (34).

- UP1000 (UP3D)

The UP1000 dental 3D scanner, made in Shenzen Nanshan, China, features advanced dual 5-million-pixel cameras with a scanning accuracy of up to 5 micrometers.

Utilizing non-contact blue light technology, this device supports dynamic and static articulator scans and is equipped with innovative dynamic articulator scanning technology. This broadens coverage of the entire jaw model and enhances occlusal accuracy. Its high-resolution capabilities are particularly effective for capturing detailed color texture scans, including hand-drawn margin lines and base tooth edges, improving the precision of dental restoration designs.

Moreover, the UP1000 easily integrates with major CAD software by exporting open formats like STL, PLY, OBJ, and U3M, enhancing workflow efficiency and flexibility in dental labs (35).

- S900 ARTI (Zirkonzahn)

The Zirkonzahn S900 ARTI Scanner is a high-precision dental scanner with advanced capabilities that was developed in South Tyrol, Italy. It features a dual-axis rotation system, which enhances scanning accuracy and efficiency.

The scanner's 10-micrometer accuracy makes it highly reliable for creating precise dental restorations and prosthetics. The scannable objects include individual molds, arch segments,

complete dental arch models, bite registrations, opposing dentitions, wax-ups, veneers, and abutments. A dual-scanning option is also available for scanning modeled frameworks.
The Zirkonzahn S900 ARTI Scanner offers easy positioning of the scan model using a laser pointer, ensuring precise alignment. Patient-specific information captured with the PlaneSystem® and Plane Analyzer can be fully digitized and seamlessly integrated into the Zirkonzahn software (36).

5. DISCUSSION

Today, dental impressions are either conventional or digital techniques. The first digital device appeared on the market in the 1980s, with limited usage indications. However, their range of indications has greatly expanded through constant refinement and applying different technologies. Dental scanners are categorized into intraoral and laboratory scanners. The final result of both types of devices is displaying a virtual model in specialized software designed for creating future dental restorations. Dental scanners are used for creating virtual patients, diagnosis and treatment planning, and producing orthodontic appliances. In implantology, they assist in surgically guided operations and the three-dimensional positioning of implants. In prosthetics, digital impressions are utilized for making inlays, onlays, veneers, single crowns on teeth and implants, bridges up to five units on teeth and implants, and partial dentures (37).

Intraoral scanners (IOS) are used directly in the clinic, allowing dentists to take digital impressions chairside. Extraoral scanners (EOS) are used primarily in dental laboratories.

Regarding the surrounding environment, intraoral scanners operate inside the patient's mouth and are susceptible to blood and saliva, affecting scan accuracy. However, extraoral scanners are not subject to these challenges as they scan in a controlled laboratory environment, free from biological contaminants, allowing for more stable and accurate scanning conditions.

Challenges in intraoral scanning include trouble identifying subgingival finish lines, inaccuracies when bleeding or moisture near the gingival margins, and errors caused by reflective surfaces in the oral cavity (38).

Intraoral scanners use structured light or laser scanning technology to capture the intraoral environment. These scanners emit light patterns that distort the contours of the oral structures, which the sensors then record to create a digital model. On the other hand, extraoral scanners often employ more advanced scanning technologies, such as high-resolution photogrammetry and laser triangulation (8, 29).

Intraoral scanners offer immediate feedback, enabling on-the-spot corrections. Immediacy streamlines clinical workflows, reduces the time needed to create and fit prosthetic work, and minimizes errors by instantly sharing digital impressions with laboratories (37).

Intraoral scanners provide high precision regarding accuracy and speed, achieving levels below 30 micrometers. There isn't a universally agreed-upon clinically acceptable accuracy range for intraoral scanners (IOS), but the acceptable misfit for fixed restorations that avoids clinical issues typically ranges from 50 to 200 µm. Many studies consider a misfit of 120 µm clinically acceptable, drawing on findings from the seminal McLean and Fraunhofer study (39).

The Institute of Digital Dentistry assessed the precision of three intraoral scanners: the Shining 3D Aoralscan 3, Medit i700 Wireless, and CEREC Primescan. The Primescan achieved the highest accuracy with a deviation of only 20 micrometers, setting the standard for detail capture. The Medit i700 Wireless showed a slightly higher deviation of 30 micrometers, indicating moderate accuracy. The Shining 3D Aoralscan 3 had the largest deviation at 35 micrometers, demonstrating the least precision among the three (40).

A study comparing the TRIOS 4 and Primescan intraoral scanners found that the TRIOS 4 had mean dimensional variations of 47 ±27 µm, and the Primescan had them at 57 ±8 µm. Primescan, however, proved significantly more accurate, with a smaller standard deviation (64 ±15 µm) compared to TRIOS 4. Primescan also exhibited the least deformation sagittally and transversely (41).

For implant prosthetic work, another study compared how well the TRIOS 3 and Medit i700 intraoral scanners scanned two scan bodies. The TRIOS 3 did better in terms of precision and trueness, especially when looking at the full arch model and scan body area (38).

The choice of scanning technique is crucial for ensuring the highest accuracy. Proper handling and scanning methods significantly influence the precision of intraoral and extraoral scanners, making training and technique optimization essential for the scanning process. The study aimed to assess the accuracy of various intraoral scanners (IOS) across different scanning strategies and operator experiences. Each IOS was used to perform ten scans of a complete maxillary dental arch made of epoxy resin, utilizing four distinct scanning techniques.

The data analysis showed that the Medit i700 and Primescan models did the best in terms of both accuracy and trueness. There were no statistically significant differences between them in the first and second scanning methods ($p > 0.05$). Specifically, the Medit i700 achieved the most accurate results for trueness (24.4 ± 2.1 µm and 21.4 ± 12.9 µm, respectively) and precision (23.0 ± 1.6 µm and 30.0 ± 18.0 µm, respectively) across the scanners. In the third scanning technique, the Medit i700 recorded the highest trueness, while the Primescan exhibited the best precision (24.0 ± 2.7 µm and 26.8 ± 13.7 µm, respectively) (25).

Primescan generally shows the best results in precision and accuracy among intraoral scanners, with deviations as low as 20 micrometers. These numbers highlight Primescan's superior performance in capturing detailed and accurate scans compared to its competitors.

Intraoral scanners significantly enhance patient comfort by eliminating the need for traditional impression material. The scanning process is quick, noninvasive, and provides a more pleasant experience (30).

A study by Yuzbasioglu et al. (2014) demonstrated that using digital impression techniques reduced the total treatment time and the time needed to create an impression compared to traditional methods. The researchers recorded the duration of digital impressions at 248.48 ± 23.48 seconds, while traditional impressions took 605.38 ± 23.66 seconds.

So, digital impressions are great for speed and workflow efficiency, but traditional analog impressions are still the best option in some clinical situations where you need to capture a lot of soft tissue or have difficult gingival conditions.

A well-known in vivo study compared the accuracy of intraoral scanners with traditional alginate impressions in maxillae without teeth. The results showed that conventional methods are better at capturing the peripheral soft tissues needed for the marginal seals of removable prostheses. Digital systems also do not work as well as traditional ones when taking subgingival preparation margins or when the gingival margin is bleeding (27).

Intraoral scanners simplify the archiving process, as digital files can be easily stored and accessed, unlike physical models, which require significant storage space and are prone to degradation over time (3).

On the other hand, extraoral scanners capture high-resolution images with accuracy levels down to 10 micrometers. They support multiple output formats and often include automation features such as auto-die scanning and rapid full-arch scanning, which reduce manual labor and enhance productivity. A significant advantage of extraoral scanners is their ability to

accurately capture subgingival preparations and handle larger restorative tasks, making them more suitable for complex dental work than intraoral scanners (29).
An in vivo study found that extraoral scanners achieved higher accuracy for full-arch scans than intraoral scanners. However, for partial arch scans, intraoral scanners demonstrated more accurate results within clinically acceptable limits when compared to full-arch scans (37).

6. CONCLUSION

Advancements in technology are constantly bringing highly accurate digital scanners to market. Scanners accurately send information from the patient's mouth into the system. They become easier to operate, quicker, and more precise. Artificial intelligence and software both contribute to improved scanning precision and quality. These methods reduce errors to a minimum and make essential repeats quick and easy.

Digital imprints and intraoral scanners have enabled physicians to assess patient preparations more thoroughly, recognize their own errors more readily, and advance their methods and abilities. Patients benefit from therapy that does not require imprint materials and avoids the discomfort associated with analog impressions. The physician receives the scan, analyzes it, and transmits it to the lab in seconds or minutes. The time to get very accurate prosthetic work is reduced due to faster and easier communication between the laboratory and the clinic.

Extraoral scanners are essential to dental laboratories because they can precisely handle larger, more complicated models. Accurate dental restorations depend on quickly processing several imprints or models, which these scanners provide through efficient processes.

While choosing between intraoral and extraoral scanners, the unique requirements of accuracy, application environment, and workflow demands should be considered. When used immediately at the chairside, intraoral scanners enhance patient experiences and speed up service delivery. Extraoral scanners are favored because they can effectively handle intricate and substantial jobs in a laboratory environment.

This progress indicates that digital impressions and intraoral scanners will soon be widely used in all areas of dental medicine. The ongoing development of these technologies promises even greater precision, speed, and ease of use, securing their place as indispensable tools in modern dentistry.

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