Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

SCANNING PROTOCOLS. HOW IT INFLUENCES THE RESULT OF A DIGITAL SCAN?

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ABSTRACT

Introduction: Digital workflows have transformed modern dentistry, with intraoral scanners (IOS) replacing conventional impression techniques. These devices require specific scanning protocols to ensure accuracy, which is a key factor for contributing to successful outcomes. **Objective:** To evaluate how different scanning protocols affect the accuracy and reliability of digital impressions using intraoral scanners. **Material and Methods:** This work is a systematic literature review of in vitro studies, clinical trials and comparative analyses focused on intraoral scanning strategies. Research was conducted through PubMed and Medline using Boolean operators with terms like "intraoral scanners", "digital impressions" and "scanning protocols." Only English-language articles from the last 10 years were included. **Results:** The analysis revealed that structured and segmented scanning strategies consistently outperform linear or manufacturer-recommended techniques, especially in full-arch impressions. Factors like operator experience, scanner type and protocol path significantly affect both trueness and precision. Notably, strategies such as cut-out rescans, S-shaped paths and quadrant-based scans improved outcomes across multiple IOS models. **Conclusions:** Scanning protocols play a critical role in digital impression accuracy. Although no single scanning strategy can be considered superior in all cases, outcomes appear closely tied to clinical context, user experience and the type of scanner employed. Standardized, evidence-based protocols could greatly improve consistency and clinical success in digital dentistry.

KEYWORDS

Dentistry, Intraoral scanners, Digital Impressions, Scanning protocols

RESUMEN

Introducción: Los flujos de trabajo digitales han transformado la odontología moderna, reemplazando las impresiones convencionales por escáneres intraorales (IOS). Estos dispositivos requieren protocolos de escaneo específicos para garantizar precisión y exactitud, aspectos clave para un resultado exitoso. **Objetivo:** Evaluar cómo diferentes protocolos de escaneo afectan la precisión y fiabilidad de las impresiones digitales obtenidas mediante escáneres intraorales. **Material y Métodos:** Este trabajo consiste en una revisión sistemática de la literatura, incluyendo estudios in vitro, ensayos clínicos y análisis comparativos centrados en estrategias de escaneo intraoral. La búsqueda se realizó en bases de datos como PubMed y Medline con operadores booleanos y términos como “intraoral scanners,” “digital impressions” y “scanning protocols.” Solo se incluyeron artículos en inglés de los últimos 10 años. **Resultados:** El análisis reveló que las estrategias de escaneo estructuradas y segmentadas superan sistemáticamente a las técnicas lineales o las sugeridas por los fabricantes, especialmente en impresiones de arcada completa. Factores como la experiencia del operador, el tipo de escáner y el recorrido del protocolo afectan significativamente tanto la veracidad como la precisión. Estrategias como el recorte y reescaneo, los recorridos en forma de S y los escaneos por cuadrantes mostraron mejores resultados con varios modelos de IOS. **Conclusiones:** Los protocolos de escaneo desempeñan un papel fundamental en la precisión de las impresiones digitales. No existe una estrategia universalmente superior; los resultados óptimos dependen del contexto clínico, la destreza del operador y la tecnología utilizada. Protocolos estandarizados y basados en evidencia pueden mejorar significativamente la consistencia y el éxito clínico en odontología digital.

PALABRAS CLAVE

Odontología, Escáneres intraorales, Impresiones digitales, Protocolos de escaneado

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1. INTRODUCTION

1.1. Background

Over the past decades, technology has brought sweeping changes in our daily life and also in scientific or medical fields like dentistry. One of its most impactful shifts is the introduction of the field known as digital dentistry. Key advancements include the inauguration of computer-aided design/ computer-aided manufacturing (CAD/CAM), three-dimensional imaging, and, more recently, intraoral scanners (IOS) that replace traditional dental impressions (1,2). CAD/CAM technology exists since the 1980s in various domains and has evolved significantly since then (3). Unlike the traditional methods that rely on physical materials like alginate or polyvinyl siloxane to capture dental structures, intra-oral scanners rely on capturing three-dimensional (3D) images that will be processed and used by the clinicians (4). Conventional impression materials, while generally reliable, are prone to various problems like possible discomfort for the patient, material shrinkage and inaccuracies that can occur during the handling and pouring process (4,5). Such drawbacks have led to the surge of adopting IOS devices, which can bypass many of these limitations by generating immediate digital impressions ready for evaluation and digital processing (5–8). As these IOS devices have become an everyday tool for dentist, there is a growing need to carefully study and refine the scanning methods used, known as “scanning protocols”, to make sure of getting the most accurate and precise results (6).

1.2. “Accuracy”, “Trueness” and “Precision”

Due to the complexity of the technologies of these devices, it is important to clarify terms like “accuracy”, “precision” and “trueness”. The term “accuracy” was at one time used only to cover one component now named “trueness”. Although often thought as synonyms, “accuracy” and “precision” have distinct meanings. According to dictionaries, “accuracy" relates to the closeness of a result to a true value, while “precision” refers to the consistency of the results. The International Organization for Standardization (ISO) stated that the term “accuracy” was used at one time only to cover the one component now named “trueness”. So “trueness” now relates to the closeness of a result to a true value, “precision” refers to the closeness of agreement between independent test results and “accuracy” is used to refer to both trueness and precision (9). Clinically, this means that high-quality devices must produce results that are not only close to the true anatomical dimensions but also consistent across repeated scans.

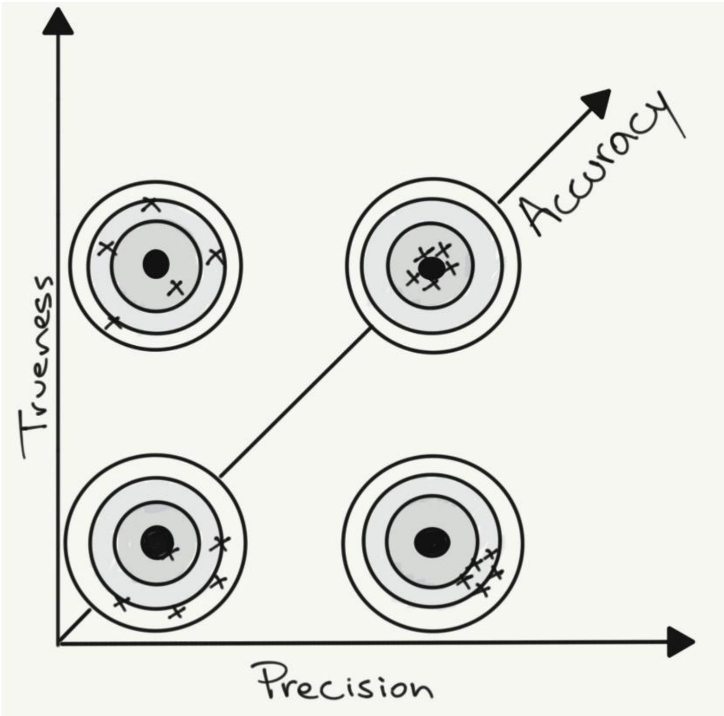

Figure 1: Image representation of the accuracy definition according to current ISO definitions

1.3. Data Recording and Processing

Converting physical structures into digital data is the main function behind these intraoral scanners. First of all, data acquisition is required, images will be taken with the help of the IOS. Depending on the IOS, there are different technologies for this acquisition. For example, different IOS use various light sources such as, Blue Light Scanning or LED-based systems (10). Moreover, for the data acquisition different types of scanning strategies can be used. The typical strategy begins with scanning occlusal, then buccal and finally lingual (11). However, there are various other types of strategies that we will see later and how their choice can have an impact on the trueness and precision (12). During the data acquisition it is also very important to control the scanning environment like saliva, light, patient movement in order to minimize any interferences which could reduce the accuracy of the outcome (13,14). Next, the data processing and the reconstruction of the 3D model takes place. Since IOS capture multiple overlapping images, so called “point clouds”, which are thousands of individual points that the scanner collects while scanning the surface (6). The system then connects all of these points using triangular patterns to form a so called “tessellated mesh”, which is like a net of triangles that are joint together and form a continuous 3D model using a best-fit alignment algorithm like for example Surface Matching (Iterative Closest Point Algorithm) or Geometric Feature Recognition (Edge & Contour Matching). The alignment accuracy can depend on scanning strategies, patient anatomy and software optimization (11,15). Then, depending on the scanner the data will be directly stored in a Standard Tessellation Language (STL) file or firstly converted from a proprietary file format to STL and become the foundation for any processing in CAD/CAM software (6,16). Advanced algorithms can further refine the model, correct inconsistencies and fill in gaps by stitching overlapping areas together. This process is highly dependent on the accuracy of the data acquisition process, as errors at this stage can compromise the final prosthesis (11,13–16).

1.4. Different IOS brands and their technologies

While the end goal of all IOS devices remains the same, the technology used by each different one to capture accurate digital impressions might differ significantly. Various different brands such as, AC Primescan, (Dentsply Sirona, Charlotte, NC, USA), Trios 4 (3Shape, Copenhagen, Denmark), iTero Element 5D (Align Technology, San Jose, CA, USA), Medit i700 (Medit, Seoul, Republic of Korea), AC Omnicam, (Dentsply Sirona, Charlotte, NC, USA) and Dexis IS 3700 (Dental Imaging Technologies Corporation, Hatfield, PA, USA) use distinct data collection methods and manufacturer-recommend scanning protocols which will be highlighted in Table 1. Below is an overview of various modern intraoral scanners and their respective technology:

Parallel Confocal Microscopy

This technique uses focused light and a tiny aperture to only capture the reflected light, eliminating out-of-focus light in order to enhance accuracy. The scanner illuminates the surface of the object with three beams of different colour which combine to provide white light, multiple scans of the prepared area are recorded as a single image (11,17,18). A type of parallel confocal microscopy scanner is the iTero Element 5D (Align Technology, San Jose, CA, USA), a popular choice in orthodontics and restorative dentistry due to high trueness and real-time visualization.

Active Triangulation

For Active triangulation, a light source projects a pattern onto the surface that needs to be scanned and a camera will capture any deformation or displacement of this pattern on the surface. Then the scanner will calculate the precise spatial coordinates of the object by analyzing the angle between the light source, the object and the detector (17,18). The Dexis IS 3700 (Dental Imaging Technologies Corporation, Hatfield, PA, USA) scanner uses this method to achieve high-speed imaging with colour accuracy which improves workflow efficiency for clinical professionals. AC Omnicam, (Dentsply

Sirona, Charlotte, NC, USA) utilizes active triangulation to enable powder-free scanning alongside real-time visualization which proves effective for chairside restorations and CAD/CAM workflows.

Active Wave Sampling

Active wave sampling consists in the dynamic sampling of optical waves in real time. While adapting to the scanning environment, it collects data points based on the movement of the scanner and reflectivity of the scanned surface. In other words, it combines both motion tracking and surface reflectivity to ensure accurate data acquisition (17,18). AC Primescan, (Dentsply Sirona, Charlotte, NC, USA) integrates active wave sampling with a Smart Pixel Sensor, enabling the capture of up to 1,000,000 3D data points per second. This provides unmatched detail, especially for full-arch scans and implant workflows, making it one of the most precise scanners in the market.

Optical Sectioning

This method involves the construction of a 3D model with the capture of multiple images at various depths. These “slices” will help effectively reconstruct the 3D structure of the dental surfaces. Trios 4 (3Shape, Copenhagen, Denmark) utilizes Ultrafast Optical Sectioning, allowing high-speed scanning while reducing image noise. This scanner is ideal for full-arch scans and integrates artificial intelligence (AI) to optimize data acquisition. Medit i700 (Medit, Seoul, Republic of Korea) incorporates multi-layer imaging with AI-assisted error correction, ensuring faster and more accurate impressions while maintaining lightweight ergonomics and affordability for widespread clinical use (11).

1.5. Scanning protocols

When talking about scanning protocols, we mostly refer to the specific procedures and settings that can influence the outcome of a digital scan (11,12,19–25). Numerous factors can influence the final outcome of a digital scan like for example lightning, angle of the scanner, moisture, speed at which the scanner is moved, scanning pathways and operator skill (2,13). So learning and understanding these different factors has become crucial in order to maximize the clinical benefits of this technology, while minimizing potential sources of error (2,6,26,27). Manufacturers often provide guidelines for optimal use, however these recommendations may not cover the range of clinical scenarios that happen in real practice, where a more tailored approach will be needed.

Brand	Preparation	Scanning sequence
AC Primescan, (Dentsply Sirona, Charlotte, NC, USA)	• Ensure optimal moisture control • No powder required • Position scanner at a slight tilt for better capture • Ensure optimal visibility	• Start at palatal of left lateral incisor and go towards the right terminal tooth while scanning the palatal surfaces with a slight tilt in order to also capture the occlusal surface • Go back to left lateral incisor while scanning buccally with a tilt to complement the missing occlusal elements • Repeat for the other side • One extra scan for the anterior region
AC Omnicam, (Dentsply Sirona, Charlotte, NC, USA)	• Powder-free • Regularly calibrate • Allow Omnicam to warm up to prevent fogging of the sapphire glass surface • Ensure clean & dry oral cavity • Ensure optimal visibility	Scan sequence for first quadrant: • Start by scanning the occlusal surface of the furthest back right tooth (terminal molar). • Tilt the scanner 45° towards the palate and scan from distal to mesial (towards the opposite lateral incisor). • Return to the right terminal tooth by scanning back over the palatal surface. • Tilt the scanner 90° onto the occlusal surface, and scan mesially again toward the opposite lateral incisor. • Now tilt the scanner 45° toward the cheek (buccal) and move back distally to the right terminal tooth. • Tilt further (total 90° buccal angle) and make one last mesial pass to the opposite lateral incisor. Scan sequence for second quadrant: • Begin on the already scanned premolar's occlusal surface, and tilt the scanner 90° palatally, moving distally across the palatal side of the front teeth towards the terminal molar. • Next, tilt the scanner 45° palatally and scan from distal to mesial back towards the front teeth. • At the front teeth, tilt the scanner 45° buccally, and scan mesial to distal across the buccal surface. • Then increase the tilt to a full 90° buccal, and return distally to mesially back to the front teeth. • Finally, tilt the scanner back occlusally and scan mesially across the occlusal surfaces toward the right terminal molars.

Trios 4 (3Shape, Copenhagen, Denmark)	• **Powder-free** • **Ensure scanner tip is clean and calibrated** • **Dry teeth surfaces to minimize reflections & increase accuracy** • **Ensure optimal visibility**	• **Begin from occlusal surface of second molar towards anterior** • **Slight "wiggle" motion in the anterior sector to capture buccal/palatal or labial aspects** • **Rotate to record palatal/lingual side from one end of the arch to the other and then repeat the same for buccal side** • **Bite registration of desired occlusion**
Medit i700 (Medit, Seoul, Republic of Korea)	• No powder required • Dry teeth • Soft tissue retraction for better accuracy	• Start with a buccal-occlusal scan from right first molar to the right third molar and then proceed occlusally towards the opposite arch • Wiggle motion in the anterior region • Proceed with the occlusal scan of the left posterior sector • From there, rotate and go back to right third molar over the palatal surfaces • Lastly, go back to the opposite arch over the buccal surfaces
Dexis IS 3700 (Dental Imaging Technologies Corporation, Hatfield, PA, USA)	• Ensure dry field • No powder required • Retract soft tissues for optimal visibility	• Start from the occlusal surface of the right third molar and move toward the left third molar • Continue scanning the palatal surfaces from left to right • Scan the buccal surfaces from right to left, ensuring smooth and continuous motion
iTero Element 5D (Align Technology, San Jose, CA, USA)	• Ensure a dry field • No powder required • Keep scanner tip clean • Calibrate if necessary	• Start from the occlusal surface of the right third molar and move toward the left third molar • Continue scanning the palatal surfaces from left to right • Scan the buccal surfaces from right to left, ensuring smooth and continuous motion • An extra scan over the anterior region to refine interproximal capture.

Table 1 : Manufacturer recommended scanning protocols for the following brands (25,28)

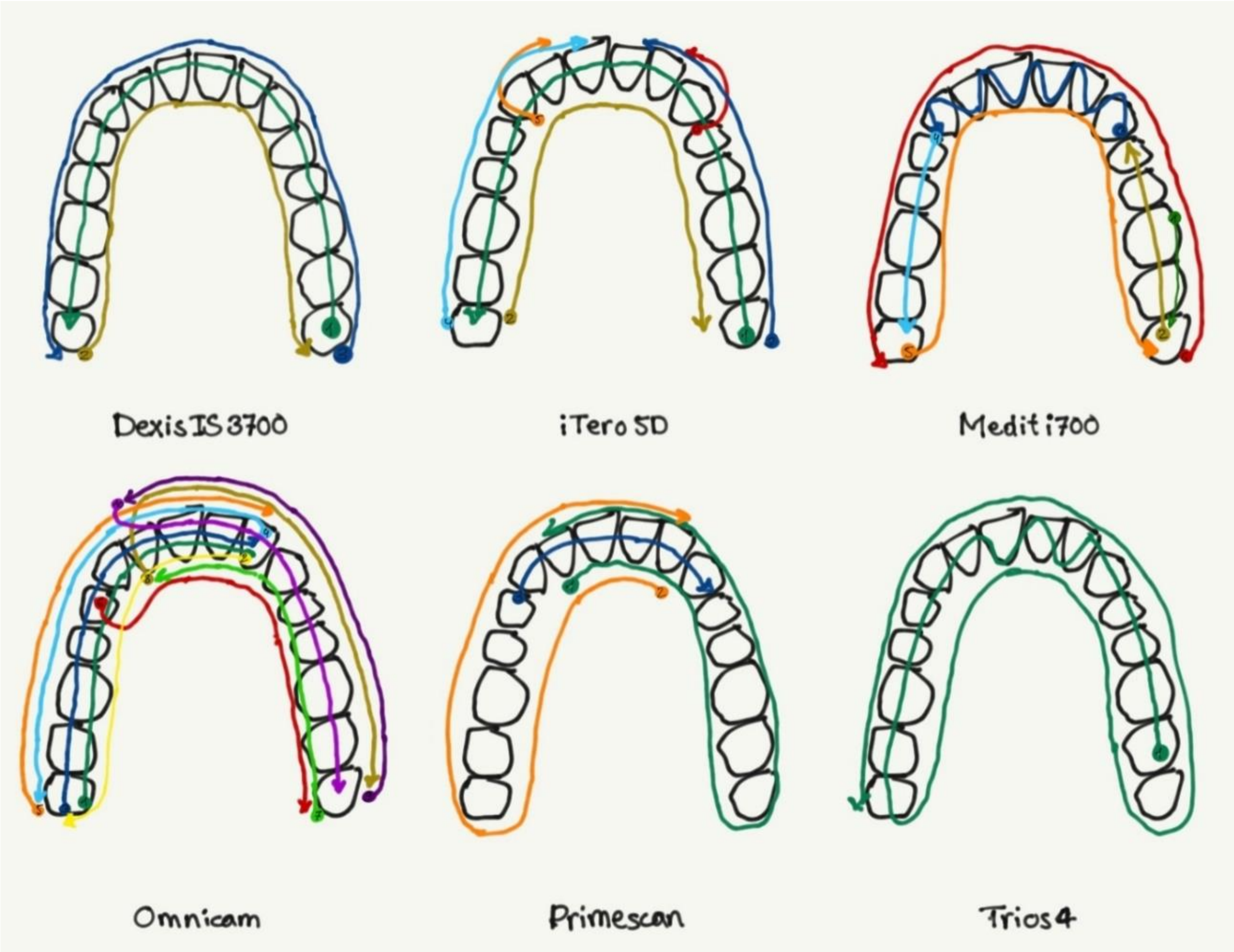

Figure 2 : Manufacturer recommended scanning protocols (25)

While scanning intraorally you can encounter unique challenges, especially when dealing with edentulous areas or complex/detailed tooth morphologies. Teeth present many variations in their form, translucency and texture, all of which can complicate the scanning process. These anatomical factors require careful consideration of scanning protocols in order to minimize or avoid artifacts and ensure accurate data capture. Furthermore, despite the anatomical challenges IOS operate in a challenging environment, where various factors like saliva, limited lighting, movement may interfere with the accuracy of data capture (13,14,18).

Poorly executed scanning protocols can result in data inaccuracies, such as misalignments, surface irregularities or incomplete data capture, all of which undermine the diagnostic and therapeutic utility of digital scans (26,27). Moreover, inconsistent scanning protocols contribute to variability in scan outcomes, which can complicate treatment planning across multiple specialities within dentistry, like prosthodontics, orthodontics, and implantology, where accuracy is essential. For instance, restorative dentists use digital impressions to design crowns, veneers, incrustations, avoiding some of the errors that traditional methods could have introduced (3). Moreover, orthodontists increasingly rely on IOS to create accurate models for clear aligners and other corrective devices, where proper fit and alignment is crucial (29). Prosthodontics, as a speciality, has long emphasized the importance of trueness and precision in their treatments in order to avoid future problems like marginal filtration or the lack of passive fit between prosthesis and tooth or between prosthesis and implant. This transition from conventional workflows relying on capturing the shape and contour of teeth physically to digital workflows has raised the standards for accuracy, efficiency, and particularly patient comfort in prosthetic dentistry (6).

In other words, the accuracy and reliability of these scans relies heavily on the practitioners adherence to scanning protocols, which have been carefully designed to ensure the best data capture and minimize errors (11).

These scanning protocols can differ from brand to brand as seen before in Table 1 or depending on what kind of restoration needs to be done. For example, for crowns and bridges the focus is more on capturing the prepared tooth/teeth, adjacent structures to it and the occlusion. You start scanning the occlusal aspect of the prepared area and then go buccal and palatal/lingual, and focus on tilting and angulating the scanner in order to prevent any mistakes like not capturing undercuts or the subgingival margins. Then you will continue to scan the adjacent structures, the opposing arch and finally the bite registration. The protocol can allow to rescan the margins for refinement and capture any missing details. This will require a more high-resolution scan, capturing little and precise details in order to get a good fit and marginal adaptation (1,21,24,25,30,31).

While being one of the most challenging areas to scan, scanning protocols will try to minimize errors and improve accuracy of full-arch digital scans. For full arch scans the scanning protocol will vary significantly from crowns or bridges. While they still need to be accurate, the main focus is to ensure dimensional stability and avoid any stitching errors. The protocol typically follows the same approach most of the times, which can vary slightly depending on the brand of scanner. You start from the occlusal aspect of one molar and slowly progress to the other side in one single, stable and continuous movement. Then you incline the scanner and come back to the starting molar over the buccal aspect and finally go back to the other side of the arch while scanning the palatal/lingual aspect. Then repeat the same for the other arch and the bite registration. A more segmented approach can also be used, scanning by quadrants which then will be merged together by stitching (11,12,19–25). In order to reduce errors, it is important to prepare the patient and control the environment like saliva, soft tissues, follow the proposed scanning protocol with sufficient overlap. Overlapping is the way IOS use pattern recognition to stitch multiple images together with partial overlapping to create the full model (10,32).

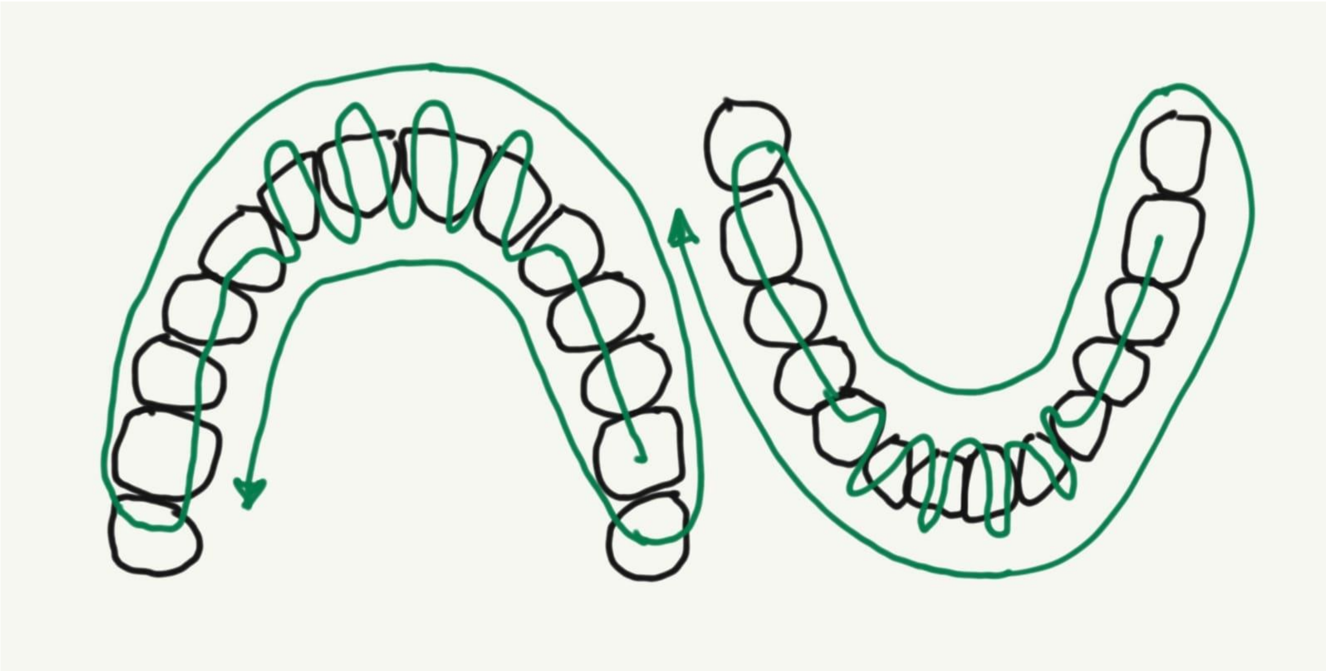

Figure 3: IOS scanning protocol full arch by 3Shape (Copenhagen, Denmark)

1.6. Justification

Given all these challenges, the optimization of IOS protocols has become crucial for achieving high quality digital impressions. In prosthodontics, achieving an accurate fit is paramount, as any little discrepancies can lead to poor retention, marginal gaps, patient discomfort and foremost the short term failure of the restoration. For example, wrong angulation of the scanner, presence of saliva or failure to cover all the critical areas can result in incomplete or distorted, which will affect the quality of the prosthetic fit. By investigating how different scanning parameters affect scan quality, clinicians can establish evidence-based protocols that enhance accuracy, efficiency and reproducibility of digital impressions.

2. OBJECTIVE

The objective of this thesis is to evaluate the influence of different scanning protocols on the accuracy and reliability of digital impressions obtained using intraoral scanners.

3. MATERIAL AND METHODS

3.1. Study Design

This study follows a systematic approach to analyze what effect scanning protocols have on the accuracy and outcomes of digital scans. By critically evaluating existing literature, the study aims to provide a comprehensive overview of how different scanning approaches impact digital impressions in clinical and research contexts. The systematic approach ensures the results are evidence-based and reproducible.

3.2. Search Strategy

The literature search was conducted using databases accessible via the CRAI Dulce Chacón library, including Medline and PubMed. These platforms were selected due to their extensive database of articles.

To ensure a focused and relevant dataset, the following search terms were employed: “intraoral scanners”, “scanning protocols”, “digital impressions” and “accuracy”. Boolean operators were used to refine the results, enabling a precise combination of keywords and filtering of extraneous studies. The search was limited to articles written in English and published within the last 10 years to ensure contemporary relevance. However most articles found were published during the last 10 years due to the fact that intraoral scanners have been introduced recently in the field of dentistry.

3.3. Inclusion and Exclusion Criteria

The inclusion criteria for this review are as follows:

- Studies involving the use of intraoral scanners and digital scanning protocols.
- Research focusing on the accuracy and reliability of digital impressions.
- Articles published in English within the past 10 years.
- Studies related to applications of digital scanning.

Exclusion criteria include:

- Studies published in languages other than English.
- Articles older than 10 years.
- Studies focusing exclusively on non-digital impression techniques or protocols not involving intraoral scanners.
- Case reports, opinion pieces, and editorials that do not include empirical data.
- Implant or Edentulous related articles

3.4. Search Equation

The search strategy employed Boolean operators to combine keywords and ensure comprehensive coverage. The search equation was as follows: (((Intraoral scanner) OR (Digital Impressions)) AND ((scanning protocols) OR (scanning strategies))).

3.5. PICO Question

P: Patients undergoing digital impressions using intraoral scanners.

I: Use of different scanning protocols.

C: Comparison of protocols in terms of accuracy and outcome.

O: Improved accuracy and reliability of digital impressions

This PICO framework provides the foundation for assessing how scanning protocols influence the outcomes of digital impressions and serves as a guiding structure for this systematic review.

Resulting PICO question:

In patients undergoing digital impressions with intraoral scanners, how do different scanning protocols compare in terms of their impact on accuracy and reliability?

4. RESULTS

The results are based on an analysis of multiple studies, in vitro experiments, clinical trials about intraoral scanners and their respective scanning protocols. The main focus is comparing the accuracy, efficiency and clinical applicability of these different IOS, as well as the parameters that can have an influence on their performance.

4.1. Prisma flow chart

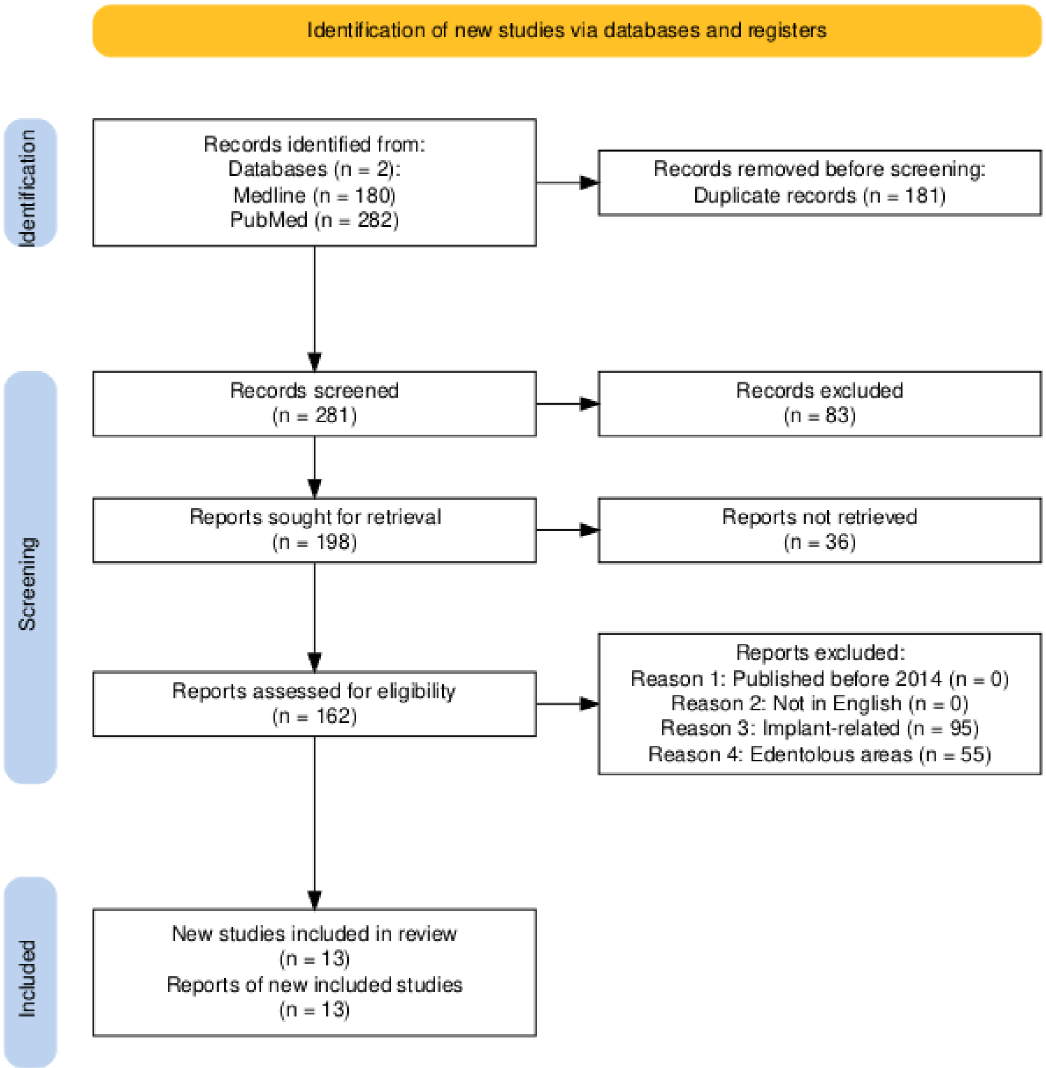

Figure 4: Prisma 2000 flow diagram

4.2. Results table

The following table will compare 13 different articles based on specific parameters.

Author, Year	Country	Study Type	Sample	Intervention	Control	Measuring Instruments	Outcome (accuracy)	Discrepancy (µm)
Müller et al., 2016(30)	Switzer-land	In vitro	Maxillary model cast	Three scan strategies: A, B & C	Reference scanner compariso n	Digital super-imposition	Strategy B had highest precision	A: 17.9 ± 16.4, B: 17.1 ± 13.7, C: 26.8 ± 14.7
Giuliodor i et al., 2023(25)	Italy	In vitro	Epoxy resin model	Six IOS, four scanning techniques	Industrial scanner reference	STL file comparison	Medit & Primescan: Strategy 1 & 3 depending on operator	T: 21.4–24.4, P: 21.4
Medina-Sotomay or et al., 2018(11)	Ecuador/ Spain	In vitro	Maxillary arch casts	Four IOS, different scan strategies	Industrial scanner reference	3D measuring software	Strategy D (iTero, Trios), B (Omnicam), C (True Def)	D ~18, B ~25, C ~22–26
Choi et al., 2024(12)	South Korea	In vitro	Mandi-bular stone cast	Four scan paths (A-D)	Desktop scanner reference	STL file analysis	Path D had the highest accuracy and most uniform results	
Passos et al., 2019(24)	Brazil	In vitro	Custom typodont	13 scanning strategies	ATOS III scanner reference	3D metrology program	Strategy M had the best trueness & precision	M best (trueness & precision <5) Other (like G or B) errors up to 18-19
Oh et al., 2020(21)	South Korea	In vitro	10 typodont pairs	Three scanning strategies: CH, CV, S	Reference industrial scanner	Geomagic Control X	Segmental scanning approach best	"CH: 75.2, CV: 102.6, S: 68.1"

Author, Year	Country	Study Type	Sample	Intervention	Control	Measuring Instruments	Outcome (accuracy)	Discrepancy (µm)
Cordaro et al., 2023(33)	Switzer-land	Clinical pilot trial	40 patient scans	Novel vs manufacturer's recommended	High-precision lab scanner model	3D-analysis software with AI	Novel more efficient	Novel: 82.8 ± 16, Control: 81.5 ±
Yahya et al., 2024(34)	Sweden	Pilot trial	30 scans per protocol	Four scanning protocols: ROCK, ZIGZAG, OBP, OWBP	Industrial ATOS scanner	GOM inspect software	OWBP protocol had best trueness	OWBP: 1–24, ZIGZAG: 7–97, ROCK: 5–41
Schlögl et al., 2025(19)	Germany	In vitro	225 scans	FL, FZ, FC, HL etc. (9 total strategies)	Reference dataset metric analysis	CMM and 3D deviation analysis	FL, FC, HL strategies performed best	FL: 171.5 , FC: 175.9, HL: 182.13
Son et al., 2023(23)	South Korea	In vitro	15 scanners	Comparison of different scan paths and distances	Superimposition with reference scan	Image processing and statistical tools	Scanning path D had highest accuracy	
Gavounelis et al., 2022(35)	Greece	In vitro	15 orthodontic casts	Three scanning paths compared	Gold standard scanner comparison	General Linear Model analysis	Manufacturer-recommended strategy performed best	Trueness: A: 37.5 ± 12.5, B: 44.8 ± 17.3, C: 43.9 ± 20
Ortensi et al., 2024(22)	Italy	In vitro	Reference model	Strategies: S1, S2, S3	Digital reference dataset	Geometric measurement tools	S3 strategy optimized accuracy	S3: 8.8–16.2 S1: 9.98 – 24.8 S2: 11.5 – 24.1
Hardan et al., 2023(20)	Lebanon	Meta-analysis	15 studies	Effects of scanning on trueness and precision	Standard scanning methods	Review Manager software	S-pattern with landmarks	

Table 2: Results table

5. DISCUSSION

Digital impressions have revolutionized modern dentistry, optimizing outcomes in prosthetic rehabilitation, implant planning or orthodontics with their accuracy and reliabilty. Among the various variables influencing the outcome of these digital scans, scanning protocols stand out as a critical factor. This discussion examines in depth how scanning strategies, rather than the scanners themselves, impact the accuracy of digital impressions. Accuracy, as defined by ISO 5725-1, is a combination of trueness and precision (trueness referring to the closeness of a measured value to the actual value, and precision denoting the reproducibility of measurements) (9). So as digital dentistry becomes more and more integrated into clinical workflows, identifying the most effective scanning protocols has become essential for optimizing the final outcome (6).

By comparing the multiple studies that were analysed, consistent findings were found: Scanning protocols significantly influence the accuracy of digital impressions. The results emphasize that the choice of scanning protocol, the segmentation of the arch during scanning and the rotation/angulation of the scanner head can either enhance or degrade the quality of the final STL file generated. Notably, the avoidance of abrupt scanner movements and the application of systematic scanning strategies often segmental or linear were associated with improved trueness and precision (12,20,22,24,30). However, does this influence have a significant impact on the final result or is the difference so minimal that it could be disregarded?

5.1. Importance of Scanning Protocols

Digital impressions require a meticulous balance of hardware precision, software capability and scanning protocol. While technological improvements in intraoral scanners (IOS) have led to greater accuracy, it is increasingly obvious that scanning strategies play an equally important role, if not greater in determining scan accuracy. The examined studies confirm that even when using the same intraoral scanner, scan accuracy is highly sensitive to the specific scanning strategy chosen. Thus, the scanning protocol is not a mere auxiliary procedure but a crucial element in the digital workflow.

Table 2 underscores that segmental scanning, structured paths, and adaptive techniques outperform linear or unstructured strategies across most metrics. Studies such as Oh et al. (2020), Passos et al. (2019), and Giuliodori et al. (2023) show consistent superiority of well-designed protocols over default manufacturer recommendations, particularly in full-arch scanning where cumulative error presents a significant challenge (21,24,33).

These protocols don't just serve to enhance trueness and precision, but also optimize the entire scanning experience. For example, segmental strategies allow operators to recover data without redoing entire scans. Adaptive scanning movements, where protocol selection responds to the tooth morphology or scanning challenges like glare or moisture, also improve data integrity. This adaptability becomes vital in clinical environments where ideal conditions are rarely guaranteed.

Moreover, understanding the purpose of these protocols contributes to the broader debate on clinical standardization. By isolating scanning strategy as an independent variable, researchers can better calibrate future studies and dental curriculum designs to focus on skill-based scanning education.

5.2. Comparative Findings

Oh et al. (2020) highlighted the segmental scanning approach as most effective compared to continuous horizontal (CH) and vertical (CV) techniques. The reported discrepancy was lowest for the segmental method (68.1 µm) and highest for CV (102.6 µm). These findings suggest that subdividing the scan into discrete sections helps mitigate cumulative alignment errors, a hypothesis further reinforced by Son et al. (2023) and Choi et al. (2024), who also demonstrated improved accuracy with path D, a segmented and directional approach (12,21,23).

Similarly, Yahya et al. (2024) evaluated four advanced scan paths: ROCK, ZIGZAG, OBP, and OWBP. They found OWBP to be the most accurate, achieving trueness values between 1–24 µm. The OWBP (Occlusal, Wiggling, Buccal, Palatal) scanning protocol begins with the intraoral scanner positioned at the occlusal surface of the second molar in quadrant 4 and continues in an occlusal trajectory up to tooth 43. From this point, the scanner transitions into a "wiggling" phase, moving in a deliberate buccal-to-lingual wave-like motion from tooth 43 to tooth 33. This specific movement enhances the capture of interproximal anatomy and minimizes the risk of scan gaps due to missed surfaces. After completing the wiggling phase, the scan resumes along the occlusal surfaces from tooth 33 to the second molar in quadrant 3. The scanning sequence then progresses buccally across the arch towards the fourth quadrant. Finally, the scan is completed by covering the palatal surfaces. This result is particularly compelling given the protocol's emphasis on minimizing back-and-forth movement and reducing looped trajectories that can lead to scan distortion. The OWBP technique reflects a growing consensus that controlled directional movement offers substantial accuracy benefits (34).

Giuliodori et al. (2023) performed a comprehensive in vitro evaluation of six different intraoral scanners using four scanning techniques, including manufacturer-recommended, cut-out rescan, a simplified method, and a novel path based on the work of Passos et al. (2019). Among the tested scanners, Medit i700 and Primescan consistently outperformed others in both trueness and precision. Interestingly, the cut-out rescan strategy and the novel technique demonstrated equal or superior results compared to manufacturer protocols, suggesting that adapting scan strategies based on clinical context and operator preference can be beneficial than just following the manufacturer recommended protocols (33).

The findings of Passos et al. (2019) are among the most significant. By evaluating 13 scanning protocols, the study provides robust evidence supporting Strategy M as the most effective, recording a trueness of 4.79 μm and precision of 4.67 μm. Strategy M, as described by Passos et al., is a linear–continuous experimental scanning protocol designed for full-arch intraoral digital impressions. The strategy begins at the palatal surfaces, starting from the left second molar occlusal, and continues in a smooth path toward the right second molar, maintaining a consistent palatal trajectory. From there, the scanner returns along the occlusal surfaces to the left second molar, then transitions to the vestibular surfaces, moving anteriorly until reaching the opposite canine. This sequence is then mirrored: the scanner resumes at the right second molar occlusal and again sweeps through the vestibular surfaces, ending at the left canine. This bidirectional, continuous linear approach minimizes abrupt directional changes and aims to reduce image stitching errors that often compromise trueness and precision in full-arch scanning. This level of accuracy is unmatched by any other study reviewed and provides a benchmark for future scanning protocol development (24).

Other notable contributions include Müller et al. (2016), who found Strategy B superior in terms of precision among strategies A, B, and C. Strategy B, as described by Müller et al. is a scanning protocol specifically developed for use with the TRIOS Pod intraoral scanner to improve full-arch impression accuracy. This strategy begins the scan at the occlusal-palatal surfaces of the maxillary right second molar and moves continuously across the arch to the contralateral side, always capturing two surfaces simultaneously—occlusal and palatal. Once the scanner reaches the end of the arch, it returns along the buccal surfaces, completing the full scan cycle (30). Moreover Ortensi et al. (2024), who noted that S3 outperformed S1 and S2 in accuracy metrics. S3 is structured into two main phases that aim to minimize stitching errors, particularly in the midline, a common site of scanning inaccuracies. In the first phase, the scan starts with the occlusal surfaces from the last distal molar and progresses anteriorly toward the canine on the same side. Upon reaching the anterior region, the scan includes buccal and palatal rotations to properly capture the incisors, which are often difficult to scan accurately due to their curvature and interproximal spacing. This portion of the scan ends at the contralateral canine, thus completing a diagonal cross-arch coverage. The second phase begins by revisiting the incisal-palatal surfaces, now serving as a stable anchor. The scanner then moves posteriorly along the palatal side of the same hemiarch, reaching the last molar, followed by a buccal sweep and finally a return pass over the occlusal surface up to the canine. This bi-phasic approach allows for detailed image acquisition with reduced distortion by limiting excessive rotations and maintaining the scanner within a stable angulation (less than 45° throughout the scan) (22). These results demonstrate that even minor variations in scan initiation and path can significantly affect the scan outcome, reinforcing the need for standardized, tested protocols (22,30).

Medina et al. (2018) assessed four intraoral scanners using four scan strategies: exterior-interior, quadrant-based, sextants, and sequential S-shaped paths. Their results highlighted that the optimal strategy varied depending on the scanner used; for instance, Trios and iTero achieved superior trueness with the sequential strategy, while Omnicam favored the quadrant-based approach. These findings imply that while certain strategies are broadly effective, scanner-specific characteristics such as imaging technology (confocal, triangulation, or active wavefront sampling) also play a critical role in determining optimal performance and choice of optimal scanning protocol (11).

A broader systematic review and meta-analysis by Hardan et al. (2023) synthesized data from 15 in vitro studies and confirmed that scan accuracy is indeed influenced by scanning strategy. They reported statistically significant improvements in accuracy when S-shaped paths and artificial landmarks were used. Moreover, they highlighted the role of dry conditions in maximizing trueness and precision, pointing to the practical implications of saliva management and tissue retraction during clinical scanning (20).

5.3. Efficiency vs. Accuracy Trade-off

An important aspect of protocol evaluation is the balance between scanning efficiency and accuracy. Cordaro et al. (2023) evaluated and compared the accuracy and scan time of two different full-arch intraoral scanning strategies using the TRIOS 3 (3Shape, Copenhagen, Denmark) intraoral scanner. The goal was to determine whether a novel scanning technique could offer advantages over the conventional manufacturer-recommended strategy, especially in terms of clinical efficiency and digital impression quality. He observed that while their novel scanning protocol did not significantly outperform the manufacturer's strategy in accuracy, it was more efficient. This introduces a crucial dimension to scanning protocol selection: clinical efficiency. In busy dental practices, saving time without sacrificing diagnostic or restorative reliability is invaluable.

Hence, in cases like this, protocols like the novel one tested by Cordaro et al. that offer efficiency with comparable accuracy may be favored in practical settings (35).

Choi et al. (2024) also support the importance of protocol efficiency. Their comparison of four scan paths (A–D) found Path D to be the most accurate and time-efficient. Path D, as described by Choi et al., begins at the left first premolar (LPM1), a central location within the arch. From this point, the scanner moves posteriorly toward the left second molar, capturing the left quadrant, then returns to the LPM1. The scan then continues across the anterior teeth toward the right side, reaching the right second molar, and finally ends after completing the scan of the right quadrant. This symmetric, center-outward scanning pattern minimizes the total scanning distance and is designed to reduce the accumulation of stitching errors by balancing data acquisition from the center to the periphery of the arch. This dual benefit makes Path D an excellent choice for full-arch digital impressions and emphasizes that well-designed protocols can and should simultaneously address speed and accuracy (12).

Efficiency must also be framed in terms of digital workflow continuity. Poor scan accuracy will lead to errors in design, milling or printing stages, therefore requiring rescans or remakes that negate any time savings at the acquisition stage. Thus, protocols that provide consistent results upfront are crucial for end-to-end workflow efficiency (12,35).

5.4. Device-Independent Scanning Protocols

One of the most striking insights across the reviewed studies is the device-independent effectiveness of certain scanning strategies. Medina-Sotomayor et al. (2018) compared four scanning strategies across Trios, iTero, Omnicam, and True Definition scanners. The results were not uniform across scanners but demonstrated that Strategy D provided the best trueness for both Trios and iTero. Omnicam performed best with Strategy B, and True Definition with Strategy C. These findings confirm that while scanning strategy effectiveness can be scanner-dependent, optimized strategies can still offer superior results compared to manufacturer defaults (11,33).

5.5. Operator Dependency and Learning Curve

Operator skill and familiarity with a scanning protocol also play a crucial role in its effectiveness. Giuliodori et al. (2023) demonstrated that for scanners like Medit i700, the discrepancy varied depending on whether the scans were conducted by an expert or novice. Trueness ranged from 21.4 μm to 36.8 μm, illustrating that even with a superior protocol, the human factor is definitely a variable. The implication is that protocol efficacy must be evaluated not just in terms of its theoretical performance but also in terms of ease of execution and reproducibility across operators with different experience levels (33).

This also suggests that protocols with built-in guidance or real-time feedback might mitigate or reduce operator-related inaccuracies. Educational programs should therefore emphasize not only scanner operation but also optimization of scanning protocols. As digital dentistry becomes more prevalent, standardized training modules on scan strategies could be helpful in reducing learning curves and improving clinical results.

5.6. Clinical Applications and Patient Outcomes

From a clinical perspective, the importance of accurate scanning protocols extends beyond fabrication of restorations to diagnosis, treatment planning, and monitoring. Orthodontic aligners, surgical guides, and implant-supported prostheses for example depend on highly precise digital impressions. Poor scanning strategy not only affects the immediate fit of these devices but may also impact biomechanical performance and patient comfort over time. Incorrect occlusal mapping due to poor scanning can result in occlusal trauma or TMJ discomfort. Misaligned implant guides due to trueness errors can increase surgical risks. Even in general restorative dentistry, an ill-fitting crown due to inaccurate scans might lead to cement washout, secondary caries or loss of retention. Moreover, the patient experience must not be overlooked. Efficient scanning protocols reduce chair time, discomfort from rescans and overall anxiety. In pediatric and geriatric populations, shorter and simpler scan procedures are particularly beneficial. Ensuring consistent results from the first scan can therefore enhance both satisfaction and clinical predictability (20,22,33,35).

5.7. Overall Outcome

Collectively, these findings affirm that there is no universally superior scanning strategy. Instead, the optimal protocol depends on a combination of various factors: the specific IOS system, the arch span being scanned, the experience of the operator and the clinical context (for example: implant vs. dentate arch). Nevertheless, certain trends are evident. Segmental or quadrant-based strategies consistently reduce cumulative stitching errors, especially in full-arch scans. Linear scan paths that avoid abrupt directional changes or vertical tilts tend to yield higher precision. Strategies that allow intermittent rescanning or 'on-and-off' scanning offer workflow flexibility, particularly in complex or long-span cases.

From a clinical standpoint, the implications of these findings are significant. With full-arch scanning playing a central role in prosthodontics, orthodontics or implantology, optimizing scan strategies can directly influence prosthetic fit, occlusal relationships and long-term treatment success. Furthermore, as digital workflows increasingly dominate modern practice, knowledge of evidence-based scanning protocols will become an essential skill for both generalists and specialists (12,22,30,33,35).

5.8. Standardization and Guidelines

Despite the growing evidence of the impact of scanning protocols, formal guidelines on their use remain quite sparse. Most recommendations are still driven by manufacturer guidelines, which may not always be the optimal choice in the clinical realities practitioners face. There is an urgent need for professional dental organizations and academic institutions to create evidence-based standards for scanning protocols.

Such standards should include:

- Definitions of acceptable discrepancy thresholds for various applications.
- Recommended scanning protocols for quadrant, arch and full-mouth cases.
- Protocol modifications for challenging scenarios (edentulous jaws, gag reflex, orthodontic appliances).
- A universal benchmarking framework for comparing protocol performance.

Including these standards in licensing exams, continuing education courses and peer-reviewed publications would elevate clinical practice and create a common language around digital accuracy (20,22,30,33).

5.9. Technological Innovations and the Future of Scanning Protocols

Recent innovations in artificial intelligence (AI), machine learning and digital processing have begun to influence the development of scanning protocols. AI-enhanced scanning platforms are being developed to provide real-time feedback, detect scan errors and suggest optimal paths based on anatomical recognition. Emerging platforms may transform scanning from a linear process into a dynamic interaction, offering real-time protocol adjustments based on patient anatomy and operator technique (36).

Smart scanning strategies could, for instance, alert operators to missed data segments or excessive scan distortion before a scan is completed. Adaptive protocols that learn from previous scans to improve future accuracy offer exciting opportunities to standardize high-quality results across all user levels (36).

5.10. Future Research Directions

To further advance the field, future research should address several unanswered questions:

1. **Longitudinal Impacts**: How do discrepancies from different scanning protocols affect the long-term success of restorations or implants?
2. **Operator Adaptation**: What is the optimal training duration for different protocols, and how does protocol complexity correlate with error rate?
3. **Pediatric and Special Needs Populations**: Are there scanning protocols specifically suited to patients who cannot remain still for long periods?
4. **Cost-Benefit Analysis**: Does protocol optimization reduce material waste and remakes enough to significantly impact practice profitability?
5. **Cross-Platform Protocols**: Can universal scanning paths be established that perform consistently across brands and models?

Answering these questions will require interdisciplinary research combining dental science, biomedical engineering, human factors and data science in order to determine the clinical importance of these protocols.

6. CONCLUSION

The findings confirm that scanning strategy plays a critical role in determining both trueness and precision, particularly in full-arch scans. Protocols that favour linear, segmental or strategically phased approaches consistently outperformed less structured or abrupt scan paths. Furthermore, scanner type, operator experience and clinical context all significantly impact outcomes, reinforcing that no single protocol is universally optimal. Ultimately, the careful selection of evidence-based scanning strategies enhances the quality of digital impressions and contributes to more predictable clinical results in the field of digital dentistry.

7. SUSTAINABILITY

This Final Degree Project contributes to several of the United Nations Sustainable Development Goals as outlined in the 2030 Agenda for Sustainable Development:

Goal 3: Good Health and Well-being

By focusing on the optimization of intraoral scanning strategies, the following scanning accuracy can lead to better-fitting prostheses, improving patient outcomes and reducing the need for repeated treatments, which contributes to improved oral health and overall well-being.

Goal 9: Industry, Innovation, and Infrastructure

This project promotes innovation in the dental field by evaluating and comparing alternative digital scanning strategies and technologies. By encouraging the adoption of advanced and efficient digital, the project supports sustainable industrial innovation and the development of more robust healthcare infrastructure.

Goal 12: Responsible Consumption and Production

By proposing optimized scanning techniques that reduce time, material waste, and potential clinical errors, this study contributes to more sustainable dental practice. Efficient scanning paths can decrease the number of re-scans and adjustments, leading to reduced use of physical impression materials and less environmental impact from prosthetic fabrication processes.

Goal 13: Climate Action

Although the project's direct environmental footprint is limited, promoting digital over traditional impression methods aligns with strategies for climate action. Digital methods typically reduce the need for shipping, storage and use of consumables, leading to lower greenhouse gas emissions in the long term.

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