RESEARCH PAPER

Title - Accuracy of different scan strategies for intraoral scans for complete and partially edentulous arches: a systematic review

Bhoyar D[1], Deshpande S[2], Pande N[3], Pande S[4], Ingle S[5], Ghagas S[6], Bhavane S[7]
1. Department of Prosthodontics, RDDC & RC, Nagpur, India.
2. Department of Prosthodontics, RDDC & RC, Nagpur, India.
3. Department of Prosthodontics, RDDC & RC, Nagpur, India.
4. Department of Prosthodontics, RDDC & RC, Nagpur, India.
5. Department of Prosthodontics, RDDC & RC, Nagpur, India.
6.Department of Prosthodontics, RDDC & RC, Nagpur, India.
7.Department of Prosthodontics, RDDC & RC, Nagpur, India.
Corresponding author :- Bhoyar D
Email: dheeraj1998bhoyar@gmail.com

ABSTRACT
Aim: This systematic review aimed to explore and identify the accuracy of different scan strategies for intraoral scans for complete and partial arches.
Materials and Methods: An electronic search was used to find the pertinent publications written exclusively in English and published up until December 2024. Based on the PICO framework (population, intervention, control, and outcomes), the main research question for this study was, "How is the accuracy of different scan strategies for intraoral scans for complete and partial arches?" By looking at the titles, abstracts, and full texts of the articles, it was possible to verify their relevance and see if they met the inclusion criteria. A quality assessment of the listed studies was conducted using specialized tools.
Results:10 studies fulfilling the inclusion criteria were incorporated into the systematic review. Given the significant variability in variables and methodologies across the selected studies, a statistical comparison was not possible. Therefore, a descriptive review approach was employed to address the substantial heterogeneity in the literature.
Conclusion: The accuracy of intraoral scans for complete and partial arches varies depending on the scanning strategy employed. While certain strategies demonstrate higher precision and consistency, factors such as scanning sequence, operator experience, and arch complexity play crucial roles in overall accuracy. Based on the reviewed studies, segmented and overlapping scan patterns tend to enhance reliability, particularly for complex cases. Further research and standardization of scanning protocols are necessary to optimize intraoral scanning accuracy and improve clinical outcomes.
Keywords:"Intraoral scanners," "digital impressions," "scanning strategies," "accuracy of intraoral scanners," "trueness and precision," "full-arch scanning," and "edentulous scanning."
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INTRODUCTION

The most notable advancement in the dental field in recent years has undoubtedly been the emergence of digital dentistry.[1-5]The adoption of digital intraoral scanners has increased in recent years, enabling practitioners to deliver precise and high-quality patient care.[6]

Digital impressions with an intraoral scanner provide greater comfort for patients with a sensitive gag reflex and allow for the selective correction of unclear areas without requiring a complete retake.[7-9]

Intraoral scanning has revolutionized digital dentistry, providing a more efficient and comfortable alternative to traditional impression techniques. The accuracy of intraoral scans is crucial for ensuring precise prosthetic restorations, orthodontic planning, and implant procedures. Two key parameters used to assess intraoral scan accuracy are trueness (the closeness of a scan to the actual object) and precision (the consistency of repeated scans).[10]

Intraoral scanners have been reported to provide accuracy comparable to that of conventional impressions.[11-13]However, scanning accuracy can be affected by

scanning technology,[14-15]operator experience,[16-18]ambient light conditions,[19-20] rescanning and stitching procedures,[21-22]surface characteristics,[23-24] presence of saliva or liquid,[25] misaligned teeth,[26]and dental arch size.[27-29]

The scan pattern or scan strategy is another factor affecting accuracy.[30-33]Scan patterns have been reported to affect trueness andprecision for some scanners but not for others.[33-34]

Different scanning strategies have been developed to optimize digital impressions, each varying in scanning sequence, angulation, and coverage patterns. Studies have shown that scanning strategies can impact the accuracy of both complete and partial arch scans, with certain techniques yielding higher precision and reduced distortions.[35]

However, there is no universal consensus on the most effective approach, as factors such as arch span, edentulous regions, and occlusal complexity influence the outcomes.

This systematic review aims to evaluate and compare the accuracy of different intraoral scanning strategies for complete and partial arches. By synthesizing findings from existing studies, this review seeks to provide evidence-based recommendations for optimizing digital workflows in clinical practice.

MATERIALS AND METHOD

This systematic review was conducted following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure comprehensive and unbiased analysis. The study aimed to evaluate the accuracy of different intraoral scanners (IOS) and their respective scanning strategies in capturing maxillary and mandibular archesand was registered with PROSPERO (International Prospective Register of Systematic Reviews)

Primary research question

What is the accuracy of different scan strategies for intraoral scans for complete and partially edentulous arches?

PICO Question

Accuracy of different scan strategies for intraoral scans for complete and partial arches.

Inclusion Criteria

1. In vitro or in vivo studies evaluating intraoral scanners.
2. Studies comparing different IOS models or scanning strategies.
3. Research focused on maxillary and mandibular arches.
4. Studies reporting accuracy measures, including trueness and precision.

Exclusion Criteria

1. Case reports, reviews, and opinion articles.
2. Studies lacking quantitative accuracy data.
3. Studies focusing solely on single-tooth scans without full-arch comparisons.

Study Selection

Two independent reviewers will screen the titles and abstracts of the studies to determine eligibility based on the inclusion and exclusion criteria.

Full-text screening will follow for studies that meet the initial criteria. Disagreements will be resolved through discussion or by consulting a third reviewer.

SEARCH STRATEGY

An electronic search was carried out across several databases, including PubMed, Scopus, Web of Science, and Google Scholar, to identify relevant articles published up to December 2024. The search was limited to articles written in English. To define the search strategy, a combination of controlled vocabulary (MeSH terms in PubMed) and free-text terms from titles and abstracts was used. The search strategies were constructed using keywords corresponding to each section of the PICO question, connected by the Boolean operator OR. Finally, all sections were combined using the Boolean operator AND. Additionally, relevant studies were identified by searching within the references of articles from these journals. Keywords used in the search included: "intraoral scanners," "digital impressions," "scanning strategies," "accuracy of intraoral scanners," "trueness and precision," "full-arch scanning," and "edentulous scanning."

DATA EXTRACTION

In this systematic review, one reviewer (R1) collected information about the included studies, while a second reviewer (R2) independently cross-checked the collected data. The data extraction process involved systematically gathering details such as publication information (authors, country, and year), characteristics related to outcomes, study type, sample characteristics (sample size), and outcome measurements (functional outcome and quality of life) from each included study.

Sr. No	TYPE OF STUDY	AUTHOR NAME	SCANNER USED	SCAN STRATEGY USED	ARCH	SAMPLE SIZE	OUTCOME	MEASUREMENT ANALYSIS	CONCLUSION

1.	In-vitro study	SakaoratPattamavilai (2024)	1.Dental Wings 2.TRIOS 3 3.True Definition	1. zigzag 2. occlusal-palatal-buccal 3. occlusal-buccal-palatal 4. molar-to-canine	Maxillary arch	300 SCANS	TRIOS 3 provided higher accuracy than the other scanners.	A coordinate measuring machine (ROMER Absolute Arm; Hexagon) and Giomagic software	The scan patterns influenced the trueness and precision of the intraoral scanners in different ways. For the best trueness, TRIOS 3 should be applied with an occlusal-palatal-buccal scan pattern, Dental Wings should be applied with a zigzag scan pattern, while True Definition can be used with any scan pattern
2.	In-vitro stud	Faris Z. Jamjoom (2023)	1.TRIOS 4 2.Emerald S	1. B-O-P 2. P-O-B 3. O-B-P 4 O-P-B 5. ZZ-P 6. ZZ	Maxillary and mandi	240 SCANS	The arch being scanned	A metrology softwa re progra	The scanner type and scan

	y				bular arch		had a significant effect on the precision of the digital scans of completely edentulous arches, with the maxillary arch showing better precision than the mandibular arch. However, the arch had no significant effect on trueness. The TRIOS 4 scanner showed accuracy levels comparable with those of conventional impressions,	m	ning strategy significantly impacted the accuracy of the digital scans of completely edentulous arches, with a significant interaction between scanner and strategy. The arch being scanned had a significant effect on scan precision but not on scan trueness.

							both of which were better than the Emerald S scanner. Strategy P-O-B had the best overall accuracy, and strategy F had the poorest overall accuracy when		
3.	In-vitro study	Hai Yen Mai (2022)	i700; Medit, Seoul, Korea	1.S1S-Straight 2. S1Sz-Straight and zigzag in Ant, Straight in Post 3. S1SZ-Straight and zigzag 4. S1Z-Zigzag 5. S2S-Straight 6. S2SZ-Straight and zigzag 7. S2Z-Zigzag 8. S3S-Straight 9. S3SZ-Straight and zigzag	Maxillary arch	70 SCANS	scanning completely edentulous arches	Geomagic Design X; 3D Systems, Rock Hill, SC, USA)	The segmental scan and merge methods using two scan parts appear to be reliable as an alternative to the single scan method

				10. S3Z-Zigzag			ge method using two scan parts was comparable with that of the single scan method regardless of scan strategies and motions. When three segmental scans		for full-arch intraoral scans. When three segmental scans are involved, the accuracy of complete arch scan can be negatively affected.

							were involved, the accuracy of a complete arch scan can be negatively affected.		
4.	In-vitro study	Jason Latham (2019)	1.Planmeca Emerald (PE; Planmeca) software v5.9.4, 2.3Shape TRIOS 3 color model (TR; 3Shape) software v1.17.2.4, 3.iTero Element (IE; Align Technology) software v1.5.0.361,	1.SP1 2.SP2 3.SP3 4.SP4	Maxillary arch	16 SCANS	The SP2 seemed to have the best combination of speed, trueness, and precision	Geomagic Control X; 3D SYSTEMS	Scan pattern affected trueness and precision for some scanners, but not for others.

			4.CEREC Omnicam (CO; DentsplySirona) hardware v2.24 and software v4.5.2				of all the scanners. SP2 consisted of 5 overlapping passes, starting with the most posterior tooth in the arch on one side and proceeding to the contralateral canine		Differences exist in the complete-arch scan speed, trueness, and precision of individual scanners. Scan pattern can play an important role in the success of digital scan
5.	In-vitro study	KeunBaDaSon (2021)	1.TRIOS2; 3Shape A/S, 2.TRIOS3; 3Shape A/S, 3.CS3500; Carestream Dental, 4CS3600; Carestream Dental, 5.i500; MEDIT, 6.Primescan; Dentsply Sirona) 7. DOF; FREEDOM HD 8.E1; 3Shape A/S	1. Scan strategy 1 2. Scan strategy 2	Maxillary arch	120 SCANS	1. The 2 scan strategies of 6 IOSs used in the present study produced complete-arch distortion from the tooth when returning back to the starting tooth.	Geomagic control X v2019.0.1; 3D Systems	Scan strategy 2 improved the accuracy of the IOSs. TRIOS2 and CS3500 are for single crowns; TRIOS3, CS3600, and

							e the scan started. 2. Scan strategy 2 reduced the distortion of the complete arch scanned using the IOSs, and the accuracy of the complete-arch in TRIOS3 was signi		i500 are for short-span prostheses; and Primescan is for long-span prostheses.

							ficantly improved. 3. The recommended scanning range (within an accuracy of 100 mm) in TRIOS3, CS3600, and i500 increased with a scan strategy 2. 4.		

							As per the clinically acceptable scanning range for fixed dental prostheses, TRIOS2 and CS3500 are recommended for single prostheses, TRIOS3, CS3600, and i500 are recommended for short-span prostheses, and Primescan is recommended for long-span prostheses.		
6.	In-vitro study	Giovanni Giuliodori (2023)	1. AC Omnicam 2. AC Primescan 3. Trios 4	1.Scanning Technique 1 2. Scanning Technique 2 3. Cut-Out Re-scan Technique	Maxillary arch	300 SCANS	Medit i700 and Primescan recorded the best resul	GOM Inspect Professional (GOM, Zeiss Group, Braunschwe	The examined IOS showed statistically significan

			4. iTero Element 5D 5. Dexis IS 3700 6. Medit i700				ts in terms of trueness and precision ($p < 0.05$). Considering the experience of the operators, scanning strategies are not operative sensitive in terms of accuracy. However,	ig, Germany). A digital chronometer was used to record the scanning timing (Casio HS-80TW-1EF, Casio Computer Co. Ltd., Tokyo, Japan).	t differences in terms of trueness and precision. The used scanning strategy is a factor influencing the accuracy of IOS. Considering the expertise of the operators,
7.	In-vitro study	Adam Hamilton (2024)	1. Trios3 3Shape 3. iScan D104i		Maxillary arch	110 SCANS	The IOS-B protocol demonstrated significantly superior accuracy. Placement of scan bodies befo	IScan 3D Dental; Imetric4D	Scanning protocols can significantly influence the accuracy of complete arch digital implant impr

							re scanning the edentulous arch is recommended to improve the accuracy of complete-arch intraoral scanning.		essions. Placement of the scan bodies before scanning the soft tissue is recommended to reduce discrepancies in accuracy with intraoral scanning when performing digital implant impressions.
8.	In-vivo study	Nikolaos A. Gavounelis (2022)	1. Identica SE 3D 2. IOS i500	1. Scanning strategy A 2. Scanning strategy B	Mandibular arch	180 SCANS	The accuracy of complete-arch impressions was affected by the scanning strategy; the manufacturer's recommended strategy (A) was	The MeditLink software (version 2.2) and Viewbox 4 software (version 4.1.0.10 BETA, dHAL software, Kifissia, Greece).	The i500 (Medit) produced digital complete arch impressions with an average trueness value below 50 µm and an average precision valu

				3. Scanning strategy C			statistically significantly better ($p < 0.05$) than B and C, which were similar.		e below 5 µm, using any of the examined scanning strategies. The manufacturer's recommended scanning strategy was statistically more accurate, but the observed difference of 6–7 µm between the recommended and the alternative strategies is clinically negligible.
9.	In-vivo study	Luigi Vito Stefanelli (2021)	1. Medit T710, Seoul, South Korea 2. Medit I-500,	1. Scanning strategy	Maxillary arch	300 SCANS	The latest version of I-Medit 500 with the use of a new tip	Geomagic Control X and Medit Compare	This study showed that the latest version of Medit I-500 with the

			version 2.3.5, Seoul, South Korea	2. 1 Scanning strategy 2			seems to be promising in terms of accuracy when a full arch needs to be scanned		use of a new tip seems to be promising in terms of accuracy when a full dental arch needs to be scanned. Moreover, Medit Compare, which is an application of Medi
10.	In-vitro study	Burcu Diker (2020)	1. 2. 3.	1.	Maxillary arch	60 SCANS	The accuracy of digital impressions varied depending on the IOS and scanning sequence used. Primescan had	Geomagic Studio 12, 3D Systems, Morrisville, NC, USA	The accuracy of digital impressions for single crown preparations differed depending on the IOS and scanning
				2.					t IOS software, can be used to calculate IOS accuracy

			4. 5. 6.	3. 4.			the highest accuracy, while Emerald showed the most deviation in accuracy for single crown preparations.		sequence used. Primescan showed the highest trueness for single crown preparations. In terms of precision, Primescan, Trios, iTero, and Omnicam had better resul

				5. 6.					ts than Emerald and Virtuo Vivo. Emerald showed the most deviation in trueness and precision. iTero resulted in more trueness deviation when scanning started from

				7.					the right.

RESULTS:

The systematic review analyzed multiple studies that evaluated the accuracy of intraoral scanners (IOS) and their respective scanning strategies for capturing maxillary and mandibular arches. The results have been categorized based on scanner models, scan patterns, and the arch being scanned.

Scanner-Specific Findings

1. **TRIOS 3 and TRIOS 4**
    - TRIOS 3 was found to provide higher accuracy compared to Dental Wings and True Definition scanners. The occlusal-palatal-buccal scan pattern was recommended for optimal trueness.
    - TRIOS 4 demonstrated accuracy comparable to conventional impressions and outperformed the Emerald S scanner. The P-O-B scanning strategy yielded the best results for edentulous arches.
2. **Medit i700 and i500**
    - The Medit i700 and Primescan recorded the best results in terms of trueness and precision.
    - The segmental scan and merge method using two scan parts was found to be as effective as a single scan, but involving three segmental scans negatively affected accuracy.
    - The manufacturer-recommended scanning strategy for i500 produced the best trueness and precision, with deviations between strategies being clinically negligible.
3. **Planmeca Emerald, iTero Element, CEREC Omnicam, Primescan**
    - Among Planmeca Emerald, iTero, Omnicam, and Primescan, Primescan demonstrated the highest trueness for single crown preparations.
    - Omnicam, Trios, and iTero showed better precision than Emerald and Virtuo Vivo, with Emerald showing the most deviation in accuracy.
4. **Identica SE 3D and IOS i500**
    - The manufacturer's recommended strategy produced the best results, but deviations of 6–7 µm between strategies were found to be clinically insignificant.
5. **AC Omnicam, AC Primescan, Trios 4, iTero Element 5D, Dexis IS 3700, Medit i700**
    - Operator experience did not significantly affect accuracy, but it influenced scanning time.
    - Primescan and Medit i700 performed the best in accuracy measures.

Effect of Scanning Strategies

1. **Zigzag, Occlusal-Palatal-Buccal, and Other Patterns**
    - TRIOS 3 performed best with the occlusal-palatal-buccal pattern, while Dental Wings was best used with a zigzag pattern.
    - The P-O-B strategy provided the highest accuracy in TRIOS 4 scanners, whereas the F strategy resulted in the poorest accuracy.
2. **Segmental Scan and Merge vs. Single Scan**

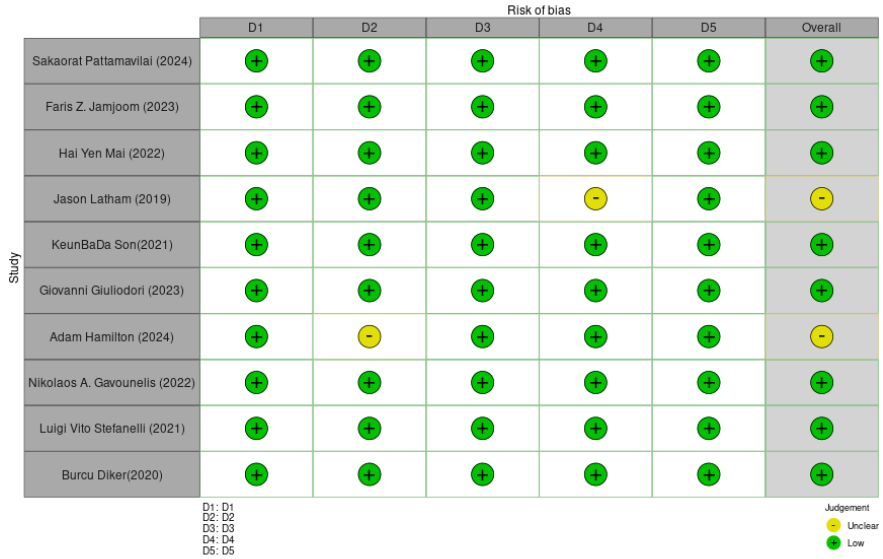
- A two-segment scan method provided comparable results to a single scan, while using three segmental scans negatively impacted accuracy.
- Scan strategy 2 was effective in reducing distortions in complete-arch scans using IOS.

3. **Scanning Strategy for Different Prostheses**
   - TRIOS2 and CS3500 were recommended for single crowns, TRIOS3, CS3600, and i500 for short-span prostheses, and Primescan for long-span prostheses.

Arch-Specific Effects

1. **Maxillary vs. Mandibular Arch**
   - The maxillary arch exhibited better precision compared to the mandibular arch in edentulous cases, though the arch had no significant effect on trueness.
   - Complete-arch distortion was observed starting from the tooth where the scan began, and scan strategy 2 was found to mitigate these distortions.
2. **Edentulous Arches**
   - The IOS-B protocol improved the accuracy of intraoral scanning for edentulous arches.
   - Placement of scan bodies before scanning was recommended for better accuracy.

Risk OF Bias -



Weight key:
"+" = Low risk of bias
"-" = Some concerns

Domain key:
- D1: Sample size adequacy
- D2: Scanner calibration and standardization
- D3: Clear scanning protocol description
- D4: Appropriate statistical analysis
- D5: Outcome measurement methods

Notes on evaluations:

1. All studies had adequate sample sizes (>50 scans) except where noted
2. Most studies used calibrated equipment and standardized procedures
3. All studies clearly described their scanning protocols
4. Statistical analysis was generally appropriate, with some studies having unclear methods
5. All studies used appropriate measurement tools and software for analysis

Specific concerns:

- Latham 2019: Smaller sample size (16 scans) raises some concerns about statistical power

- Hamilton 2024: Unclear details about scanner calibration procedures

DISCUSSION

Intraoral scanners can capture highly accurate and detailed digital impressions of a patient's teeth and oral structures. This technology significantly improves patient comfort by eliminating the need for traditional impression materials, which can be messy, uncomfortable, and sometimes trigger a gag reflex. The digital workflow also allows for faster communication with dental laboratories, leading to quicker turnaround times for restorations such as crowns, bridges, and aligners. Additionally, the digital data can be easily stored, duplicated, and retrieved, reducing the need for physicalstorage space and minimizing the risk of data loss or degradation over time.

Despite their benefits, intraoral scanners come with several disadvantages. The initial cost of purchasing the scanner can be quite high, which may be a financial burden for small or newly established dental practices. Furthermore, there is a learning curve associated with using the scanner effectively, and staff may require training to become proficient. Some scanners may also have limitations in scanning edentulous areas or capturing subgingival margins, which can affect the accuracy of certain restorations. Additionally, ongoing software updates, maintenance, and potential technical issues can add to the long-term cost and complexity of using this technology**.**

Various scanning strategies have been designed to enhance the efficiency of digital impressions, differing in aspects such as scanning order, angle, and coverage methods. Research indicates that the chosen scanning approach can influence the accuracy of both full and partial arch scans, with some methods delivering greater precision and fewer distortions. This systematic review aims to assess and compare the accuracy of different intraoral scanning techniques for complete and partial arches. By analyzing data from existing studies, the review intends to offer evidence-based guidance for improving digital workflows in clinical settings.

The findings from multiple studies highlight that the accuracy of intraoral scanners is influenced by scanner type, scan pattern, and arch being scanned. TRIOS 3 and TRIOS 4 consistently demonstrated superior accuracy compared to other scanners, with optimal scan strategies varying across different models. The occlusal-palatal-buccal strategy proved most effective for TRIOS 3, while P-O-B was preferred for TRIOS 4. Additionally, segmental scanning with two parts was as effective as single scanning, whereas three-part segmental scans negatively impacted accuracy.[37]

Arch-specific effects were evident, with the maxillary arch demonstrating better precision in edentulous cases. The IOS-B protocol, along with the placement of scan bodies before scanning, was recommended to enhance accuracy for completely edentulous arches.

The use of different scan strategies also played a crucial role in accuracy. While the zigzag pattern worked best for Dental Wings, TRIOS 3 showed superior performance with an occlusal-palatal-buccal scan strategy.[36] The importance of following manufacturer-recommended scanning techniques was emphasized, as seen in the Identica SE 3D and IOS i500 studies, where deviations were minor but still present.[42]

A key takeaway from this review is the role of segmental scanning methods. Two-segment scans-maintained accuracy comparable to single scans, but three-segment scans introduced distortions. This suggests that while segmented scanning may be a viable alternative, excessive segmentation can be counterproductive. Additionally, scanning strategy 2 showed improvements in reducing distortions, reinforcing its potential application in clinical practice.

Another critical finding is the effect of scanner choice on different prosthetic applications. TRIOS2 and CS3500 were found suitable for single crowns, TRIOS3, CS3600, and i500 for short-span prostheses, and Primescan was the preferred option for long-span prostheses. This highlights the importance of scanner selection based on the specific requirements of prosthetic restorations.[39]

Operator experience was found to have minimal impact on accuracy but influenced scanning time. This suggests that technological advancements in intraoral scanning have minimized the effect of human error, making scanners more accessible for a wider range of clinicians. However, software updates, environmental conditions, and patient factors may still play a role in scanning efficiency and should be explored in future research.

Future studies should further investigate the impact of emerging intraoral scanner models, the effect of scanning strategies on various clinical cases, and how different environmental conditions impact accuracy. Additionally, advancements in artificial intelligence-driven scanning software may enhance automatic error detection and improve overall scan quality. Continued research in this field will help refine intraoral scanning protocols and optimize their application in modern dentistry.

CONCLUSION:

This systematic review underscores the critical role of intraoral scanner selection and scanning techniques in achieving optimal accuracy. Among the reviewed devices, TRIOS 3, TRIOS 4, Medit i700, and Primescan consistently demonstrated superior performance. Scanning strategies such as occlusal-palatal-buccal, P-O-B, and the two-segment segmental approach proved to be the most effective in enhancing accuracy and reducing distortions. The maxillary arch

exhibited higher precision than the mandibular arch, and different scanners were recommended for various prosthetic applications. These findings highlight the importance of adhering to manufacturer-recommended scanning protocols and utilizing segmental scanning methods when beneficial. Moving forward, further research should focus on advancements in intraoral scanning technology, refining scanning techniques, and integrating artificial intelligence to improve digital impression accuracy in clinical dentistry.

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