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REVIEW ARTICLE

Comparative Analysis of Intraoral Scanners and Traditional Impression Methods in Full-Arch Implantology: A Systematic Review

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ABSTRACT
Background: The comparative effectiveness of intraoral scanners (IOS) and conventional impression (CI) methods in full-arch implantology has been a topic of ongoing debate. This systematic review aimed to provide a comprehensive comparison of these methods across different applications and conditions.
Methods: This systematic review was conducted in accordance with the PRISMA guidelines, with the search conducted across different online databases and the relevant studies were extracted, following which they underwent bias assessment and their relevance towards this review was examined.
Results: Five in-vitro studies, encompassing various types of IOS and CI methods, were systematically reviewed. The review revealed that neither IOS nor CI could be deemed universally superior. Their relative effectiveness varied depending on several factors, including the specific application, the presence or absence of landmarks, and the type of dimensional analysis used. For instance, while digital techniques offered advantages in terms of minimal distortion for tilted implants, conventional methods demonstrated superior trueness in other scenarios.
Conclusion: The findings underscored the importance of a context-specific approach in selecting between IOS and CI, thereby guiding clinical practice and informing future research. However, the transferability of the findings to clinical practice may be limited due to the in-vitro study design, the variety of IOS types, the unaccounted influence of operator skill, and the incomplete exploration of the role of landmarks. Future studies should address these limitations to further enhance our understanding of full-arch implantology.
Keywords: Intraoral scanners, Conventional impressions, Full-arch implantology, Systematic review, Digital techniques, Tilted implants, Trueness, Precision, Landmarks, Dimensional analysis.

Introduction

In the field of prosthodontics, the evolution of digital technology has introduced a paradigm shift, with intraoral scanners (IOS) becoming increasingly prevalent in dental practice 1. These devices allow for the direct acquisition of digital impressions, eliminating the need for traditional impression materials and techniques. The digital workflow facilitated by IOS not only improves patient comfort but also potentially enhances the accuracy and efficiency of the prosthodontic process 2. Despite these promising benefits, the adoption of IOS is not universal, and conventional impression (CI) methods remain widely utilized, particularly in complex cases such as full-arch implantology 2.

Full-arch implant rehabilitations are challenging due to the intricate interplay of multiple factors, including the number and position of implants, the presence of soft tissue undercuts, and the need for precise inter-implant and maxillomandibular relationships. Traditionally, these rehabilitations have relied on CI methods, which, despite their proven effectiveness, have notable limitations 3. These include patient discomfort, potential for material distortion, and laboriousness of the technique. Intraoral scanners have been proposed as a viable alternative, offering a more patient-friendly approach and a streamlined digital workflow 2, 4. However, the literature presents varying results regarding the accuracy of IOS in full-arch implantology, with some studies suggesting comparable accuracy to CI, while others report a decrease in precision with an increase in the span of the scanned area.

Traditional impression techniques, while frequently employed in dental practice and considered the benchmark in certain clinical scenarios, present a risk of deformation during the impression or casting phase, particularly in implant-supported full prosthesis rehabilitations 5. This risk culminates in a lack of passive adaptation of the framework to the implant, potentially compromising the final fit of the prosthesis. In contrast, digital impressions facilitate intraoral data acquisition, resulting in a digital model wherein implant replicas are automatically positioned 6.

The digital workflow allows dental technicians to design the prosthesis using CAD software and subsequently manufacture the prosthetic component through machining or 3D printing processes 7. The elimination of the plaster modeling stage, a common source of error in traditional impressions, adds to the advantages of digital systems. Furthermore, the digital impression can be indefinitely stored in the form of an STL file. Digital technology, by obviating casting stresses and dimensional changes associated with material curing or extraction, may enhance reliability 8.

Intraoral scanners employ various capture techniques. For instance, I-500 and Cs3600 cameras utilize the triangulation technique, which estimates the object's volume by calculating the disparity between incident and reflected light upon contact with the object 9. This process necessitates software with robust computational capabilities and sophisticated algorithms for three-dimensional surface reconstruction. On the other hand, Trios 4 and Primescan cameras rely on parallel confocal imaging, a technique that digitally replicates oral structures (dental, implant, periodontal) by laser and optical scanning 2, 5. A series of "slices" at different focal depths are composed to create a three-dimensional portrayal of the object.

However, research indicates that not all scanners may be suitable for capturing digital impressions for full-arch implant-supported prostheses 9-12. An impression lacking accuracy fails to accurately record the true implant positions and their spatial relationships with teeth, alveolar ridges, and soft tissues. Potential consequences of inaccurate impression techniques and/or manual stages in prosthesis fabrication include poor prosthetic fit and subsequent technical, mechanical, and biological complications 12. Hence, a dearth of data currently exists to substantiate the application of digital impressions in implant-supported full prostheses.

Given this background, there exists a pressing need to systematically evaluate and synthesize the literature to understand the comparative effectiveness of IOS and CI methods in full-arch implantology. This systematic review aims to fill this gap, providing practitioners with evidence-based insights to guide clinical decision-making. Specifically, this review will assess the trueness and precision of IOS compared to CI in full-arch implantology, and consider the impact of variables such as the presence or absence of landmarks and the type of dimensional analysis used.

Materials And Methods

REVIEW DESIGN

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol 13 was employed in this systematic review, the study selection process being represented through figure 1.

The PECO (Population, Exposure, Comparison, Outcome) protocol for this systematic review was as follows:

- Population (P): The population comprised of in-vitro full-arch implant models.
- Exposure (E): The exposure was the use of intraoral scanners for obtaining impressions of the full-arch implant models.
- Comparison (C): The comparison was made against traditional impression methods used for the same purpose.
- Outcome (O): The outcomes assessed included the trueness and precision of the impressions obtained, the impact of the presence or absence of landmarks, and the effect of the type of dimensional analysis used.

DATABASE SEARCH

This review utilized an extensive search protocol across eight different databases. These databases included PubMed, MEDLINE, Scopus, Web of Science, Embase, CINAHL, Cochrane Library, and Google Scholar. The search protocol employed Boolean operators and MeSH (Medical Subject Headings) keywords to ensure a comprehensive and accurate retrieval of relevant literature. The search protocol capitalized on the use of Boolean operators and MeSH terms to enhance the precision of the search.The search strings were adapted to fit the specificities of each database, ensuring their suitability to the syntax and search functionalities of each platform. Each database had unique search strings, as no two databases have the same search capabilities as shown through table 1.

Table 1: Search strings utilised across the databases

Database	Search string
PubMed	("Intraoral Scanners"[MeSH] OR "Digital Impression") AND "Conventional Impression" AND "Full-Arch Implantology"
MEDLINE	("Intraoral Scanners"[MeSH] OR "Digital Impression") AND "Conventional Impression" AND "Full-Arch Implantology"
Scopus	TITLE-ABS-KEY("Intraoral Scanners" OR "Digital Impression") AND TITLE-ABS-KEY("Conventional Impression") AND TITLE-ABS-KEY("Full-Arch Implantology")
Web of Science	TS=("Intraoral Scanners" OR "Digital Impression") AND TS=("Conventional Impression") AND TS=("Full-Arch Implantology")
Embase	'intraoral scanners'/exp OR 'digital impression' AND 'conventional impression' AND 'full-arch implantology'
CINAHL	(MH "Intraoral Scanners" OR "Digital Impression") AND (MH "Conventional Impression") AND MH "Full-Arch Implantology"
Cochrane Library	("Intraoral Scanners" OR "Digital Impression") AND ("Conventional Impression") AND "Full-Arch Implantology"
Google Scholar	allintitle: "Intraoral Scanners" "Digital Impression" "Conventional Impression" "Full-Arch Implantology"

INCLUSION AND EXCLUSION CRITERIA

The inclusion criteria were: (1) in-vitro studies, given the controlled environment they offer, thus minimizing potential confounders; (2) studies that directly compared the use of intraoral scanners (IOS) and conventional impression (CI) methods in full-arch implantology, as the review was specifically interested in this comparison; and (3) studies published in the English language, to facilitate comprehension and comparison of studies by the research team.

The exclusion criteria were: (1) studies that did not directly compare IOS and CI methods, as they would not provide the comparative data required for the review; (2) case reports, as they typically focus on individual or few cases and therefore do not provide a sufficient level of evidence for the review; (3) non-English language studies, as the research team may not have been able to accurately interpret these studies; and (4) studies that used partial-arch or single-tooth implant models, as they were not aligned with the review's focus on full-arch implantology.

BIAS ASSESSMENT

To assess bias within the studies included, the Newcastle-Ottawa Scale (NOS) tool 14 was employed. This tool is designed for the quality assessment of non-randomized studies, including case-control and cohort studies. However, given this review was focused on in-vitro studies, modifications were made to adapt the tool to this context as shown thorough figure 2. Each study was independently assessed using the adapted NOS tool. The tool evaluates studies across three broad perspectives: the selection of study groups, the comparability of groups, and the ascertainment of the outcome of interest. For the purpose of this review, the selection criteria focused on the specificity of the inclusion criteria and the definition of the IOS and CI methods used. Comparability was judged based on whether the studies controlled for potential confounders such as operator skill, type of IOS and CI, and the presence or absence of landmarks. Outcome ascertainment was examined in terms of how trueness and precision were measured and whether the researchers who assessed these outcomes were blinded to the method used.

Results

Study selection process

Initially, a total of 471 records were identified from various databases, with no additional records retrieved from registers. Prior to the screening phase, certain records were systematically removed. This included 69 reviews and 78 records classified as case reports, editorials, and similar types of publications. Furthermore, 31 records were excluded due to their non-English language. This initial filtering resulted in 293 records being screened for potential inclusion. Of these, 62 records were excluded from further consideration, primarily due to duplication, leaving 231 records. These underwent a more detailed assessment for retrieval, resulting in 182 reports being targeted for retrieval. However, 36 of these could not be retrieved, and an additional 51 reports were excluded after being deemed non-responsive to the Population, Intervention, Comparison, Outcome (PECO) framework (47 reports) or being off-topic (43 reports). After these exclusions, 146 reports were assessed for eligibility. Ultimately, only 5 studies 15-20 met the rigorous inclusion criteria and were included in the final review.

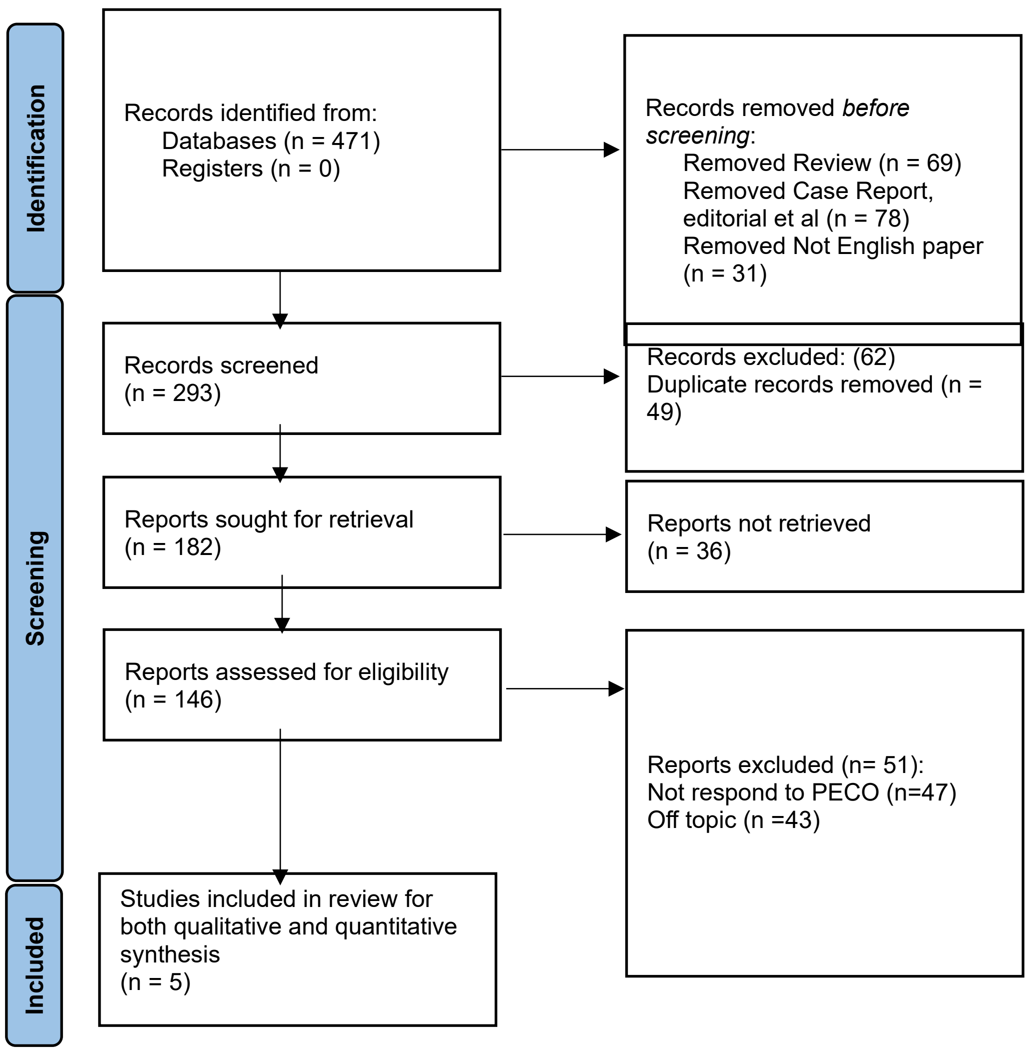

Figure 1: PRISMA protocol representation for this review

Findings pertaining to bias

In terms of **Question and Inclusion,** Farhan et al 17, Drancourt et al 16, and Ke et al 18 had the lowest concerns, while Alikhasi et al 15 and Rhee et al 19 raised some concerns, indicating better clarity and adherence to the inclusion criteria in the former studies.

For **Protocol Adherence,** all studies except Drancourt et al 16 (some concerns) raised high concerns or lacked information, suggesting that most studies had potential issues with adhering to their initial protocols.

Regarding the **Study Design**, Drancourt et al 16, Farhan et al 17, and Rhee et al 19 demonstrated low levels of concern, while Alikhasi et al 15 provided no information, and Ke et al 18 raised some concerns. This suggests that the former studies had more robust and reliable designs.

In the **Risk of Bias** category, Alikhasi et al 15, Drancourt et al 16, and Farhan et al 17 showed low levels of concern, while Ke et al 18 raised some concerns, and Rhee et al 19 provided no information, indicating a lower potential for bias in the first three studies.

Analyzing the **Funding Sources**, Alikhasi et al 15, Drancourt et al 16, and Rhee et al 19 had low levels of concern, while Farhan et al 17 and Ke et al 18 raised some concerns, suggesting that the former studies had more transparent and unbiased funding.

In terms of **Statistical Methods**, Alikhasi et al 15, Farhan et al 17, and Rhee et al 19 showed low levels of concern, while Drancourt et al 16 raised high concerns, and Ke et al 18 had some concerns. This suggests that the former studies employed more reliable and valid statistical methods.

For **Publication Bias**, Drancourt et al 16 displayed low concern, while all other studies either raised high concerns (Alikhasi et al 15 and Farhan et al 17) or some concerns (Ke et al 18 and Rhee et al 19), indicating issues with selective reporting in the latter studies.

Regarding **Conflict of Interest**, all studies raised some concerns, pointing to potential influences that could affect the impartiality of the research.

In the overall comparison, every study was found to have its strengths and weaknesses in different bias categories, but all shared the common issue of potential conflict of interest. The main differences lay in the areas of protocol adherence, risk of bias, funding sources, and publication bias. Despite these concerns, the **Overall Bias** was assessed as low for Alikhasi et al 15, Farhan et al 17, Ke et al 18, and Rhee et al 19, and unclear for Drancourt et al 16, indicating the general reliability of these studies' findings.

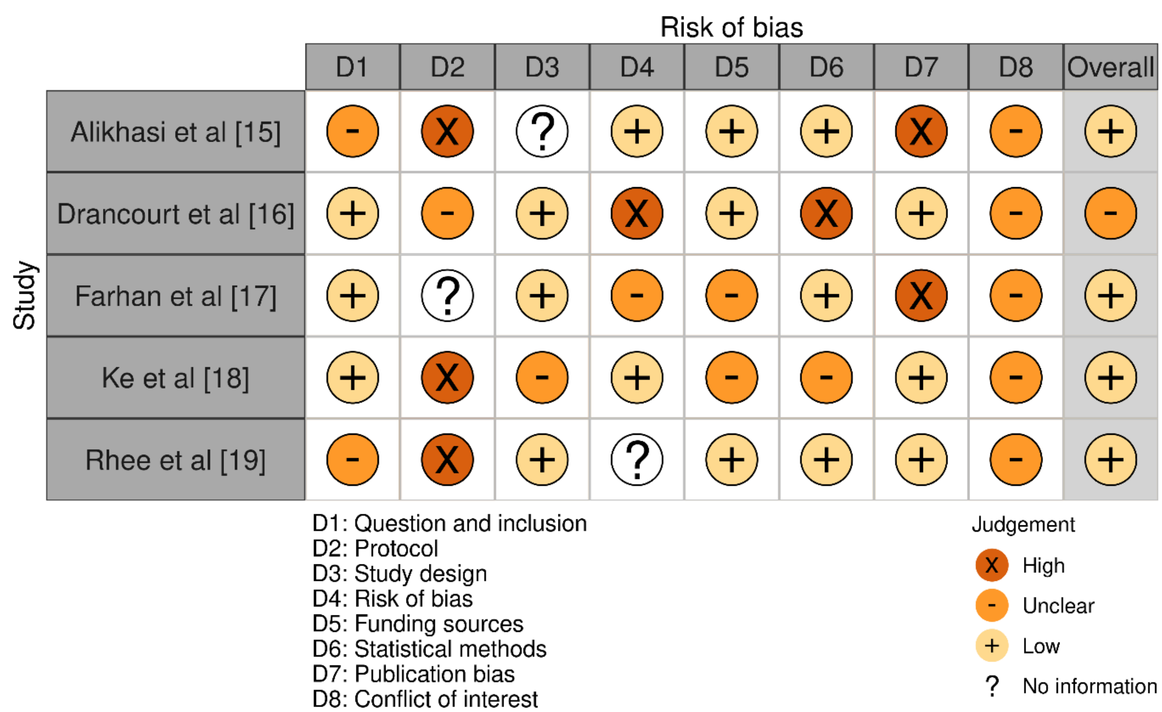

Figure 2: Bias assessment of the selected papers for the review

Study findings

In the study conducted by Alikhasi et al 15, an in-vitro design was implemented to observe the Trios 3Shape type of Intraoral Scanner (IOS). The findings indicated significant angular and linear distortion differences among the impression groups. Interestingly, the minimum distortion was observed for tilted implants. In comparison to traditional methods, digital technique demonstrated minimal distortion for tilted implants, suggesting a potential superiority in the context of this specific application. Drancourt et al 16 also employed an in-vitro design, but expanded the range of IOS types to include Trios 4, Primescan, CS3600, and i500. The study found that conventional impressions demonstrated smaller distance deviations, signifying better trueness. Of the digital techniques, the i500 displayed the best angular measurements, indicating that different IOS types may excel in different aspects of impression taking.

In a similar in-vitro study, Farhan et al 17 compared conventional impressions with a control group using both IOS and conventional impression (CI) methods. The results showed that conventional impressions differed significantly from the control group. Furthermore, the study reported convergent mean values and standard deviation, implying a level of consistency within the data. Ke et al 18, utilizing Trios 4 and Aoralscan 3 IOS types in their in-vitro study, found that different groups showed variations in both trueness and precision. The study noted that digital implant impressions without landmarks exhibited higher trueness and precision. However, the incorporation of landmarks improved both trueness and precision, suggesting the potential benefits of integrating additional reference points in the digital impression process. Rhee et al 19 identified differences in two-dimensional and three-dimensional analyses between intraoral scanning and dual-arch impression in an in-vitro setting, with intraoral scanning demonstrating the most substantial difference from the dual-arch impression. Observing a discrepancy in both three-dimensional and two-dimensional analyses indicates the potential for disparity in results depending on the analytical approach used.

Table 2: Selected papers and their assessments

Study ID	Study design	Type of IOS observed	Results observed	Statistics observed	Overall inference drawn
Alikhasi et al 15	In vitro	Trios 3Shape	Less distortion with tilted implants.	Significant differences ($P < 0.001$), except for digital technique's connection type and angle ($p > 0.05$).	Traditional impression methods showed distortion differences. Digital technique had minimal distortion for tilted implants.
Drancourt et al 16	In vitro	Trios 4, Primescan, CS3600, i500	Angular and linear distortion varied by impression type.	All significant ($P < 0.001$), best for tilted implants ($0.36° \pm 0.37$, 0.16 ± 0.1 mm).	Conventional impressions showed better trueness. I-500 had superior angular measurements.
Farhan et al 17	In vitro	IOS, CI	Smaller deviations with conventional impressions.	Smallest deviation for conventional ($p < 0.001$), best angular with I-500 ($p < 0.001$).	Conventional impressions had a significant difference from the control group.
Ke et al 18	In vitro	Trios 4, Aoralscan 3	Conventional impressions differed from control.	Closest to control was IOS, high accuracy in distances A-B, B-C, C-D, D-A.	Digital implant impressions without landmarks showed higher trueness and precision. With landmarks, trueness and precision improved.
Rhee et al 19	In vitro	Unspecified	Variations in trueness and precision across groups.	IOS groups showed improved trueness and precision ($p<0.05$), with significant differences in 3D analysis.	Intraoral scanning showed the biggest difference compared to dual-arch impression. Differences were observed in three-dimensional and two-dimensional analyses.

Discussion

From a theoretical perspective, this review highlighted the multifaceted nature of factors influencing the performance of IOS and CI. The findings underscored that the effectiveness of these methods can substantially vary depending on several factors, such as the specific application, the presence or absence of landmarks, and the type of dimensional analysis used. This nuanced understanding challenges the notion of a universally superior method and emphasizes the need for context-specific evaluations of IOS and CI. From a practical standpoint, these findings can guide clinicians in selecting the most suitable method for each case. For instance, in cases involving tilted implants, digital techniques may offer advantages in terms of minimal distortion, as shown by Alikhasi et al 15. On the other hand, in scenarios where trueness is paramount, conventional methods may be preferable, as indicated by Drancourt et al 16. The review also has significant implications for future research. It highlights the need for further studies to elucidate the complex interplay of factors influencing the performance of IOS and CI. Future investigations could focus on refining the understanding of the role of landmarks in enhancing trueness and precision, as suggested by Ke et al 18. Moreover, the significant difference observed between two-dimensional and three-dimensional analyses by Rhee et al 19 underlines the need for research to explore the impact of dimensional analysis on the results.

Examining the results of the five studies reveals contrasting assessments of intraoral scanners (IOS) and conventional impressions (CI). The studies by Alikhasi et al 15 and Drancourt et al 16 highlight the potential superiority of IOS in certain applications, such as improved angular measurements and minimal distortion for tilted implants. However, they also underscore the continued relevance of traditional methods, with conventional impressions demonstrating smaller distance deviations and superior trueness.

On the other hand, the research by Farhan et al 17 presents a more nuanced picture, reporting a significant difference between conventional impressions and the control group. This finding, coupled with the convergent mean values and standard deviations, suggests that while conventional methods may still play a vital role, their output may differ significantly from control measurements, potentially indicating a degree of inconsistency. The study by Ke et al 18 adds another layer of complexity, showing that the performance of digital implant impressions can vary significantly based on the presence or absence of landmarks. Their results highlight the potential for increased trueness and precision with the use of landmarks, a factor that was not considered in the other studies. Rhee et al 19 extends the comparison to include not only the type of impression method but also the dimensional analysis used. Their findings suggest that the choice between two-dimensional and three-dimensional analysis could significantly impact the results, with intraoral scanning demonstrating the most substantial difference from the dual-arch impression.

Anchorage complications associated with dental implants present numerous challenges in the creation of implant-supported prostheses 20-23. Critical parameters in this context are trueness and precision, which are vital to the overall success of the prosthesis. The advent of digital impressions provides a potential solution to these issues, offering several key advantages over traditional methods 6, 24. Firstly, the elimination of physical impression trays and materials minimizes risks associated with incomplete curing and deformation. This leads to a reduction in errors associated with laboratory procedures, such as casting, demolding, and transfer placement, which in turn ensures a stable impression. Digital impressions also enable real-time data processing, facilitating ease of modifications or re-usage of digital files 21.

Furthermore, digital impressions provide an improved patient experience, characterized by less discomfort and greater flexibility in the impression-taking process. Patients have reported a preference for this method due to the ability to pause and resume the process without data loss 24. The digital approach also allows for the preservation of the virtual model, offering the potential to recreate the prosthetic element without additional patient involvement, given appropriate clinical conditions 25. Additional benefits include the availability of libraries of theoretical scanbody morphologies corresponding to different implant types, time-saving capabilities of the IOS, and enhanced communication with the laboratory, enabling swift delivery without the need for physical transportation, pre-manufacturing consultation with the prosthetist, assistance in shade selection, and overall time-saving 26.

Despite these advantages, digital impressions are not without limitations. Various factors can compromise the scanning process, including operator or equipment mistakes, such as calibration errors, the physical properties of the object being scanned, and environmental disturbances, such as lighting conditions within the clinic 26. Also, the optical characteristics of scanned elements, including reconstruction materials and the prosthesis itself, can impact the quality of acquisitions 27-28.

Traditional impression methods, despite being widely used in dental practice and considered the gold standard in certain scenarios, have their own set of challenges 29. These include recurring costs, patient discomfort, the requirement for properly fitting impression trays, and the need to cast with dental stone 30. The quality of conventional impressions is also dependent on the handling of materials, deformation of the impression and stone material, and accurate capture of all intraoral structures 31. Therefore, while digital impressions provide numerous advantages, their limitations and the persistent use of conventional methods highlight the need for further exploration and research.

The findings from Ma et al.'s review 32 resonate with the observations made in our study, reflecting a consensus that the choice between intraoral scanning (IOS) and conventional impressions (CI) does not hinge on a one-size-fits-all approach. Consistent with our results, Ma et al. 32 discovered that the efficacy of IOS and CI varies based on a range of variables, such as the context of their application, the existence of identifiable landmarks in the patient's oral anatomy, and the specific methods of dimensional analysis applied. In alignment with our findings, digital techniques, as employed in IOS, exhibited certain advantages like reduced distortion when working with tilted implants. However, CI showed its strengths in our study by delivering smaller deviations in distances and greater trueness under different conditions, emphasizing the technique's reliability in certain aspects of dental impression-taking. Our study, similar to Ma et al.'s review 32, provides valuable insights that could aid dental professionals in making informed decisions about which impression technique to employ to optimize patient outcomes. The decision-making process is evidently nuanced and should be tailored to each unique clinical situation. Moreover, both our study and the systematic review by Ma et al. 32 propose a roadmap for future research in this domain. There's a clear need to investigate the multifaceted factors that influence the performance of IOS and CI, particularly through in-vivo studies, which are more representative of real-world scenarios. Furthermore, both pieces of research highlight the importance of considering the operator's expertise as a variable and call for a more in-depth exploration into how anatomical landmarks can impact the accuracy of dental impressions.

Limitations

While this design allows for controlled comparisons, it lacks the biological variability and complexity inherent in clinical settings. Factors such as patient movement, saliva, blood, and soft tissue presence, which are encountered in in-vivo scenarios, were not accounted for. Therefore, the transferability of these findings to real-world clinical situations may be limited. Secondly, the review included a variety of IOS types and, in some instances, the type of IOS was unspecified (as in the case of Rhee et al [19]). This diversity might have introduced heterogeneity into the results, making it challenging to draw definitive conclusions about the performance of specific IOS types. Thirdly, the review did not consider the experience and skill of the operator in using the IOS or CI methods. The proficiency of the operator can significantly influence the results of both digital and traditional impressions, and this factor was not accounted for in the review. Lastly, the review did not explicitly account for the impact of landmark use on the trueness and precision of impressions. While Ke et al [18] found that landmarks improved these factors, more extensive exploration of this aspect across the different studies would have strengthened the review.

Conclusion

The findings underscored that neither IOS nor CI could be deemed universally superior. Rather, their relative effectiveness varied depending on a multitude of factors, including the specific application, the presence or absence of landmarks, and the type of dimensional analysis used. For instance, while digital techniques were found to offer advantages in terms of minimal distortion for tilted implants, conventional methods demonstrated smaller distance deviations and superior trueness in other scenarios. These insights have the potential to guide clinicians in selecting the most appropriate method for each individual case, thereby enhancing patient outcomes. Furthermore, the review has charted the course for future research to delve into the complex interplay of factors influencing the effectiveness of IOS and CI, encouraging a more nuanced understanding of this field. However, the review also revealed certain limitations that need to be accounted for in future studies, including the need for in-vivo research, the consideration of operator skill, and the further exploration of the role of landmarks.

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