Influence of scan pattern on full-arch scans with three digital scanners

Corresponding author

M.W. Wagner
Witten/Herdecke University, Witten, Germany

Abstract

Objectives
Digital imaging has become one of the standard procedures in dental practice. A variety of different intraoral scanners are available for this purpose. A universally valid and accepted procedure for digitizing a specific anatomical situation is not yet available. This makes it difficult to obtain an accurate and reproducible result. The aim of the study was to develop a standardized workflow that improves quality and guarantees precise results regardless of the scanner type. The deviations between the data record and the original should be as small as possible.

Material & methods
The data sets were collected from eight different scan protocols and compared with a master scan (laboratory scanner). The protocols were applied five times to a test jaw. The data were collected with three different intraoral scanners in a light box with identical lighting conditions. To quantify the deviations, the scans were superimposed and the deviations in regio 41 and 47 were compared. The statistical analysis was carried out by an ANOVA and a Tukey-HSD post-hoc test. Results None of the strategies proved to be superior overall. The deviations were on average 0.57mm (SD ± 0.13mm) in the anterior region and 0.72mm (± 0.3mm) in the posterior region. Strategy 3 (swiping movements from 37 to 47 along the dental arch) was able to generate the most accurate data for the anterior region with mean deviations of 0.52mm (± 0.117mm) and strategy 5 (lingual from 37 to 47 - occlusal from 47 to 37 - vestibular from 37 to 47) for the posterior region with mean deviations of 0.61mm (± 0.3mm). Differences between the different scanners were also detected.

Conclusions
Depending on the target or size of the digital impression, choosing the right scanning strategy can increase the "accuracy and precision" of the data set. Not only the target region, but also the scanner used should be considered. The available results cannot identify a generally superior strategy currently. This is of particular importance, as deviations in the digital impression can affect the "fit accuracy"of dental restorations. Nevertheless, the aim of further comparative studies should be to develop a universal scanning method that delivers consistently realistic, accurate and precise results regardless of the scanner.

Primary Author

M.A. Vukovic[1]
W.D. Grimm[2]

1
Praxisteam Hasslinghausen, DGParo Clinical Competence Center, Sprockhövel, Germany

2
Witten/Herdecke University, Periodontology, School of Dentistry, Faculty of Health, Witten, Germany

Keywords

Dental implant, Microgeometry, Surface modifications, Surface treatments

DOI

10.23805/JO.2024.599

INTRODUCTION

An accurate impression of the oral situation is the basis for appropriate indirect restorations such as crowns, bridges and inlays (1). Despite improvements in impression materials and methods, errors can lead to inaccuracies that affect the fit. Digital impressions offer new possibilities for taking impressions of the oral situation. However, as with conventional impressions, factors that affect accuracy must be considered. Digital technologies have led to new workflows in dentistry (2). CAD/CAM systems have been used to digitally fabricate dental restorations since the 1980s. There are two paths: the indirect digital workflow, in which a conventional model is digitized with a laboratory scanner, and the direct path, in which the oral situation is scanned with an intraoral scanner (3). Either way, the restoration can be reconstructed on the computer and fabricated using additive or subtractive manufacturing techniques. The goal of introducing intraoral scanners (IOS) to dentistry is to achieve reproducible accuracy in impression-taking while saving time (4). Studies have shown that IOS systems provide similar or even more accurate results than conventional impressions. The scanning strategy plays an important role in the acquisition of data and the accuracy of the impression. There are several intraoral scanners with different technologies and features (5).

IOS Basics

There are different digitization methods for generating data sets (24). IOS systems can be divided into powder-free and non-powder-free systems. The acquisition of all topographic surfaces in the oral cavity is limited due to the design and anatomical conditions (6, 7). There are different software and hardware solutions available from intraoral scanner manufacturers to generate a digital data set. In addition, there are different data formats for storing the digitized jaw. A distinction is made between "accuracy" and "precision", where "accuracy" indicates how close the measured value is to the target value and "precision" describes the scatter of the measurement results (8).

MATERIALS AND METHODS

Scanning was performed with eight different scan protocols per scanner and then compared to a master scan. Each protocol was applied five times to one test jaw. Data acquisition was performed with three different intraoral scanners, all placed in a lightbox with identical lighting conditions. To quantify the deviations, the scans were aligned in region 37-35 and superimposed. On the contralateral side, the deviations were compared in regions 41 and 47. To compare the "accuracy" of the scans, two software solutions were tested: CoDiagnostiX™, and Exocad™. Exocad™ proved to be the better software for comparing the scans, as it was easier to make a reproducible comparison. Statistical analysis was performed using ANOVA and a Tukey-HSD post hoc test.

RESULTS

None of the strategies used proved superior overall. Mean deviations of 0.57 mm (standard deviation ± 0.13 mm) were observed in the anterior region, while deviations of 0.72 mm (± 0.3 mm) occurred in the posterior region. It was observed that strategy 3 (Fig. 1) (wiping movements from 37 to 47 along the dental arch) produced the most accurate data in the anterior region, with mean deviations of 0.52 mm (± 0.117 mm), while strategy 5 (Fig. 1) (lingual from 37 to 47 - occlusal from 47 to 37 - vestibular from 37 to 47) produced the best results in the posterior region, with mean deviations

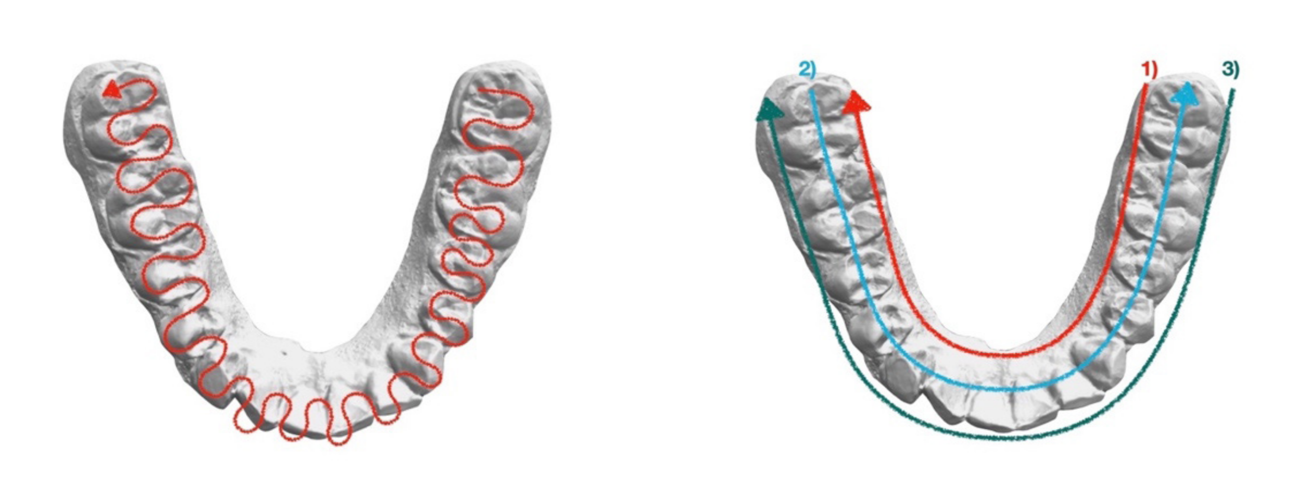
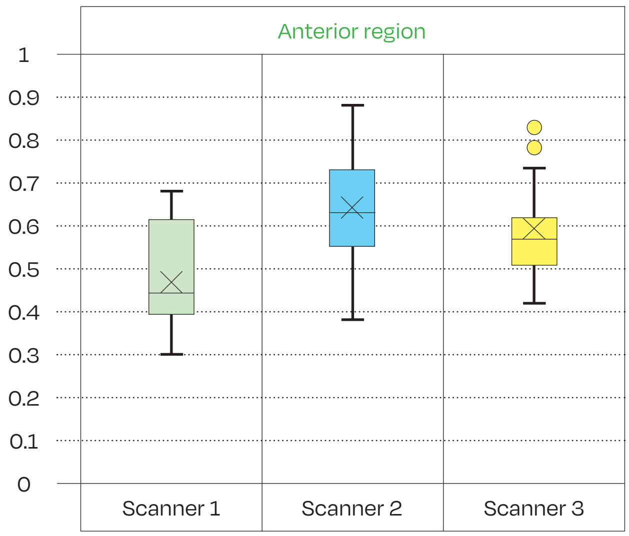
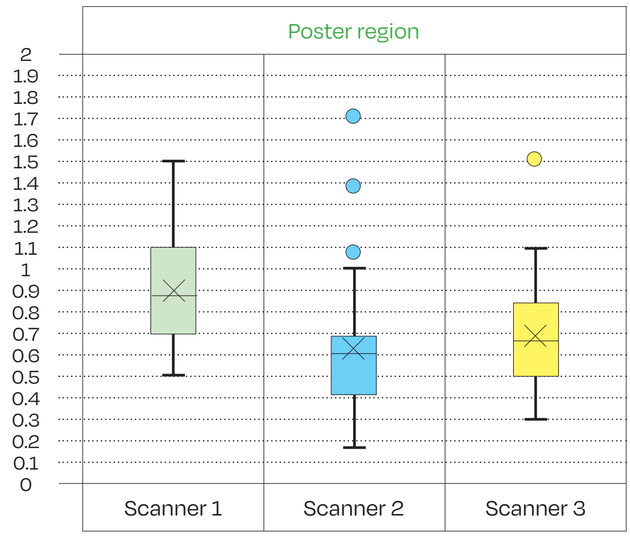


Fig. 1 Strategy 3 and 5



Tab. 1 Anterior Region, all scans



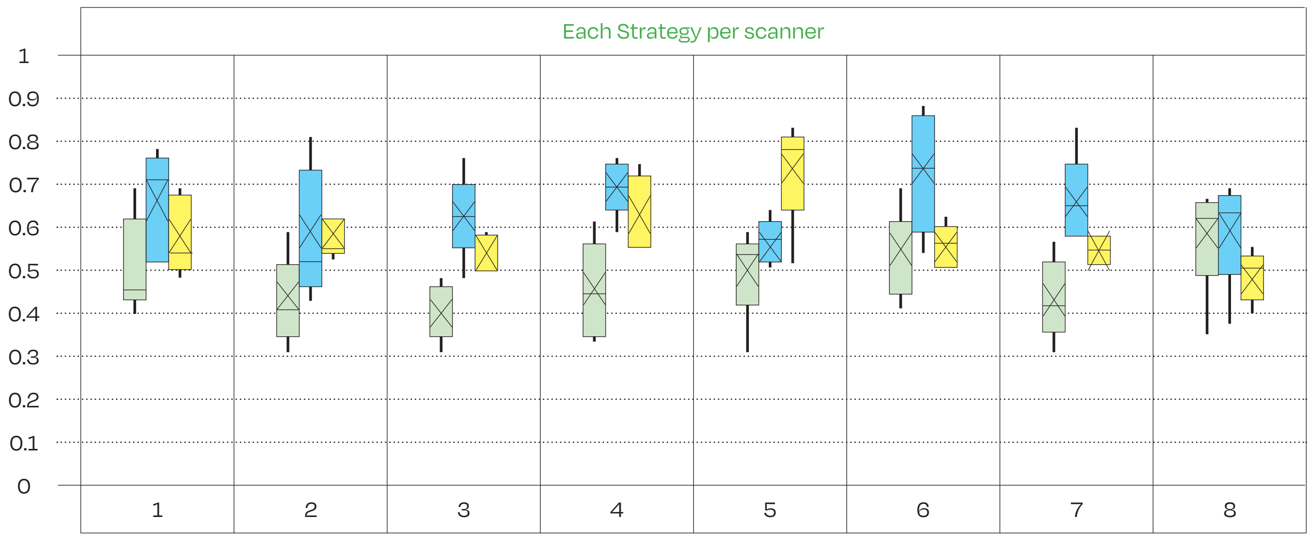
Tab. 2 Posterior Region, all scans

of 0.61 mm (± 0.3 mm). Differences were also found between the scanners used. Three categories were distinguished: First, all scans from one scanner were averaged and compared to the other scanners. This was done in both the anterior and posterior regions. In both the anterior (Table 1) and posterior regions (Table 2), the direct comparison between scanners 2 & 3 yielded a non-significant result. Overall, the results were inhomogeneous. In the second comparison, all scans of a strategy from all scanners were compared to each other so that the most accurate strategy could be selected regardless of which scanner was ultimately chosen. This comparison did not yield significant results in either the anterior or posterior region.
Each strategy per scanner was additionally tested for significance in the comparison (Table 3). The two-factor ANOVA yielded a significant result for the interaction of scanner and strategy in the anterior region (p=0.002), also indicating that the performance of the strategies depends on the choice of scanner. However, when the strategies of each scanner are considered in pairs with a one-factor ANOVA, the result is heterogeneous in terms of p-value. In the posterior region, there is no overall homogeneous result across the means. Significance testing with a two-factor ANOVA revealed that the p-value for a "scanner strategy" comparison was not significant (p=0.174). The within-scanner comparison is not significant. There is a trend (p=0.051) for scanner 2.

DISCUSSION

Discussion of the experimental design

Three different intraoral scanners were used in this



Tab. 1 Each Strategy per scanner. Legend: scanner 1 ▢ scanner 2 ▢ scanner 3 ▢

study: Medit i500®, Trios 3®, and Omnicam®. Previous studies have compared these scanners individually, but not against each other in terms of "scanning strategy accuracy". The latest, Dentsply / Sirona scanner, Primescan®, has been evaluated as the most accurate scanner in some studies. Since this scanner was not available in this study, it is recommended that it be included in future studies. Dimensionally stable materials were used for the model to achieve reproducible results (9-11). Previous studies used different materials. Ender et al. (2019) used field-split ceramics for a maxillary model and found that more translucent materials had greater deviations (10). Overall, the results are only indicative of the expected behavior in a patient's mouth and further in vivo studies should be conducted (12). The "accuracy" of intraoral scanners is influenced by several factors, including the "scanning strategy" (13-17). This has been noted in other literature sources. An extensive literature search revealed several scanning protocols with minor variations. Manufacturers have developed different scanning protocols to achieve the most accurate results due to the specific differences in their systems. In the latest models of intraoral scanners, "accuracy" is no longer affected by the scanning strategy, according to the manufacturers. For example, the Trios5® from 3shape™ no longer requires a specific scanning protocol due to new software algorithms (18). This scanner should also be included in future studies. "Reproducibility" and "high accuracy" were considered when selecting the CAD program for this study. Several studies have used Exocad software™ to evaluate scans (19-21). Feng et al. (2021) used Exocad™ in a similar study and evaluated the scans with a color scale to visualize the distance between the scans (22). A similar comparison was made in the present study. Two areas were considered: "occlusal deviation" and "bucco-lingual deviation". Compared to other studies that used industrystandard software solutions, this study chose a dental product to provide a more realistic evaluation (10, 11, 23, 24). The goal of this study, to identify a scanning strategy that would produce the lowest possible deviation across all scanners, could not be achieved. There are significant differences between the individual strategies and scanners. A clinically relevant influence of the choice of strategy in relation to the impression size as well as the scanner used could also be determined. The results of this study show a significant "influence of scanning strategy" on "accuracy".

All scans from one strategy in the anterior region

In this study, the scanner from an older model cycle (Scanner 1) was found to provide the most accurate results in the anterior region of all scans from one scanner. This is in contrast to another study by Diker et al. (2020) in which the Trios 3® was more accurate than the Omnicam (24). Diker et al. (2020) found significant differences in accuracy between the different scanners, with the Primescan® from DensplySirona™ being the most accurate.

Scanner Strategies in the Anterior Region

Feng et al (2021) found significant differences in the "accuracy" of different scan head movements. An S-shaped movement showed the most accurate results (22). Strategy 3 in this study is similar to this movement. It should be investigated whether combinations of head movements and scanning strategies can lead to more accurate results. In the present study, no correlation was found between the "scanning strategies". Strategy 3 was the most accurate in the anterior region, but had a wider range. Strategy 6 had the least variability. A similar study found that a sequential strategy also had low variance (25).

Strategies of the scanners in the anterior region

In this section, the variations of the different scanning strategies for each scanner are considered. A study by Latham et al. (2018) found that the scanning protocol similar to that of the Omnicam® manufacturer was the most accurate (14). However, the results contradict the results of the present study in which this protocol was the least accurate. A study by Gavounelis et al. (2021) examined the effects of "deviating" from the manufacturer's strategy for the Medit i500® and found similar results. A similar study by Medina-Sotomayor et al. (2019) found no significant differences between "scanning strategies" (25). However, there are differences in the models, materials, and comparison programs used that may lead to these discrepancies.

DISCUSSION OF POSTERIOR REGION RESULTS

All scans from one scanner

Ender et al. (2019) investigated size variation in whole jaw scans and found different results compared to the present study (10). Renne et al. (2017) and Resende et al. (2021) also showed different results regarding "scanner accuracy" (26, 27). Nagy et al. (2020) found the Trios 3® to have the lowest variation (11). These differences may be due to various factors and study design. The results highlight the need for further in vivo studies, as the variations are extreme when using the Medit i500® for dental work and may affect the "accuracy" of fit of the restoration. Impression accuracy studies between different materials have also been conducted (Haghi et al., 2017) (28).

All scans of a strategy

The results in this section show that strategy 5 has the least variation across the entire jaw. This is in contrast to the study by Feng et al. (2021), where different head movements showed significant differences in the "accuracy" of the scans (48). It is recommended that further studies investigate the combination of strategy 5 with an S-shaped head movement to determine if this leads to significantly better results. A study by Müller et al. (2016) found no significant differences in "accuracy", but a significant difference in "precision" between the different scanning strategies (16). Strategy B in this study corresponds to the presented strategy 5, which provided the most accurate results over the entire jaw. If a consistent strategy is to be used for all areas, strategy 3 is recommended because it has the least overall variation. However, if a universal strategy is not to be used, a detailed analysis of all scans and strategies is required to perform a comprehensive comparative analysis.

Scanner Strategies in the Posterior Region

The Medit i500® scanner shows the least deviation in the posterior region, with the exception of strategies 2.6 and 2.8. Gavounelis et al. (2021) also found that the "sequential scanning strategy" was the most accurate (29). In the present study, strategy 2.5 produced the most accurate results, in contrast to the study by Gavounelis et al. (2021), where Figure B was the least accurate. Differences may be due to various study design factors, such as the use of a model instead of real jaws and different practitioners. In a study by Medina-Sotomayor et al. (2018), the Trios 3® with a "wiping motion strategy" was the most accurate, while the Medit with strategy 3 was the least accurate (25). However, in the present study, strategy 3 of the Medit i500® was not the least accurate. The Trios 3® showed the least variation with strategy 3.5, and there were significant differences between scanners and strategies (see Table 2).

Outlook

The outlook of the present study emphasizes that IOS offer new opportunities for dental practices and can bring significant simplifications (30, 31). The use of IOS eliminates the inconvenience and discomfort associated with conventional impressions, such as manipulation in the mouth, odor annoyance, and potential gag reflex. In addition, digital impressions reduce the potential errors and inaccuracies that can occur with conventional impressions and allow for immediate on-screen review and correction of preparations. IOS also have advantages in orthodontic treatment and can lead to improved fit of restorations and aligners. In addition, IOS can be used for proximal caries detection, shade determination and archiving of orthodontic models. They also offer advantages in terms of infection risk, quality assurance, documentation, and forensic purposes (32). However, it is emphasized that careful consideration of investment costs and practice implementation is required. There are also some limiting factors for the use of IOS, such as deep cavities, subgingival preparations and endodontic lesions (33). Studies also suggest that the integration of IOS into dental education should be encouraged to prepare students for the use of digital technologies in practice (34). In addition, potential future developments are discussed, such as the use of smartphones for 3D digitization of models and the investigation of potential hazards associated with IOS (35, 36). Overall, the outlook shows that IOS are a promising technology with the potential to improve dentistry, but further research and development is needed to further optimize their application areas and effectiveness.

CONCLUSION

The paragraph states that depending on the target or size of the digital impression, choosing the right scanning strategy can increase the accuracy and precision of the data set (7). It is noted that there is currently no generally superior strategy. Variations in the digital impression can affect the "accuracy of the fit" (24). The scanning protocol may affect the "accuracy" and "precision" of the scan. Results may be affected by various factors and other in vivo influences such as blood, saliva, soft tissue, crowns and bridges may lead to different results. However, the goal of further studies should be to develop a universal scanning procedure that consistently provides realistic and accurate results regardless of the scanner.

REFERENCES

1. Wöstmann B. Die Abformung als Grundlage für eine langfristige prothetische Versorgung. zm 2005;95:32-9
2. Zimmermann M. Auftakt zum digitalen Workflow in Praxis und Labor. ddm 2017;5:40-8
3. Schubert VC. Untersuchungen zur Ganzkieferabformung von parodontal geschädigten Gebissen. Gießen: Universitätsbibliothek; 2021
4. Güth JF, Edelhoff D, Schweiger J, Keul C. A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. Clin Oral Investig 2016;20(7):1487-94
5. Seelbach P, Brueckel C, Wöstmann B. Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig 2013;17(7):59-64
6. Goracci C, Franchi L, Vichi A, Ferrari M. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. Eur J Orthod 2016;38(4):422-8
7. Abduo J, Elseyoufi M. Accuracy of Intraoral Scanners: A Systematic Review of Influencing Factors. Eur J Prosthodont Restor Dent 2018;26(3):101-21
8. Streiner DL, Norman GR. "Precision" and "Accuracy": Two Terms That Are Neither. Journal of Clinical Epidemiology 2006;59(4):327-30
9. Al Ibrahim I, Keeling A, Osnes C. The effect of operator scanning speed on the trueness and precision of full-arch digital impressions captured in vitro using an intraoral scanner. J Osseointegr 2021;13:265-70
10. Ender A, Zimmermann M, Mehl A. Accuracy of complete- and partial-arch impressions of actual intraoral scanning systems in vitro. Int J Comput Dent 2019;22(1):11-9
11. Nagy Z, Simon B, Mennito A, Evans Z, Renne W, Vág J. Comparing the trueness of seven intraoral scanners and a physical impression on dentate human maxilla by a novel method. BMC Oral Health 2020;20(1):97

13. Bocklet C, Renne W, Mennito A, Bacro T, Latham J, Evans Z, et al. Effect of scan substrates on accuracy of 7 intraoral digital impression systems using human maxilla model. Orthod Craniofac Res 2019;22 (1):168-74
14. Latham J, Ludlow M, Mennito A, Kelly A, Evans Z, Renne W. Effect of scan pattern on complete-arch scans with 4 digital scanners. J Prosthet Dent 2020;123(1):85-95
15. Latham JL. Evaluation of the Effect of Scan Strategy on the Accuracy of 4 Intraoral Digital Impression Systems: Medical University of South Carolina; 2018
16. Passos L, Meiga S, Brigagão V, Street A. Impact of different scanning strategies on the accuracy of two current intraoral scanning systems in complete-arch impressions: an in vitro study. Int J Comput Dent 2019;22(4):307-19
17. Müller P, Ender A, Joda T, Katsoulis J. Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. Quintessence Int 2016;47(4):343-9
18. Stefanelli LV, Franchina A, Pranno A, Pellegrino G, Ferri A, Pranno N, et al. Use of Intraoral Scanners for Full Dental Arches: Could Different Strategies or Overlapping Software Affect Accuracy? Int J Environ Res Public Health 2021;18(19):1-13
19. 3Shape. TRIOS 5 Wireless. Zahntechnik Wirtschaft Labor –5/2022, 56
20. Ferrari M, Keeling A, Mandelli F, Lo Giudice G, Garcia-Godoy F, Joda T. The ability of marginal detection using different intraoral scanning systems: A pilot randomized controlled trial. Am J Dent 2018;31(5):272-76
21. Abd El Galil EG, Mohamed SL, Rizk FN, Sabet ME. Evaluation of two computer-aided design software on the adaptation of digitally constructed maxillary complete denture. J Indian Prosthodont Soc 2021;21(4):383-90
22. Lerner H, Nagy K, Pranno N, Zarone F, Admakin O, Mangano F. Trueness and precision of 3D-printed versus milled monolithic zirconia crowns: An in vitro study. J Dent 2021;113:1-15
23. Feng C-W, Hung C-C, Wang J-C, Lan T-H. Accuracy of Different Head Movements of Intraoral Scanner in Full Arch of Both Maxilla and Mandible. Appl Sci 2021;11(17):1-12
24. Nowak R, Wesemann C, Robben J, Muallah J, Bumann A. An in-vitro study comparing the accuracy of full-arch casts digitized with desktop scanners. Quintessence Int 2017:667-76
25. Diker B, Tak Ö. Comparing the accuracy of six intraoral scanners on prepared teeth and effect of scanning sequence. J Adv Prosthodont 2020;12(5):299-306
26. Medina-Sotomayor P, Pascual M A, Camps A I. Accuracy of four digital scanners according to scanning strategy in complete-arch impressions. PLOS ONE 2018;13(9)
27. Renne W, Ludlow M, Fryml J, Schurch Z, Mennito A, Kessler R, et al. Evaluation of the accuracy of 7 digital scanners: An in vitro analysis based on 3-dimensional comparisons. J Prosthet Dent 2017;118(1):36-42
28. Resende CCD, Barbosa TAQ, Moura GF, Tavares LDN, Rizzante FAP, George FM, et al. Influence of operator experience, scanner type, and scan size on 3D scans. J Prosthet Dent 2021;125(2):294-9
29. Haghi HR, Shiehzadeh M, Nakhaei M, Ahrary F, Sabzevari S. Effect of technique and impression material on the vertical misfit of a screw-retained, three-unit implant bridge: An in vitro study. J Indian Prosthodont Soc 2017;17(1):41-7
30. Gavounelis N, Gogola C-M, Halazonetis D. The effect of scanning strategy on intraoral scanner's accuracy2021.
Stanley M, Paz AG, Miguel I, Coachman C. Fully digital workflow, integrating dental scan, smile design and CAD-CAM: case report. BMC Oral Health 2018;18(1):134
31. Zimmermann M, Kern M. Intraoralscanner – ein aktueller Überblick. ZWR 2016; 125:274-82
32. Suese K. Progress in digital dentistry: The practical use of intraoral scanners. Dent Mater J 2020;39(1):52-6
33. Zarone F, Ruggiero G, Ferrari M, Mangano F, Joda T, Sorrentino R. Accuracy of a chairside intraoral scanner compared with a laboratory scanner for the completely edentulous maxilla: An in vitro 3-dimensional comparative analysis. J Prosthet Dent 2020;124(6):761.1-.7
34. Lam WY, Mak KC, Maghami E, Molinero-Mourelle P. Dental students' preference and perception on intraoral scanning and impression making. BMC Med Educ 2021;21(1):1-6
35. Saghiri MA, Nath D, Oguagha O, Saghiri A. A new reliable alternate method to an intraoral scanner (in-vitro study). Phys Med 2021; 12:1-6
36. Prall C, Friemel J. Dental 3D Scanner - A risk factor? J Osseointegr 2021;13(4 Supplement):289-92