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Factors influencing the efficiency of intraoral *scanners* in dental prosthesis: Narrative review

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ABSTRACT
The objective of this literature review is to critically analyze the factors that influence the efficiency of intraoral scanners. Searches in electronic databases were performed using indexed keywords and free terms. The research was limited to full articles written in Portuguese and English and published in journals between 2011 and 2024. Intraoral scanning systems can be used reliably for diagnostic purposes and for short-span areas. However, for full-arc scanning, this system is more susceptible to distortion. Regarding the different scanner systems, the studies indicated variable results that do not allow a preference for the system to be realized. It is concluded that for the performance of prosthetic rehabilitation, the accuracy of the scanners is higher when the extension of the scan is reduced and when the scanned surfaces have minimal irregularities.

Keywords: Dental impression materials, Dental prosthesis, Computer-aided design.

1 INTRODUCTION

Dental impression is a routine procedure required in many areas of dentistry to copy oral tissues and reproduce them in models. These, whether physical or digital, are used for diagnostic purposes, planning or making prostheses, orthodontic appliances, etc. In order for the impression to fulfill its purpose, the patient's oral tissues must be copied appropriately, as the imprecision may cause maladaptation of the prosthetic piece, and consequently, a thick cementation line, infiltrations and secondary caries, in addition to excessive occlusal adjustments, which can generate fragility of the prosthetic piece, and impair the longevity of the treatment (Guth et al., 2013; Ender and Mehl, 2013).

The emergence of CAD/CAM technology in Dentistry in the late 1970s has led to several changes in dental clinics and prosthesis laboratories with the automation of processes and optimization of the quality of final products, especially in the area of prosthesis. Compared to conventional impressions, intraoral scanning has advantages, such as not requiring printing materials, trays, disinfection, and pouring plaster models. In addition, once the professional is trained, it becomes a simplified and less sensitive technique, easy storage of patient data (Solaberrieta et al., 2019). The use of intraoral *scanners* is also reported to reduce clinical time, increase patient comfort, and allow impression visualization immediately (Akyalcin et al., 2013, Kim et al., 2016, Burzynski et al., 2017).

The use of *intraoral scanners* requires an expensive investment to obtain these devices and they rely on the skill of the professional to ensure an adequate scan. In order for intraoral scanning to be recommended for routine use, it is desirable that the accuracy be at least similar to conventional impressions (Persson et al., 2006). Accuracy and truthfulness are key aspects in determining the accuracy of systems. Veracity indicates how close the measurements obtained are to the actual dimensions of the object, while accuracy refers to the consistency of repeated measurements (Imburgia et al., 2017).

The accuracy of prosthetic specimens made from intraoral scanning can be comparable to conventional methods (Chochlidakis et al., 2016). However, several factors are not completely clarified in the literature and may affect the final veracity of these systems, such as operator skill, capture system, presence of implants, scanning pattern, digitized area, and type of prosthetic space (Renne et al., 2017). This literature review seeks to clarify these aspects, since it is essential that professionals have knowledge to minimize distortions, leading to maximum equipment efficiency.

2 OBJECTIVE

The objective of this literature review was to analyze the factors that influence the efficiency of *intraoral* scanners.

3 MATERIAL AND METHOD

The databases used for the elaboration of this narrative literature review were MEDLINE via Pubmed, Google Scholar and LILACS/BBO via VHL. The included articles were selected from a search with indexed descriptors (MeSH and DeCs) and free terms combined through Boolean operators in the English language: "intraoral scanners" OR "digital flow" OR "CAD/CAM technology" OR "accuracy and precision" and Portuguese: "intraoral scanners" OR "digital flow" OR "CAD/CAM technology" OR "accuracy and precision". The selected articles were published between 2011 and 2024 in English or Portuguese.

4 LITERATURE REVIEW

The quality of the virtual image obtained by intraoral scanning is influenced by several factors that were addressed in this study, namely: extension of the scanned site, morphology and surface of the object, and the type of scanning. In addition, characteristics specific to the *scanner* and the technique used were mentioned by the studies as factors that can influence the efficiency of the procedure.

4.1 PARTIAL ARC SCANNING

For years, the accuracy of *scanners* has been considerably lower than conventional printing methods. However, recent technological advances have allowed a significant improvement in the accuracy of this equipment to levels comparable to conventional molds in short-length single and multiple partial fixed dentures (PPF) in teeth and implants (Yang et al., 2015; Rudolph et al., 2016; Lee et al., 2017; de Oliveira et al., 2020), and this development allowed for a more efficient workflow in the clinical setting of Dentistry (Chiu et al., 2020).

De Oliveira et al. (2020) conducted a systematic review with meta-analysis to evaluate clinical parameters of single crowns on implants in which fingerprints and conventional printing were used. The use of the *scanner* showed better efficiency considering the clinical time and patient preference. The evaluation of the adjustment time of the prosthetic pieces showed different results, in which the digital flow varied between 1.96 and 14 minutes, while for the conventional one, it was between 3.02 and 12 minutes. Similarly, the studies included in the review by Afrashtehfar et al. (2022) indicated similar accuracy between the intraoral scanner and conventional impressions for fixed prostheses of less than 4 elements.

For 3-element PPF pillars, Ali's (2015) study shows that some of the different systems evaluated (iTero, USA and Lava C.O.S - 3M ESPE, Germany) did not have significant variation in accuracy compared to the scanning of models from the conventional technique using addition silicone. Other systems tested, however, were inferior to the impressions obtained by laboratory *scanner*. Regarding 4-element PPF, Guth et al. (2013) point out that intraoral scanning generated models with greater accuracy than molds produced by polyether impressions.

In the clinical study by Ender et al. (2016), the scanning of a quadrant had a similar level of accuracy to models produced from conventional molding with filler silicone. In addition, the accuracy of conventional impressions was lower in areas with greater detail, such as the occlusal surface. Thus, concluding that the scanning of single crowns and multiple prostheses, up to 4 elements, has comparable accuracy to conventional impressions.

4.2 FULL-ARC SCANNING

For full-arc scanning, four scanner systems *(Cerec Bluecam, Cerec Omnicam - Sirona, Germany, iTero and Lava C.O.S) were compared with molds made from filler silicone, polyether, alginate and laboratory scanner scanning*, the silicone *molds* showed higher accuracy. Alginate impressions produced molds with accuracy and precision comparable to Cerec Omnicam, iTero and Lava C.O.S, while Cerec Bluecam was more accurate. Molds using polyether suffered greater distortions, while silicone impressions scanned by laboratory *scanners* produced results inferior to conventional molds, but comparable to intraoral scanning systems (Ender and Mehl, 2015).

In a clinical study, Ender et al. (2016) compared the accuracy of intraoral *scanners* with conventional group scanners for full-arc scanning, similar to the previous study. All *scanners* were inferior to conventional impressions, except for alginate. The highest accuracy was obtained by mold and addition silicone printing performed by laboratory *scanner*, followed by polyether printing. The performance of the evaluated systems (Cerec Bluecam, Cerec Omnicam, iTero, Lava C.O.S, Lava True Definition, TRIOS and TRIOS Color) were similar, except for the Lava C.O.S which had lower accuracy.

The qualitative evaluation of the systematic review by Abduo and Elseyoufi (2018) revealed that different scanning techniques are associated with different distortion patterns. The most evident distortion pattern in totally edentulous rims was obtained in the most posterior region of the arch. The earlier segment had higher accuracy than the later segments for the scanner-generated digital models. The authors concluded that, in general, intraoral scanning systems are more vulnerable to distortions than conventional methods.

Another aspect to be considered in scanning, especially in fully edentulous arches, is the soft tissue ratio, depth of the palatal vault, and width of the arches. Gan et al. (2016), in an in vivo study comparing the influence of these factors on the veracity and accuracy of the scan, demonstrate that soft tissue fingerprints were better and without significant interference from the height of the palatal vault. However, there was an inversely proportional correlation between the width of the arch (narrow, medium and wide) and the accuracy of the intraoral scan, i.e., the greater the width of the arch, the lower the efficiency of the *scanner*.

In a review conducted by Afrashtehfar et al. (2022), the clinical recommendation based on the included studies is that for extensive permanent fixed prostheses (above 4 elements) or removable total dentures, the conventional approach is recommended over the use of intraoral scanning. However, they point out that more clinical trials are needed to determine the clinical efficacy of intraoral scanning for broader oral rehabilitations.

4.3 SUBSTRATE MORPHOLOGY AND SURFACE

Nedelcu et al. (2018) stated that scanning under conditions of subgingival preparations should be critically evaluated due to the technical limitations and variations of *scanner systems*. During these procedures, some clinical situations, such as the presence of saliva, limitation of mouth opening, and positioning of the teeth in the arch may contribute to the inaccuracy of the digital model, due to the difficulty of light reflection.

Park et al. (2018) evaluated the accuracy of the Identica Blue (MEDIT, Korea), TRIOS, and Carestream 3500 (Carestream Dental, USA) scanners in different intraoral environmental conditions such as temperature, relative humidity, and lighting. In the comparison between the *scanners*, the TRIOS had similar accuracy and reproducibility with the Identica Blue. Although there was a subtle difference in accuracy based on the type of *scanners*, no significant differences were shown in the different simulated environmental conditions and accuracy was maintained between the scanners used.

The systematic review with meta-analysis conducted by Hardan et al. (2023) investigated whether the accuracy of *intraoral scanners* is influenced by different scanning factors and conditions. The meta-analysis data demonstrated that fingerprint accuracy improved significantly in dry environments. In addition, precision and accuracy were improved when artificial landmarks were used and an S-shaped scanning pattern was followed. However, the type of light used did not have a significant impact on the accuracy of the equipment. Thus, aspects such as the use of landmarks and fingerprints in dry conditions could improve the accuracy of *intraoral* scanners.

Another aspect addressed in two clinical studies is the accuracy of *the scanners* being influenced by the morphology of the tooth. Acute angles and proximal areas negatively influenced the reproduction of details. On the other hand, the *laboratory scanner* was less affected by the location and morphology of the teeth. Filler silicone impressions showed minimal deviations, while alginate and polyether impressions had localized distortions (Flugge et al., 2013; Ender et al., 2016).

Carbajal Mejia et al. (2017) tested the accuracy of using the TRIOS scanner (3Shape, Denmark) compared to silicone addition molds in incisor samples prepared for single crowns and obtained favorable results for the use of intraoral scanning. However, Yang et al. (2015) highlight the sensitivity of the equipment in accurately capturing images in marginal areas, since intraoral *scanners* were more vulnerable to distortions than conventional impressions.

The study by Su and Sun (2015) points to another factor related to the preparation of anterior and posterior teeth, in which the scanning of molar preparations tended to be more accurate than that of incisors. Another study corroborated this finding, demonstrating that incisor preparations for single crowns had greater inaccuracy than molars, a fact attributed to the steeper surfaces of incisors compared to molars (Rudolph et al., 2016).

Carbajal Mejia et al. (2017) evaluated the effect of changing the occlusal angle of convergence of maxillary central incisor preparations. The intraoral scanner was efficient in accurately recording the prepared tooth, regardless of the angle, while the accuracy of the impression with addition silicone deteriorated at an angle of less than 8º. This result was attributed to the material's vulnerability to distortion and tearing in areas with great parallelism.

4.4 INTRAORAL SCANNING SYSTEMS

Nedelcu and Persson (2014) evaluated the accuracy of four *scanners* (Cerec Bluecam, Cerec Omnicam, iTero and E4D - D4D Technologies, USA) for scanning unit crowns and there was variation in the results, in which a similar accuracy was found for the Lava C.O.S, Cerec Bluecam and iTero systems, with the E4D scanner being inferior to the others.

For scanning 3-element PPF pillars, Ali (2015) observed differences in veracity between the different *scanners* (Cerec Bluecam, iTero, Lava C.O.S, and E4D). The most accurate systems were iTero and Lava C.O.S, and the lowest accuracy was reported for E4D followed by Cerec Bluecam. For scanning 4-unit PPF metal abutments, Guth et al. (2017) obtained the best accuracy associated with Lava True Definition (3M ESPE, Germany) followed by Carestream 3500, Cerec Bluecam, Cerec Omnicam, and ZFX intrascan (Zfx GmbH, Germany), respectively. In addition, the authors attributed the results to the positive effect of powder coating for metal scanning.

Uhm et al. (2017) evaluated the accuracy of four systems (Cerec Bluecam, Cerec Omnicam, TRIOS, and Carestream 3500) for 4-element PPF inlay and abutments. For *inlay* scanning, while all systems had similar accuracy, the TRIOS and Carestream 3500 had the highest accuracy. On the other hand, for 4-element PPF, Cerec Omnicam and Carestream 3500 performed the best in the accuracy of the images obtained.

In general, as mentioned earlier, there is a pattern of reduced accuracy as the scanning range increases. The result of Mehl et al. (2009) for the scanning of unitaries using Cerec Bluecam was more accurate than that of a quadrant. Similarly, Su and Sun (2015) using the TRIOS scanner reported that there was a reduction in scanning accuracy as the amplitude increased. The authors concluded that regardless of the system performed, the intraoral scanner has an acceptable accuracy if the scanning site is smaller than a hemiarch.

Wang et al. (2024) compared the accuracy of five *intraoral scanners* by a coordinate-based method in fully toothed and partially edentulous models. Control images were obtained using a laboratory *scanner* (Ceramill Map 600) and the intraoral scanners were TRIOS 3 (3Shape), Planmeca Emerald, iTero Element 5D, Medit i500 and Shining A Oralscan 3. For the fully toothed mold, Element 5D demonstrated the highest accuracy in most of the measured parameters. In the partially edentulous mold, Element 5D and Emerald exhibited higher accuracy in most of the measured parameters. In this way, the Element 5D scanner offered a high level of accuracy and was suitable for both situations.

Le Texier et al. (2024) conducted an in vitro study to evaluate the accuracy and precision of three *intraoral scanners* to scan a maxillary and mandibular total prosthesis. The purpose of this study was to test methods to facilitate duplication and replacement of total prostheses, since the stored file would allow its rapid replacement in case of loss, damage and need for repairs. For this, the total dentures were scanned with a flatbed scanner (D2000) to obtain the reference model and the *intraoral scanners* tested were TRIOS 4, Primescan and IS3800. The TRIOS 4 and Primescan showed comparable accuracy to the reference model, the latter having the lowest sagittal and transverse deformation. Although the equipment does not have the same precision, it has sufficient properties to perform the proposed procedure.

Another aspect described by Chiu et al. (2020) refers to the accuracy of scanning at the preparation margin of total crowns using different resolution parameters of an intraoral scanner (TRIOS 3, 3Shape). The authors observed significant differences in imaging between tooth surfaces, with the distal surface showing the largest discrepancies, and concluded that adjusting the *software* to a high-resolution mode, which obtains more data over a period of time, may not necessarily benefit the accuracy of the scan, while tooth preparation and surface parameters affect accuracy.

4.5 SCANNING TECHNIQUES

Ender and Mehl (2013) investigated the effect of different scanning strategies for Cerec Bluecam and Lava C.O.S. For Cerec Bluecam, the diagonal and rotational orientations of the *scanner* camera were superior to the occlusal orientation. For the Lava C.O.S., the accuracy was the same for occlusal, buccal and lingual orientation and rotational orientation around each tooth. However, direct guidance had superior accuracy.

Anh et al. (2016) evaluated different scan sequences for iTero and TRIOS. For each *scanner*, one scan sequence started on the right and the other sequence started on the left. Although the difference between the orientation sequences was statistically significant, in terms of precision, the difference was minimal, and the iTero showed greater sensitivity to sequence alterations.

The study by Muller et al. (2016) compared the veracity and accuracy of three scanning strategies for TRIOS: occlusal-buccal surface of the entire arch followed by the palatine surface, occlusal-palatine surface of the entire arch followed by the buccal surface, and alternation or rotation between the vestibular and palatal surface. The authors concluded that the second strategy had greater precision and accuracy. However, the significant difference was observed only for precision, and regardless of the strategy adopted, the more posterior region suffered greater distortion.

5 DISCUSSION

In unitary cases, the available evidence indicates similarity in the accuracy of intraoral scanning and addition silicone printing (Yang et al., 2015; Lee et al., 2017) and polyether printing (Rudolph et al., 2016). In impressions of PPF abutments, intraoral scanning is comparable to impressions using filler silicone and polyether (Guth et al., 2013; Ali, 2015). In cases of full-arc scanning, studies have consistently revealed the superiority of addition silicone printing over intraoral *scanners* (Ender and Mehl, 2013; Ender and Mehl, 2015; Ender et al., 2016). However, although statistical differences have been observed between the use of intraoral *scanners* and conventional impressions, the clinical significance of this difference in precision has not yet been determined.

The inaccuracy associated with intraoral scanning may be related to excessive reflection in the image capture processes, due to metallic restoration or excess saliva, or hard-to-reach areas, which can influence the quality and sharpness of the image (Kravitz et al., 2014; Nedelcu and Persson, 2014). Steep surfaces, acute angles, proximal areas, and subgingival margins often cause shading and are more likely to suffer greater discrepancies (Flugge et al., 2013; Rudolph et al., 2016; Ender et al., 2016).

Because scanning is not able to capture the entire arc with a single scan, multiple overlapping images must be taken and combined through an algorithm. As a consequence, each process may have additional discrepancies. Eventually, the error can be propagated to all processes (Flugge et al., 2013). This explains the observation of most of the included studies, in which the inaccuracy increases directly proportional to the measurement of the amplitude of the digitization (Ender and Mehl, 2013, 2015; Muller et al., 2016; Kuhr et al., 2016).

Conventional printing and laboratory scanning do not require numerous overlaps, unlike intraoral scanning; therefore, they can potentially be more accurate. In addition, each image taken from the laboratory scanner spans the entire arc, which means recording the entire dimension of the arc in each shot of the image (Su and Sun, 2015; Renne et al., 2017).

In the analysis of the efficiency of *intraoral scanners*, although all equipment is capable of generating virtual models of acceptable accuracy in certain applications, they share similar limitations. From the studies included in the review, no recommendation can be made as to which system has superiority. This difference can be attributed to the methodology of the studies, the operator's familiarity with the system, the learning curve associated with the use of these systems, and the ergonomic design and calibration of the *scanners* (Kim et al., 2016; Rudolph et al., 2016; Muller et al., 2016; Wang et al., 2024). Part of the differences in results may also be related to systems continually undergoing updates to improve performance.

For metal pillar scanning, some studies have indicated that systems using powder coating provided more accurate and consistent results on different substrates (Nedelcu and Persson, 2014; Guth et al., 2017). This is due to the increased reflection of light emitted by the scanned surface. On the other hand, the superiority of scanning over the use of powder has not been reported by several studies (Ali, 2015; Ender and Mehl, 2015; Renne et al., 2017; Lee et al., 2017). Therefore, the positive effect of applying the powder to the surface of the pillars does not seem to be clear.

The scan sequence and camera movement can influence the accuracy of the virtual model. Diagonal orientations or rotation of the *scanner* were found to be more accurate than occlusal orientation, which can be attributed to a greater record of overlapping areas and prominent features (Ender and Mehl, 2013; Muller et al., 2016). Therefore, from the limited evidence, it can be speculated that scanning accuracy can be improved by reducing the reliance on software stitching of multiple scanned images. This can be achieved by increasing the number of overlapping areas, recording the amplitude of the arch in the early stages of scanning, and starting at surfaces with more defined anatomical morphology.

5.1 CLINICAL RECOMMENDATIONS BASED ON THE FACTORS THAT CAN INFLUENCE THE EFFICIENCY OF INTRAORAL SCANNERS

The included studies revealed several factors that may influence the accuracy of intraoral scanning systems, such as length of the edentulous space, scanning sequence, and morphology of the scanned surface. While intraoral scanning can be safely used to acquire diagnostic models and for treatment planning purposes, some recommendations are necessary for performing final prosthetic rehabilitations.

According to the current level of evidence, scanning the maxillary and mandibular arches at maximum intercuspation yields more accurate rehabilitations. This recommendation is supported by clinical studies that indicate that 3- or 4-element prostheses made using fingerprints exhibit similar accuracy to prostheses made by conventional techniques (Guth et al., 2013; Ahrberg et al., 2016). For larger rehabilitations, in addition to accurately recording the tooth surface, the occlusal relationship must be recorded, which is made more difficult after the preparation of several teeth.

There is some evidence that smooth surfaces are easier to pick up by *scanners* compared to uneven and wavy surfaces (Flugge et al., 2013; Ender et al., 2016). Thus, the professional should pay attention to these recommendations in the process of preparing the teeth. In addition, areas of sudden change in curvature may suffer greater distortions (Rudolph et al., 2007). Therefore, it is recommended to avoid sharp angles, "boxes" and gutters.

One of the limitations often encountered in digital imaging systems is the accuracy of the marginal area (Yang et al., 2015). Studies indicate that the margins of the prosthesis are vulnerable to inaccuracy, and this can be attributed to the difficulty of virtually copying the margin of the preparation (Aboushelib et al., 2012). However, further studies are needed to provide recommendations to practitioners on the design of the preparation margin, saliva control, cost efficiency and clinical time, and long-term outcomes.

6 CONCLUSION

With the limitations of the review, it was possible to conclude that:

The accuracy of *intraoral scanners* is comparable to conventional impressions when used for diagnostic purposes and in cases of short-term scanning;

Smooth surfaces and dry environments produced scan results with greater accuracy;

The different intraoral *scanners* available on the market showed similar accuracy, however, there were limitations due to the lack of standardization of the evaluations.

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