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Evaluation of the accuracy of the optical scanners used in the modern dental practice

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Abstract. The aim of this study is to evaluate the accuracy of the laboratory optical scanning method used in modern dental practice in a CAD/CAM workflow. The assessment was made using the most common case in practice – tooth prepared for a metal-ceramic crown. An acrylic resin tooth was prepared for the metal-ceramic crown according to standard guidelines. The master matrix was scanned by an extraoral Ceramill Map 400 digital scanner. The scanned data of the prepared tooth was processed to an STL model and a digital copy was created. The same sample was measured by a high-precision contact coordinate measuring machine (CMM) and a second digital model was created. The two scans were aligned in one coordinate system and compared. Comparative analysis was used to evaluate the accuracy of the optical scanning method and the advantages and disadvantages of such equipment were highlighted. The conclusion was drawn that the comparative analysis with the results of contact CMM scanning is a very appropriate approach to validating the accuracy of the digital extraoral scanners, whose significance in the modern dental medical practice is expected to grow rapidly.

1. Introduction

CAD/CAM systems were borrowed by dentists from mechanical engineering; its use has become more and more popular in the recent decade. Producing digital impressions has many advantages over conventional impressions. It provides increased efficiency compared with the conventional one and is considered easier for less experienced clinicians. Further, the need is eliminated of the physical prosthetic's field copy and the accompanying possible technical mistakes, such as wrong choice of impression material, difference between impression material's shrinkage and casting material's expansion, air bubbles, movement of the tray and insufficient impression material. Fewer steps in transferring information to laboratory lead to faster and better results. All this results in the additional advantages of saving time and clinical hours and reducing the number of visits. This is why, digital impressions are increasingly becoming the most preferred and efficient technique used the field of dental prosthetics [1, 2].

Generally, dentists use intraoral or extraoral laboratory scanners. The digital impression can be taken by the dentist by a chairside scanner. On the other hand, when an extraoral laboratory scanner is considered, first a physical record of the tooth/teeth is needed. In that case, two possibilities arise, to

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scan the taken impression or to scan the stone cast made by the impression. Laboratory scanners' usage has more indications than the chairside scanners [3]. Many studies concerning the accuracy of different scanners have been conducted, most of them focusing on the intraoral scanning devices' accuracy and precision, because they totally eliminate the need of physical impression. Nedelcu et al. found that intraoral scanners are sufficiently precise to replace the conventional impressions [4]. According to Vogtlin et al., the digital impressions have sufficient accuracy, but have some limitations when it comes to the prosthetic's field size [5].

Intraoral scanners are preferred by many dentists, although their usage is still limited. Due to additional factors as the saliva, patient movements, blood, prosthetic field's size [6], those devices are used for smaller restorations.

With the extraoral laboratory scanners, these disadvantages could be avoided. According to some studies, intraoral and extraoral scanners show similar authenticity [7]. Laboratory scanning is more precise and accurate than the intraoral one because of the lack of patient-related factors influencing the scanning process. [8] In some studies, the result achieved with laboratory scanners are used as a reference to explore and compare the accuracy and precision of the different intraoral scanners [4]. However, the laboratory scanner's accuracy needs to be evaluated and confirmed in order to assess the applicability of the equipment.

The stationary laser-equipped scanners are the most frequently employed ones. The leading approaches to scanning methods make use of conoscopic holography and a structured laser beam. Scanners are easy to operate, with an average scan time of about a minute. Their accuracy is in the order of 10 – 20 μm [9].

Contact scanners are suitable to evaluating the result achieved with the optical scanners as reported in [5, 10]. Coordinate measuring machines (CMM) are more accurate than optical scanners but they are time-consuming and require the subject to be placed on a precise flat surface and must touch the object during the examination by means of a contact probe [9].

The aim of this study is to evaluate the accuracy of the laboratory optical scanning method as used in modern dental practice in CAD/CAM workflow.

2. Method and material

On a plastic model, the lower first left molar was prepared for a standard metal-ceramic crown. The marginal design is prepared at the gingiva's level with a rounded shoulder according to Marxcors with 0.6 mm NTI-Kahla GmbH (Germany) rotary tools were used.

For the proximal surfaces, a diamond bur with a diameter of 0.12 mm (blue coding) and a conically shaped active tip was used, and for the occlusal surface, a cylindrical bur with a diameter of 0.16 mm (blue coding) with a slightly rounded tip. The prepared tooth was smoothed with diamond burs with the same diameter and red coding. Thus, the tooth abutment had the following characteristics: marginal design at the level of the gum, with a rounded 0.6-mm-wide shoulder; proximal surfaces converging in occlusal direction with a slope of 5 degrees (figure 1 and figure 2).

Figure 1. Frontal view of the model.

Figure 2. Occlusal view of the model.

The model was scanned by a Ceramill map 400 extraoral digital scanner with an accuracy of 20 μm.

The data from the scanning is processed to an STL model and a digital copy was created (figure 3 and figure 4).

At the next stage, the same physical model was scanned with contact coordinate measuring machine (CMM) - Hexagon metrology (Optiv Performance 664). It is a 3D-multi-sensor coordinate

measuring machine which combines optical and tactile measurement in one system. The tactile sensor has a spherical head with a diameter of 0.6 mm and working table with size of 664 mm×664 mm. The device has compact 6-way touch-trigger probe with an accuracy of ±1.00 μm.

The prepared acrylic resin tooth was fixed on the working table where the machine was calibrated. The probe touched to different places on the model's surface. Based on this data, a second digital model was created. Finally, the two digital models were compared.

Figure 3. The physical model placed in the laboratory scanner.

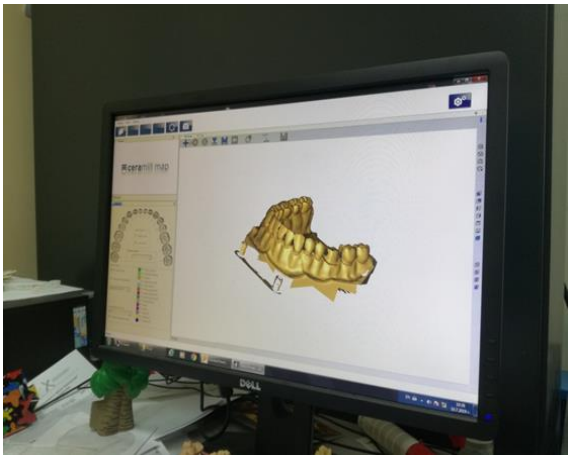

Figure 4. Digital copy of the model.

3. Results

Special software was used to compare the digital copies. The first one, created based on the data obtained by digital scanning with an accuracy of ±20 μm, and the second one, produced by the CMM with an accuracy of ±1.00 μm, the latter being used as a reference because of the device's high accuracy. The digital scanner's image was aligned with the previous one in the same coordinate system. Both copies were compared as to marginal design and proximal and occlusal surfaces (table 1).

The comparison revealed a deviation of less than 8 μm, which is acceptable, as a high level of surface overlap between the two digital models was achieved.

Table 1. Scanner`s accuracy measured for different surfaces.

	CMM accuracy (μm)	Extraoral scanner deviation (μm)*
Vestibular surface	1.00	>8
Lingual surface	1.00	>8
Mesial surface	1.00	>8
Distal surface	1.00	>8
Occlusal surface	1.00	>8

* The software cannot detect deviations of less than 8 μm.

4. Discussion

CAD/CAM systems are being used in modern dentistry uses on a daily basis. Extraoral laboratory optical scanners are used as a gold standard to reproduce the prosthetic field, although some authors find no significant difference between the results achieved with intra- and extraoral scanners [7]. Nowadays, laboratory scanners are considered as most accurate and faster to create digital copy needed for next stages of the CAD/CAM workflow. However, the risk of mistakes due to the impression material, for example, is yet to be avoided. Villaumbrosia et al. [10] compared the trueness

and precision of six extraoral scanners. According to their study all extraoral CAD/CAM scanners were clinically acceptable but statistically significant differences between some of the extraoral scanners were found. They found that the scanning is more accurate when the scanned surface is smooth and regular. Another study noted the importance of the scanned region's exact location (occlusal surface, cervical region) [7]. All these differences could be explained by the way the light is refracted, by the used technology or the method to scan the objects.

Contact scanners are not affected by the light and the type of material which the scanned object is made of. Being most precise technology, the CMM can be used to validate the optical scanners' data. However, CMM is a slower and more expensive technology and therefore, not suitable for daily workflow. The results obtained in this study show that optical scanners are accurate enough to be used in practice as a faster and less expensive method for obtaining a digital impression from a prosthetic field.

5. Conclusions

Based on the results of this study the following conclusions were made:

- The laboratory optical scanning method is sufficiently accurate to be used in the modern dental practice without a risk of significant deviation that could compromise the final CAD/CAM product.
- The CMM can be used as a method to check and verify the dental optical scanner's accuracy because its accuracy is higher and it makes use of specific technology that is not affected by the optical and structural characteristics of the scanned object.

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