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Intraoral scanner accuracy: The influence of manual movement?

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ABSTRACT

Aim To determine the variable caused by human error during scanning to a fixed scanning distance over the dental arch using a robotic arm.
Materials and methods For this *in vitro* study three different groups were investigated: The investigation Group (IG) using an intraoral scanner mounted to a robotic arm, the clinical group (CG) using an experienced dental investigator and the control group (C) using a dental laboratory scanner. All scans were stored in .stl formats for further analysis. Comparison of the different scans were statistically analysed using Finale Surface Software.
Results By comparing it via best match all scans could be compared. The highest precision could be achieved using the dental laboratory scanner in control group (C). The largest deviation of accuracy distribution could be measured in the clinical group (CG).
Conclusion With the highest mean deviation in the scanning process measured by the clinical group, the distance between the scanning tip and the teeth as well as the scanning path plays a major role in the outcome accuracy of the STL model.

KEYWORDS Intraoral scanner; Trueness; Precision; Digital; Impression.

INTRODUCTION

Digital dentistry is evolving rapidly during the last two decades. This brings out new digital workflow abilities. Among others the use of intraoral scanners instead of conventional impressions are improving in speed and quality. This is due to the fact, that actual intraoral scanners do not only scan the tooth surface. As the color scan, digital dynamic evaluation, checking for saliva on the preparation line and eliminating it automatically during the digital modelling, is software related and today the clinical benefit becomes even more obvious. Using intraoral scanners, milling and restoring a tooth in a single visit is possible in dental practice (1). Furthermore, caries detection is already available in various intraoral scanners (2). With the rapid technical development, the scanning speed has increased as well. Scanners can be updated quickly via their inbuilt internet connection and can be updated online.
With the first prosthetic restoration milled on the base of a digital intraoral impression in 1985 enormous development happened in this field. While in 2012 the first version of "Bluecam" (Dentsply Sirona GmbH; Bensheim, Germany) was merely able to take single pictures of the area and digitally overlap these, the newest version of the "Primescan" (Dentsply Sirona GmbH; Bensheim, Germany) coming to the market in 2019 takes video shots scanning the area in movement. With the use of modern graphic cards additional to the cpu, digital impressions are faster than the conventional impression techniques measured by time for taking silicon or alginate impression (3). Furthermore, sending the digital models to the dental laboratory instead of manual transportation of impression spoons takes less time and logistics: As impression materials such as alginate undergoes shrinking when water is withdrawn or billows if too much water is added. Silicon impression need a specific postponement before pouring it out with a casting material. Nowadays the overall accuracy of intraoral scanners matches the one of conventional impression taking (4). The patient acceptance is higher with the usage of intraoral scanners rather than the classic bulky impression materials. Studies on this indicate that the patients tend to favor digital impressions over conventional ones (5).
Implementation to the new workflow needs some

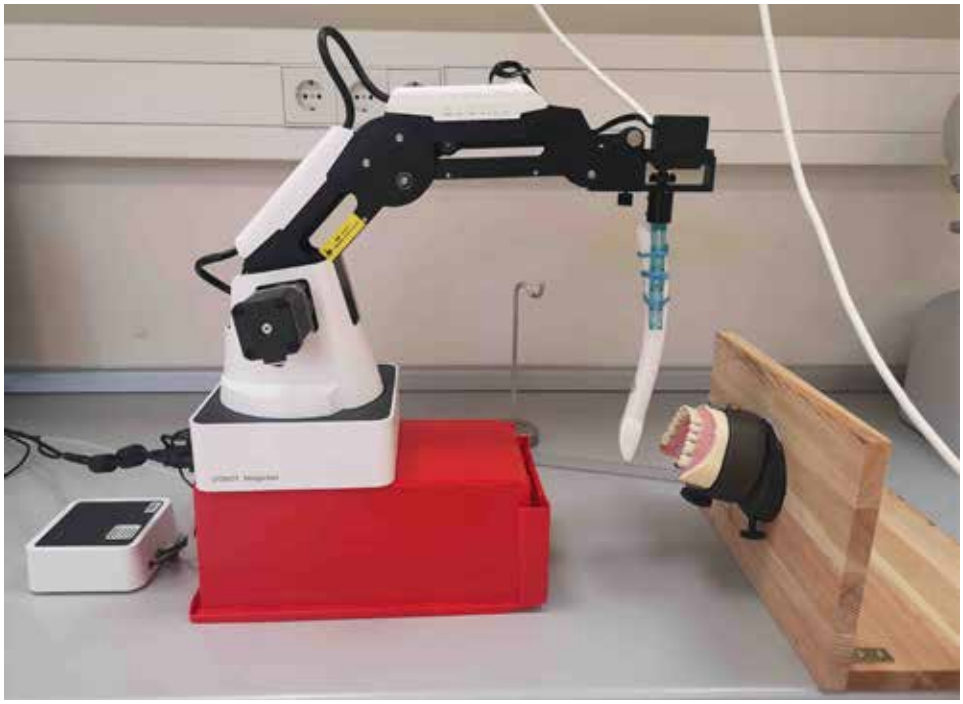

FIG. 1 Following the predetermined path the model has been automatically scanned using the robotic arm for reproducible outcome.

adjustment in the daily practice. The software and the scanning also need training to be mastered. According to the literature there is no scientific consensus about the scanning pathway for all scanners. Some manufacturers suggest different ways to approach the scan field, but the choice of the pathway rests on the shoulders of the dentist (6).

Regardless of the scanning pathway the accuracy of the scanners is well elaborated. Michalinakis et. al investigated the accuracy of three different intraoral scanners (7). The average scan accuracy for a full arch scan ranged below 100 µm and there was no significant difference in the trueness by polyether impressions (7). On the other hand, the accuracy of intraoral scanners differs strongly in literature. Even for the same intraoral scanner device different preciseness was found. This effect was not yet investigated in depth. One possible explanation was assumed to be focus on the distance between lens and teeth. Others proposed the effect of the scanning pathway as a possible explanation. The scanner which is held by a human hand always moves up and down as well as sideways slightly by the distance between the teeth and the scanner. With this movement, even unwanted, a possible variable is added to the scanning accuracy.

The aim of this study is to evaluate the role of the changing distance between the scanner and the scanned area.

MATERIALS AND METHODS

For this *in vitro* study three different groups were investigated. The first group is the investigation group (IG). The second group is the clinical group (CG). The third group is the control group (C).

For IG analysis the intraoral scanner was safely mounted to a robotic arm (DOBOT Magician) (Fig. 1). The arm has a position reproducibility of maximal deviation with 0.2 mm. It was programmed to take the same way every time with the intraoral scanner mounted to it. It was programmed to scan the whole dental arch optimally due to the manufacturer recommendations in way and distance to the tooth.

CG represents the clinical group. The scanner is used in its clinically designed way. An experienced dental investigator scans the model repetitively for 12 times. If a scanning interruption occurs the last recognizable position of the model is used as restarting point. The investigator was blinded for the study.

The model was additionally scanned by a dental laboratory scanner (3Shape D800, Copenhavn, Denmark) for controls (group C). The scanner has an accuracy of 8-12 µm (as per manufacturer's instructions). For the scanning the model was mounted on a base plate and optically scanned on a motor driven table. The model was scanned 12 times (Fig. 2).

All data from the scanner were stored as .stl files for further analysis.

For the scanning investigation a model was manufactured. This contained extracted teeth assembled to simulate a full dental arch. Teeth 16, 21 and 27 had sufficient amalgam restorations. Composite restorations can be found on teeth 11 and 12. Three implant abutments were incorporated. For a more clinical simulation a gingiva mask was added. On teeth 17, 21 and 27 an implant measuring metal

FIG. 2 Model specimen used in the present study.

ball is added for higher precision on three different points. The model was stored in a humid environment to prevent drying out.
The STL's are now compared. The differences are statistically analysed. Every model of the IG-Group is digitally overlayed and compared to the master model. The maximum deviation from the three fixed points on the model from the IG-Group to C-Group are measured. Additional medium deviation from models of IG- to C-Group is measured. The same analysis is done for CG-and C-Group. The digital overlaying was performed by Final Surface. The statistical results were evaluated by using Sigma Plot and Excel.

RESULTS

All 12 scans from the different groups could be used and matched using Final Surface Software (Final Surface ©-3D Software, Berlin, Germany). As matching method best fit with regards to the maximum deviation on the models were applied. Due to the different scanning methods of the dental laboratory scanner and the intraoral scanner, a lower accuracy was predicted for the scans by the intraoral scanner. This is confirmed by the resulting data.
The highest precision could be achieved using the dental laboratory scanner in the control group (C). The accuracy had the lowest deviation of the three groups. The deviation ranged from a minimum of 10 µm to a maximum of 26 µm. Group C had the lowest deviation in values.
The results of the control group show the lowest mean deviation compared to robotic arm, or the clinical group. The largest deviation of accuracy distribution could be measured in the clinical group (CG).
The deviation ranged from a minimum of 40 µm to a maximum of 70 µm.

DISCUSSION

This study investigated the impact of precision of dental scanners *in vitro* using three groups. A significant difference between the first two groups, the robotic arm and the scans by hand can be found.
In vitro testing is always designed without any limitations to the handling or reduced scan accuracy due to movement or challenging environment of the intraoral situation. Clinical factors that influence the outcome such as saliva, blood, the tongue or any other anatomic structures were eliminated. *In vitro* testing can show optimal results because of the optimum scenario provided for the study design and missing handling limitations (8).
As errors below a maximum of 0.2 mm for complete dentures have been reported to be clinically acceptable, errors of 0.3 mm or more can be clinically relevant (9). For single teeth and fixed prosthetic restorations the clinical acceptance is lower, with a maximum overall deviation of 120 µm (10). In this study the average scan accuracy by the robotic arm ranged by 10-26 µm. By handheld usage the scan accuracy was significantly lower with a maximum deviation of 27 µm-67 µm. As the scanning accuracy is only one factor of the overall accuracy, there is no definite number for the scanning accuracy available in literature. The overall accuracy is depending on other factors such as, for example, the production process of the fixed restoration and the finishing procedures. Nonetheless, higher accuracy and reproducibility lead to a more accurate fitting of the fixed prosthetic restorations and helps to reduce treatment time as no more adaptions are necessary.
The lowest deviation of the model was detected for the laboratory scanner. Without any disturbance of light, with a fixed mounted scanning lens and same distance to the scanned object a higher reproducibility can be achieved. With intraoral scanning accuracy increase, the clinical outcome of impression taking or scanning is becoming equally acceptable (11).
For analysing the total accuracy and comparing the scanning results, the mean deviation in superimposition was used to calculate the precision of the models. With the model in the dental laboratory scanner always scanning in the same position and scan path the superimposition for overall trueness had the highest overall precision with least deviation. The mean deviation for the handheld scanner was compromised due to the superimposition. Each model was aligned by mean deviation, therefore the overall precision is dependent on the mean deviation.
In the study from Michelinakis et al. (7) it was shown that the scan accuracy of three intraoral scanners ranged from 15,8 µm up to 56,5 µm with the most precise one. This value can be confirmed for our CG group during testing, which had a standard deviation of 27 µm-67 µm. With the better outcomes with a

fixed scan path with the robotic arm it is strongly indicated that the height variation *in vitro*, and therefore *in vivo*, can influence the scanning result. As the robotic arm was programmed to move in the optimal distance and optimal scanning path, it can be concluded, that the deviations made by hand has a significant influence on reproducibility. Thus the software should be adapted to the human "error" while using the intraoral scanner.
Further investigations are necessary to prove these findings *in vivo* to confirm the outcome.

CONCLUSION

With the highest mean deviation in the scanning process measured by the clinical group, the distance between the scanning tip and the teeth as well as the scanning path plays a major role in the outcome accuracy of the STL model. This human error can't be eliminated but significantly impacts the result.

Conflict of interest
There is no conflict of interest.

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