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TITLE

Precision of guided scanning procedures for full-arch digital impressions in-vivo

RUNNING TITLE

Precision guided scanning

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ABSTRACT

Purpose: System-specific scanning strategies have been shown to influence the accuracy of full-arch digital impressions. Special guided scanning procedures have been implemented for specific intraoral scanning systems with special regard to the digital orthodontic workflow. The aim of this study was to evaluate the precision of guided scanning procedures compared to conventional impression techniques in-vivo.

Method: Two intraoral scanning systems with implemented full-arch guided scanning procedures (Cerec Omnicam Ortho; Ormco Lythos) were included along with one conventional impression technique with irreversible hydrocolloid material (Alginate). Full-arch impressions were taken three times each from five participants (n = 15). Impressions were then compared within the test groups using a point-to-surface distance method after best-fit model matching (OraCheck). Precision was calculated using the (90%-10%)/2 quantiles and statistical analysis with one-way repeated measures ANOVA and post-hoc Bonferroni test was performed.

Results: The conventional impression technique with Alginate showed the lowest precision for full-arch impressions with 162.2 ± 71.3 µm. Both guided scanning procedures performed statistically significantly better than the conventional impression technique ($p < 0.05$). Mean values for group Cerec Omnicam Ortho were 74.5 ± 39.2 µm and for group Ormco Lythos 91.4 ± 48.8 µm.

Conclusions: The in-vivo precision of guided scanning procedures exceeds conventional impression techniques with the irreversible hydrocolloid material Alginate. Guided scanning procedures may be highly promising for clinical applications, especially for digital orthodontic workflows.

INTRODUCTION

Taking digital impressions with intraoral scanning systems is a rapidly advancing technology allowing the direct three-dimensional rendering of the dental arch [1-2]. Compared to conventional impression techniques, digital impressions may be advantageous as they do not consist of many different steps including the fabrication of a plaster model. Each single step of the conventional workflow bears the possibility of errors resulting in inaccurate models [17]. Several advantages, such as time efficiency and direct model analysis have been designated for taking digital impressions [16-17]. To compete with the conventional method, digital impressions have to be as accurate as conventional impressions. Several studies are available addressing the accuracy of intraoral scanning procedures compared to conventional impressions [5,6,13,15]. Only a few studies are available regarding the accuracy of digital impressions in-vivo [4,9]. According to ISO 5725-1 standardization, accuracy is characterized by the terms trueness and precision [8]. Trueness can be described as the deviation from the original surface geometry. Precision means the deviation between multiple impressions within a test group.

In contrast to conventional methods, the acquisition of larger areas is more challenging for digital impressions because of patient-specific factors. Software algorithm processes are more complex for large data acquisitions. To obtain a highly accurate model, an ideal matching of single images is required for intraoral scanning systems. In literature, intraoral scanning devices have been shown to perform more accurately for smaller areas such as quadrants [4,9]. The main indication for orthodontic issues is the full-arch impression [12]. Elastomeric impression materials, mainly irreversible hydrocolloid materials, are reported to be the standard material for conventional impressions [3].

System specific scanning strategies have been shown to influence the accuracy of full-arch digital impressions [7]. For some intraoral scanning systems, specific scanning protocols have been developed and implemented into the scanning software in the form of guided scanning procedures. This means that that the user is instructed how to wield the intraoral scanner properly throughout the whole scanning process. Yet, no study is available that refers to the accuracy of guided scanning procedures.

The aim of this study was to evaluate the precision of digital impression systems with implemented guided scanning procedures in comparison with conventional impression techniques in-vivo. The null hypothesis was that there are no significant differences between the precision of digital guided scanning procedures and conventional impression methods.

MATERIALS AND METHODS

Three different methods for obtaining full-arch impressions were investigated in this study. The intraoral scanning systems Cerec Omnicam with software Cerec Ortho v1.1 (group CO) (Dentsply Sirona) and Lythos (Ormco) were selected for the evaluation of digital impressions. Both scanning systems had implemented full-arch guided scanning procedures. Conventional impressions were taken with irreversible hydrocolloid material alginate (Blueprint Cremix; Dentsply Sirona). For each group five test persons with complete natural dentition were included. Informed written consent was obtained from all test persons. The maxillary or mandibular arch was randomly selected via a coin toss for each test person to not risk the accusation of having selected only the part of the jaw that might have been scanned easier. Each impression method was repeated three times. A total of six intraoral scans (group OC and OL) and three conventional impressions (group AL) were performed for each test person. Each test group was composed of three maxillary and two mandibular full arch impressions respectively scans. The aim of this study was to determine the in-vivo precision of impressions by comparing the STL data files for each impression method within the test group. Procedures for obtaining the STL data files varied among the groups.

For groups CO and OL, intraoral digital impressions were taken with respect to the guided scanning protocol given by the manufacturer's instructions by the same individual well-experienced dentist. In both protocols, two quadrant scans in the form of three (group CO) or two (group OL) streaks were performed with overlapping scans of the anterior area for superimposing. The scan data was either directly exported as a STL data file (group CO) or could be extracted from a communication portal after post processing (group OL). In group AL, standard metal stock trays with perforation (ASA Permalock; ASA Dental) were used for the conventional impressions. The size of the tray was selected by ensuring that enough space was left between the impression material and the dental arch. Monophasic impressions were taken according to the manufacturer´s instructions. Impressions were disinfected for ten minutes (Impresept; 3M ESPE) and immediately poured with type IV gypsum (Cam-Base; Dentona AG). Trays were removed after 40 minutes and stone models were stored for 48 hours at room temperature and ambient humidity. Models were scanned with a highly precise laboratory scanner (Infinite Focus; Alicona Imaging)(trueness of ± 5.2 µm and precision of ± 2.5 µm) and scan data was directly exported as STL data file for further analysis.

Difference analysis of each two STL data files was performed within a test group by a matching process. As three impressions were available per patient in a test group, three matching procedures could be made for each impression. Difference analysis was performed according to a yet standardized protocol with special difference analysis software (OraCheck; Cyfex) [5,8,14]. First, the initial STL file of the full-arch was trimmed to all dental hard tissues and 1mm of attached gingiva. Second, superimposing of two STL files was done with the OraCheck software´s best-fit algorithm. Difference analysis was performed by calculation of distances from each surface point of the first data file to the surface of the second data file. Depending on the resolution of the STL data mesh, up to 90.000 distances per match could be analyzed. The calculated distances were saved as a CSV file and imported into statistical software (SPSS 22; IBM Statistics). For each STL match, 10% and 90% percentiles were calculated. The (90% - 10%)/2 percentile was used as the metrical value for the overall deviation. Determination of normal distribution was performed using a Kolmogorov-Smirnoff test. Statistical evaluation of deviation values was done with one-way ANOVA and post-hoc Scheffé test ($p < 0.05$). For each match, screenshots were made in order to visually analyze the deviation patterns by color-coded superimposition images.

RESULTS

Results for the precision of all test groups for obtaining full arch-impressions are shown in **Table 1**. Boxplots are shown in **Figure 1**. The (90% - 10%)/2 percentile values were normally distributed. According to one-way repeated measures ANOVA and post-hoc Bonferroni test, the deviation values for group AL were statistically significantly different from group CO ($p = 0.009$) and group OL ($p = 0.035$). No statistically significant difference was found between the groups CO and OL ($p = 0.572$). Group AL showed the lowest precision for obtaining full-arch impressions with 162.2 ± 65.8 µm. Group CO showed the highest precision with 74.5 ± 39.2 µm. For all test groups, values for standard deviation were relatively high with the highest values found for group AL (± 71.3 µm). The highest maximum deviation value was also found for group AL with 337.1 µm. The null hypothesis that there are no significant differences between the precision of digital guided scanning procedures and conventional impression methods had to be rejected.

For each matching process, visual analysis was performed as deviations could be visualized with the OraCheck software by a specific color-coded scheme. Typical images for the visual analysis of superimposed impressions for each test group are shown in **Figure 2**. The deviation pattern for digital impressions in group CO and OL shows most deviations at one distal end of the dental arch. Minor deviations are also visible in the anterior region. In contrast, the deviation pattern for the conventional impression showed irregular local deviations at specific regions. Deviations did not increase towards the distal arch, thus meaning that local errors were more prevalent for conventional impressions.

DISCUSSION

The aim of this study was to evaluate the precision of guided scanning procedures compared to conventional impression techniques in-vivo. Based on the results of this study, the null hypothesis that there are no significant differences between digital guided scanning procedures and conventional methods had to be rejected.

Both digital impression methods with implemented full-arch guided scanning procedures performed statistically significantly better than the conventional impression technique using irreversible hydrocolloid alginate material. The conventional impression technique with alginate showed the lowest precision for full-arch impressions with 162.2 ± 71.3 µm. The in-vivo precision for obtaining full arch impressions with digital impression methods was 74.5 ± 39.2 µm for group Cerec Omnicam and 91.4 ± 48.8 µm for group Ormco Lythos. All digital systems showed relatively high standard deviations for the precision values. There may be several reasons for this fact. First, the acquisition of steep surfaces is challenging for many intraoral scanning systems and thus a possible reason for STL data file errors. For the final digital impression, several single images had to be stitched together based on overlapping areas. If a local error occurred, perhaps as a result of non-proper scanning, these errors continued along the residual areas to be scanned. The larger the scanned areas, the more susceptible to scanning errors the intraoral scanning system performs. This observation is in agreement with recently published literature referring to the accuracy for obtaining digital quadrant and full-arch impressions [4,9,14]. The deviation pattern observed for both digital impression systems in this study was similar to what has been described in the literature [4,9]. The tendency of distortion of the dental arch towards the distal end could also be observed. In particular, the anterior region with few textural information and many steep surfaces may be a reason for non-proper stitching of single images leading to inaccurate digital impressions. The maximum values for the in-vivo precision of obtaining full-arch impressions were found for the irreversible hydrocolloid material with up to 337.1 µm. Compared to the digital impression methods with guided-scanning, the deviation pattern was different as more local deviations could be observed. These deviations may be caused by internal tearing of the material. Especially during the removal of the trays, high forces are applied and there may be compression and stretching within the material. Interproximal areas are susceptible to be torn out, as the irreversible hydrocolloid material ensures too little resistance. Another reason for the values found in this study may be the material itself. There are several studies available showing contradictory results for irreversible hydrocolloids [3,10,11].

The fact that alginate was selected as the only representative for irreversible hydrocolloid materials is a limitation of this study. This type of material was selected due to its widely use, especially in orthodontics. Alginate is reported to be the material preferred for several orthodontic indications [3]. However, alginate is not the most precise impression material available for conventional impressions. Therefore, it may be interesting to compare the results of this study with other highly precise impression materials such as polyether or vinylsiloxanether. In a previous study using an identical protocol of data analysis, the precision of gypsum models derived from conventional in-vivo impressions with monophasic polyether was determined to be 17.7 ± 6.1 µm [6]. The precision of alginate material for obtaining full-arch impressions was almost ten times worse with a precision found to be 162.2 ± 71.3 µm in this study. Even if alginate may not be the most precise impression material available, there are several advantages such as time efficiency and simple clinical handling arguing for its wide clinical use.

This study represents a clinical in-vivo study. Regarding the evaluation of accuracy of digital impression systems, in-vivo results may significantly differ from results obtained in-vitro. The clinical application of intraoral scanning systems may be aggravated and the accuracy of obtaining full-arch digital impressions may be significantly worsened by non-proper handling. There is a flat learning curve for obtaining full-arch scans intraorally which is why guided-scanning procedures aim to facilitate the scanning process. There are studies reporting that the clinical use of intraoral scanner is aggravated because of several patient specific factors such as patient movement and limited space [4,5]. Additional more common factors such as saliva or soft tissue management may alter the results for the accuracy of digital impressions in-vivo. Results published for the in-vitro accuracy of digital impression have to be evaluated regarding this aspect.

In this study only patients with complete natural dentitions were included. It is important to state that for orthodontic issues, patients with malocclusion and mal positioning of teeth are usually subject to impression taking. For all intraoral scanning systems data capturing of unstructured surfaces such as gingiva may be subject for some kind of scanning inaccuracies. Single images have to matched to obtain the final 3D model. For these special cases slightly dusting of the light reflecting unstructured gingiva tissue is often helpful. To the knowledge of the authors, no studies are available reporting from scanning inaccuracies as a result of mal positioning of teeth. For these cases it is important to first scan the entire full arch according to the respective scanning strategy and to wield the intraoral scanner to scan missing surfaces difficult to reach only at the end of the scanning process.

To the knowledge of the authors, this is the first study focusing on the accuracy of guided-scanning procedures for obtaining full-arch digital impressions in-vivo. Guided-scanning procedures aim to facilitate the process for taking digital impressions as the user is directly instructed by the software to wield the intraoral scanner along an ideal scan path. System specific scanning strategies have been shown to significantly influence the accuracy of full-arch digital impressions [7]. Matching of single images needs to be perfect to ensure highly accurate digital impressions. For these reasons, intraoral scanners perform more accurately for small areas compared to larger areas. The proper scanning strategy is consequently highly relevant for larger areas such as full-arch scans. It would be interesting to compare guided-scanning procedures to the commonly used non-guided procedures for obtaining digital impressions. For the intraoral scanner Cerec Omnicam used in this study, a software allowing non-guided scanning is available (Cerec Software v4.x). The in-vivo precision for obtaining full-arch impression in-vivo with this software has been reported to be 48.6 ± 11.6 µm [4]. For the group CO using a guided scanning procedure, the in-vivo precision in this study was found to be 74.5 ± 39.2 µm. The same hardware of the intraoral scanning system given, guided scanning procedures may not perform identically to non-guided procedures for obtaining full-arch scans. The reason for this may be that different algorithms and different scanning paths are applied in the Cerec Software v4.x for obtaining full-arch impressions.

In this study, statistical analysis was based on the calculation of quantiles instead of using maximum and minimum values for difference analysis. When comparing complex 3D surfaces, several aspects such as different surface resolutions of 3D models have to be taken into account. The generation of 3D surfaces e.g. by the scanning systems used in this study is done using the STL data file format. In general, the size of the STL triangle is different between different intraoral scanning systems and because of STL´s foundation on data density even multiple scans with the same system show a different surface resolution of the 3D model. Reasons for this phenomenon are such specific factors as handling and different software algorithms used for the surface digitalization. This will lead to different STL triangle resolution at the same surface and has to be taken into account for the statistical interpretation of results.

Interestingly, longtime after this study had been finished, the Ormco Lythos scanner has been pulled off the market. However, a dental version of the scanner based on the same data capturing principle but with color representation and without the guided-scanning procedure had been presented and announced to be sold to general dental practitioners by KaVo company some time ago. Despite this announcement, this product was never introduced to the market. Instead, KaVo company is now focusing on the development of a new scanner being part of a complete digital CAD/CAM workflow. The Ormco Lythos scanner has been the first scanner with a specifically integrated guided-scanning workflow. As previously described, guided-scanning procedures are highly advantageous for scanning larger areas. The integration of those mainly software based principles could thus be expected to be integrated in workflows for other intraoral scanning systems in future.

CONLUSION

Within the limits of this study, the in-vivo precision of guided scanning procedures exceeds conventional impression techniques with irreversible hydrocolloid material Alginate. Guided scanning procedures may be highly promising for clinical application, especially for digital orthodontic workflows.

Table 1: Results for the precision of digital impressions obtained with Cerec Ortho (CO), Ormco Lythos (OL) and conventional impressions with Alginate (AL) (µm), statistically significant differences for CO-AL ($p = 0.009$), OL-AL ($p = 0.035$) (one-way repeated measures ANOVA and post-hoc Bonferroni test, $p < 0.05$)

						95 % confidence intervall	
group	**n**	**mean**	**SD**	**Min**	**Max**	**lower**	**upper**
CO	15	74.5	39.2	35.1	178.2	52.8	96.2
OL	15	91.4	48.8	45.4	202.4	64.4	118.4
AL	15	162.2	71.3	84.1	337.1	122.7	201.7

Figure 1: Boxplot for precision of digital impressions obtained with Cerec Ortho (CO), Ormco Lythos (OL) and conventional impressions with Alginate (AL) (µm); circles and asterisk represent outliers and extreme values; boxplot illustration is represented with the median

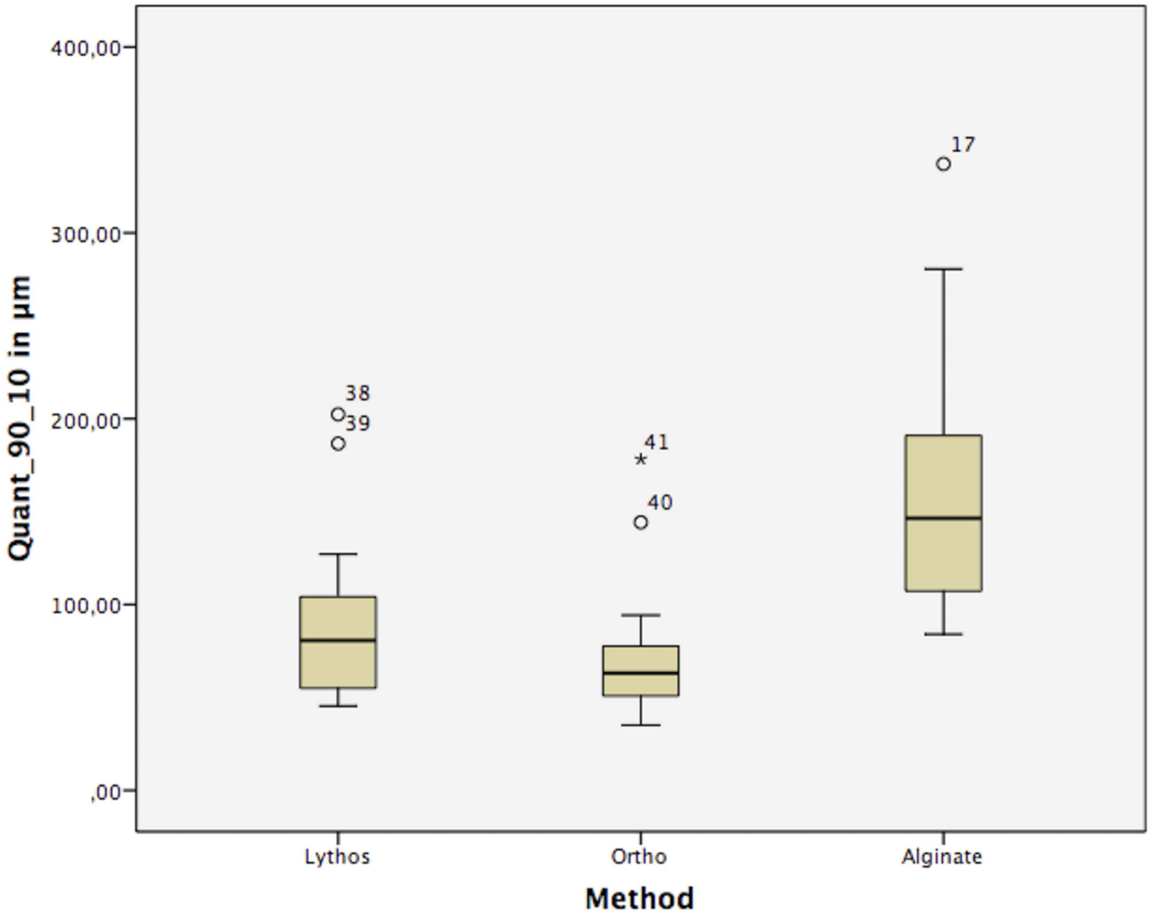
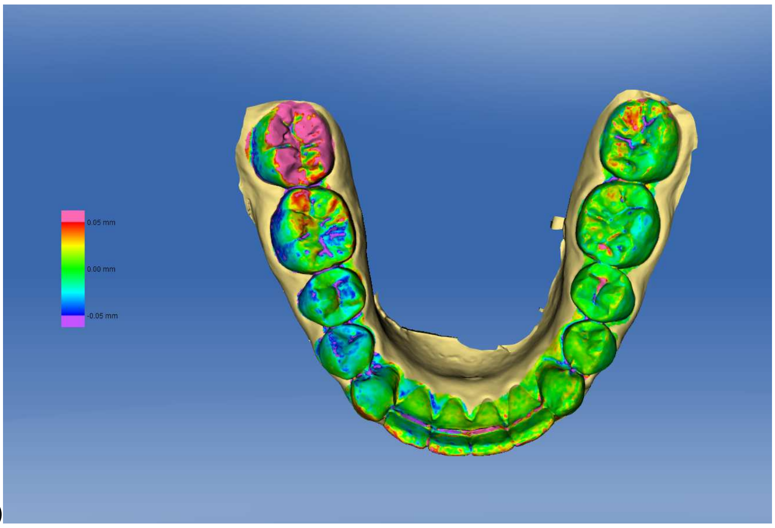
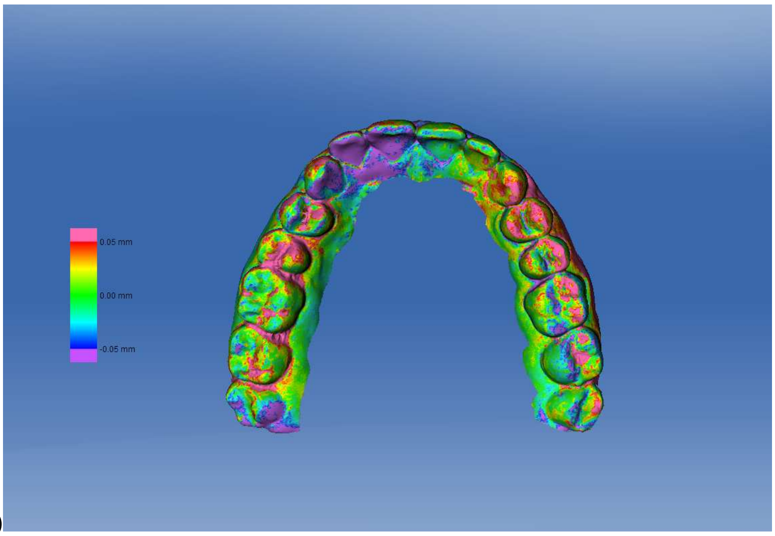


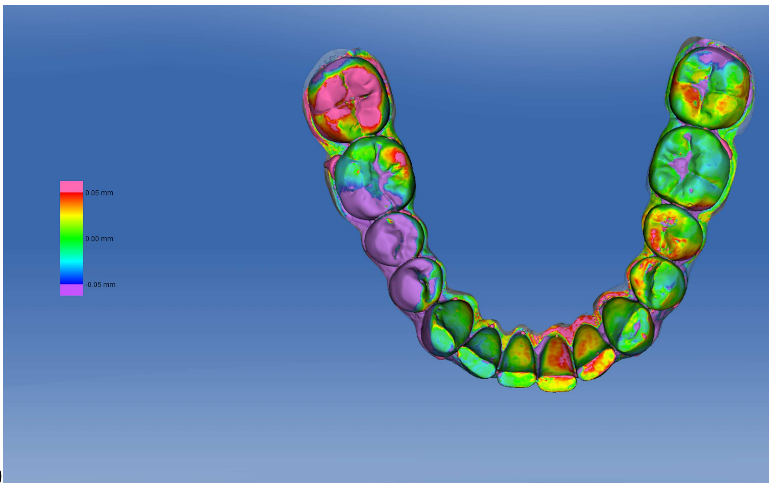
Figure 2: Deviation pattern for full-arch digital impression for group CO (Cerec Ortho) (1), group OL (Ormco Lythos) (2) and for full-arch conventional impression for group AL (Alginate) (3); deviation values are color coded ranging from (–50 µm)(purple) to (+50µm)(red); green areas show no deviation within the respective scale



(1)



(2)



(3)

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