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Intraoral scanning of the edentulous jaw without additional markers: An *in vivo* validation study on scanning precision and registration of an intraoral scan with a cone-beam computed tomography scan

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ABSTRACT

Purpose: A fully digital approach to oral prosthodontic rehabilitation requires the possibility of combining (i.e., registering) digital documentation from different sources. This becomes more complex in an edentulous jaw, as fixed dental markers to perform reliable registration are lacking. This validation study aimed to evaluate the reproducibility of 1) intraoral scanning and 2) soft tissue-based registration of an intraoral scan with a cone-beam computed tomography (CBCT) scan for a fully edentulous upper jaw.

Materials and Methods: Two observers independently performed intraoral scans of the upper jaw in 14 fully edentulous patients. The palatal vault of both surface models was aligned, and the inter-observer variability was assessed by calculating the mean inter-surface distance at the level of the alveolar crest. Additionally, a CBCT scan of all patients was obtained and a soft tissue surface model was generated using patient-specific gray values. This CBCT soft tissue model was registered with the intraoral scans of both observers, and the intraclass correlation coefficient (ICC) was calculated to evaluate the reproducibility of the registration method.

Results: The mean inter-observer deviation when performing an intraoral scan of the fully edentulous upper jaw was 0.10 ± 0.09 mm. The inter-observer agreement for the soft tissue-based registration method was excellent (ICC = 0.94; 95% confidence interval, 0.81-0.98).

Conclusion: Even when teeth are lacking, intraoral scanning of the jaw and soft tissue-based registration of an intraoral scan with a CBCT scan can be performed with a high degree of precision. ***(Imaging Sci Dent 2023; 53: 21-6)***

KEY WORDS: Computer Generated 3D Imaging; Cone-Beam Computed Tomography; Jaw, Edentulous; Reproducibility of Results

Introduction

Edentulism remains a significant global problem with a vast impact on functional and psychological health.[1] Implant-supported prostheses have been shown to markedly improve the quality of life of edentulous patients through amelioration of retention, stability, proprioception, and comfort.[1] Digital technology and implant placement go hand-in-hand and are rapidly becoming the standard of care. Three-dimensional (3D) radiographic data and information from an intraoral scan are the cornerstone for virtual implant planning and guided implant surgery.[2,3] These technologies provide valuable information and permit backward planning to optimize the implant-prosthetic result and improve the efficiency of surgery. To surmount the problem of unclear marked soft tissue outlines of the oral mucosa on a cone-beam computed tomography (CBCT) scan, a "dual

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scan" protocol is needed. This protocol requires 2 CBCT scans: a scan of the denture alone and a second scan of the patient wearing the prosthesis with a radiolucent bite index to stabilize the jaws. Radiopaque scan markers are temporarily attached to the prosthesis to facilitate adequate registration (i.e., "matching") of both CBCT scans.[3] The technique requires a non-metallic and well-fitting denture. If a good prosthetic fit is lacking, base relining or renewal of the denture is needed, leading to additional costs and chair time for the patient and clinician. Alternatively, the dual scan procedure could be omitted by registering the soft tissue data from the intraoral scan with the CBCT scan. Still, a high precision for scanning the edentulous jaw remains a prerequisite for performing this registration. The goal of the present study was twofold: 1) to assess the inter-observer variability (precision) of intraoral scans of the edentulous upper jaw; and 2) to evaluate the reproducibility of the soft tissue-based registration method of an intraoral scan with a CBCT scan without using additional markers.

Materials and Methods

Patient data

Fourteen consecutive and fully edentulous patients were selected from a cohort requiring implant-supported prostheses. The exclusion criteria were motion artifacts on the CBCT scan, recent tooth extractions, and the presence of mucosal lesions. Approval was obtained from the ethics committee (2017-3671). The study adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all individual participants prior to inclusion in the study.

Data acquisition

Digital surface scans of the edentulous upper jaws were acquired, *in vivo*, with the TRIOS© 3D intraoral scanner (TRIOS 3shape A/S, Copenhagen, Denmark) by 2 independent observers (referred to as OBS1 and OBS2, respectively). The scanning procedure was performed from the posterior alveolar crest on one side proceeding to the opposite side and ending with the palatal vault. The application of optical powder is not required for this type of scanning device. Each scan procedure took 2 to 5 minutes. Datasets from the intraoral scans were exported as Standard Tessellation Language (STL) files. During CBCT scanning, patients were instructed to keep their tongue in a relaxed position in the mouth to avoid interference with the palate. Dental cotton rolls were placed in the buccal vestibule to prevent contact with the cheek mucosa, thereby facilitating soft tissue segmentation. A CBCT scan (3D KaVo Exam, Biberach, Germany) of the upper jaw was acquired (110 kV, 9 to 45 mAs, field of view: 16 cm in diameter and 22 cm in height; scan time: 40 s; voxel size: 0.4 mm, isotropic) without dentures or additional markers. CBCT data were saved as Digital Imaging and Communications in Medicine (DICOM) files.

The intraoral scan models from both observers were imported into Maxilim software (version 2.3.0, Medicim NV, Mechelen, Belgium). Only the palatal vault was selected for the matching process, and an iterative closest point (ICP) algorithm was used to align the surface models of OBS1

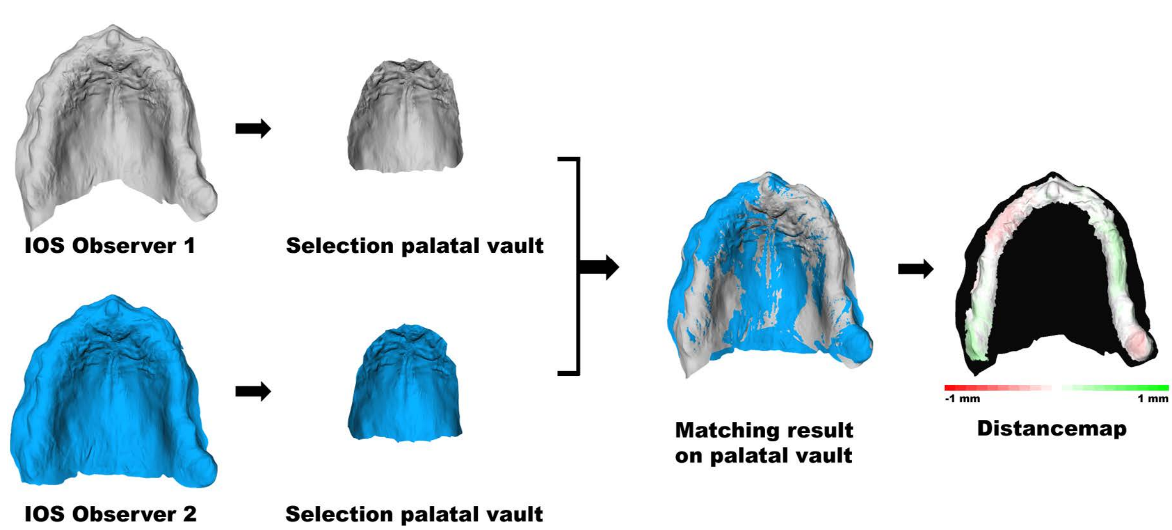

Fig. 1. Reproducibility analysis of intraoral scanning of the edentulous upper jaw. The intraoral scans of the edentulous upper jaw are matched to analyze the reproducibility between observer 1 and observer 2. IOS: intraoral scan.

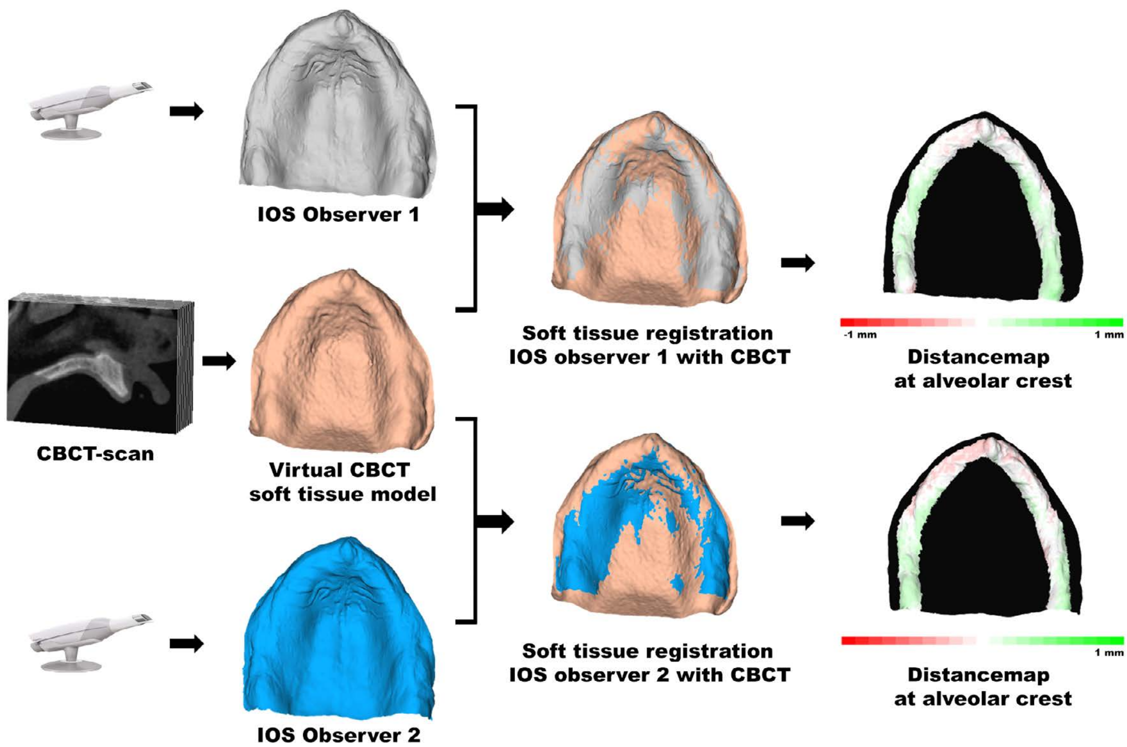

Fig. 2. Reproducibility analysis of soft tissue-based registration of the intraoral scan (IOS) with the cone-beam computed tomographic (CBCT) scan for an edentulous upper jaw. The virtual surface models obtained with the CBCT scan are matched with the corresponding IOS, and a comparison between observers illustrates the reproducibility of the matching method.

and OBS2.[4] The mean inter-surface distances between both surface scans were calculated at the level of the alveolar crest and visualized as a color-coded distance map (Fig. 1).

Soft tissue-based registration of the intraoral scan with the CBCT scan for the fully edentulous upper jaw is only possible after identifying the soft tissue outlines on the CBCT scan. Therefore, the CBCT data were imported into MATLAB© software (version 2016b, the MathWorks Inc., Natick, MA, USA) and a patient-specific gray value was determined for soft tissue reconstruction on the CBCT scan. First, a volume of interest was manually specified by selecting the axial, coronal, and sagittal boundaries of the study area in order to decrease the computational time. Next, a cost minimization function was used to iteratively determine which gray value (within the range of - 800 to - 50) resulted in the most optimal matching between the intraoral scan and reconstructed CBCT surface. Within the cost minimization, different gray values were used to reconstruct the CBCT mucosal surface, and matching of these reconstructed surfaces with the intraoral scan was performed using the ICP algorithm. The quality of the registration for each gray value was assessed by calculating the root mean square (RMS) of the distances between the two surfaces. Using the RMS as the quality standard, the optimization function converged to the most optimal gray value with the lowest RMS, which was selected to reconstruct the final soft tissue mucosal surface from the CBCT scan used for further analysis.[5]

Next, this soft tissue model of the CBCT and the intraoral scan data were imported into Maxilim. The ICP algorithm was used to register both models. An identical protocol was used to register the intraoral scan from the second observer. The mean inter-surface distance was calculated at the alveolar crest, and a color-coded distance map was created for each observer (Fig. 2).

Statistical analysis

All data analyses were performed using SPSS (version 25, IBM Corp., Armonk, NY, USA).

To validate the proposed technique, the inter-observer variability of the intraoral scan and the reproducibility of the registration method were analyzed. The inter-surface distance between intraoral scan models from OBS1 and OBS2, which was used to evaluate the inter-observer variability of intraoral scanning, is presented by descriptive statistics (mean, 95th percentile, standard deviation) and boxplots. The 95th percentile represents the inter-surface distance that includes 95% of the measurement points. The reproducibility of the soft tissue-based registration method was calculated with the intraclass coefficient (ICC) (2-way mixed-effects model). The ICC was presented with a 95% confidence interval (CI) and was interpreted as follows: values of <0.5 represent poor reliability, values of 0.5 to 0.74 moderate, values of 0.75 to 0.9 good, and >0.90 excellent reliability.[6,7] A *P*-value<0.05 was considered statistically significant.

Results

Figure 3 illustrates the precision when performing an intraoral scan of the edentulous upper jaw (i.e., the registration error between OBS1 and OBS2) and the precision of the soft tissue-based registration method (i.e., the registration error between the observer and CBCT). The registration error between OBS1 and OBS2 ranged from <0.001 to 0.39 mm. The mean inter-surface distance between the alveolar crest in both intraoral scan models was 0.10±0.09 mm, with 95% of the measurements within 0.24 mm.

The precision of the soft tissue-based registration method ranged from 0.08 to 0.33 mm, with a mean error of 0.16±0.07 mm for OBS1 and 0.15±0.08 mm for OBS2. The inter-observer variability, represented by the ICC, was high (ICC=0.94) and statistically significant ($P<0.05$). These results confirm the excellent reproducibility of the presented method.

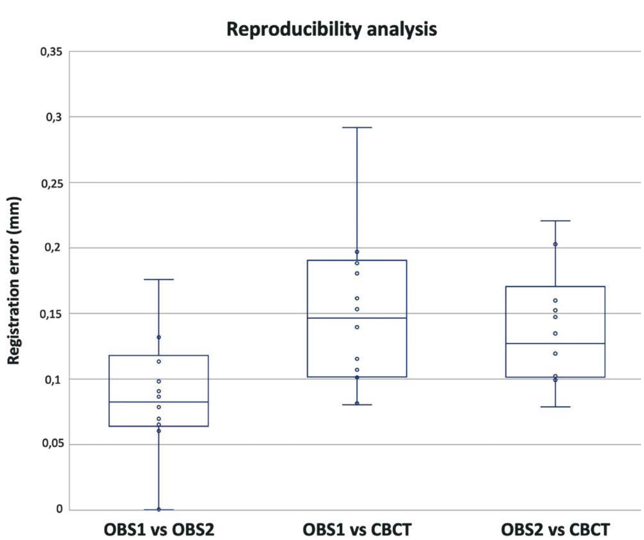

Fig. 3. Boxplot illustrating the reproducibility of scanning the edentulous upper jaw (OBS1 vs. OBS2) and registration error of the intraoral scan with cone-beam computed tomographic (CBCT) scan (OBS1 vs. CBCT and OBS2 vs. CBCT). OBS: observer.

Discussion

Clinical perfection is the result of a sequence of simple repetitive steps performed precisely in every patient. As such, it is paramount that any new technique is reproducible.[8] Modern implant therapy has changed tremendously with the rise of digital technologies.[9] Intraoral scanning eliminates patient discomfort related to conventional impression-making, problems of potential allergies, and errors associated with the distortion of impression materials.[10,11] Several studies have reported the accuracy and reproducibility of intraoral scanning in dentate and partially edentulous jaws.[12,13] The absence of reference points, characteristics of the surface to be scanned, scanning strategy, sensor size, and software are a few factors that could affect the impression accuracy.[14]

Nevertheless, studies regarding intraoral scanning of fully edentulous arches are scarce, although these patients often benefit from implant-prosthetic treatment.[10] The present study focused on 2 essential aspects regarding the virtual workflow for a fully edentulous upper jaw: 1) evaluating the precision of intraoral scanning and 2) assessing the reproducibility of the soft tissue-based registration method of an intraoral scan with a CBCT scan.

A fully edentulous jaw lacks supporting structures or clear anatomical landmarks, which can complicate the scanning process, leading to a summation of matching errors and distortions in the resulting 3D image.[15-17] The results of this study showed a small inter-observer deviation when performing an intraoral scan of a fully edentulous upper jaw. The literature has suggested that discrepancies >30 μm are acceptable and those of <150 μm are the limit to avoid long-term complications.[18] The present study had a mean registration error of 10 μm, which was in line with the findings of other authors, who mentioned deviations of <100 μm as a reference.[18] Additionally, 95% of the measurements were within 24 μm, thus confirming that all regions of the palate could be scanned in a consistent way. It is necessary to mention, however, that many previous studies used *in vitro* models and extraoral scanners to analyze scanning deviations. Patzelt et al.[15] were the first to investigate intraoral scanning of a fully edentulous jaw. These authors confirmed the feasibility of scanning the edentulous jaw, despite variation in scanning accuracy among different devices and scanning techniques. If the digitized object is too simple, such as a flat and smooth toothless jaw, it is more likely for errors to occur in the alignment of the scanned data.[12] To deal with the poorly traceable structures in scanning the fully edentulous jaw, clinicians have described the use of artificial landmarks.[16] Lee[19] facilitated the scanning process by drawing lines on the palate with a mixture of pressure-indicating paste and zinc oxide-eugenol cement. It turned out to be advantageous for a scanned object to have a complex geometric shape. However, the process of coating the palate did not solve stitching errors when broad palatal vaults of the edentulous jaw were scanned. To improve digital impressions of edentulous areas, Kim et al.[20] used an alumina marker that was attached to the surfaces of the gingiva with a light-polymerizing resin. This glued resin marker could serve as a traceable structure during the scanning procedure. However, a common problem with alumina markers was that they could detach during the scanning process, when patients mobilized them with their tongue. In contrast to the previous studies, the current paper described a high precision for scanning a fully edentulous jaw without the need for any auxiliary tools.

The second part of this study focused on the reproducibility of the soft tissue-based registration procedure for an intraoral scan with a CBCT scan. Excellent inter-observer agreement was achieved for this registration method. This is an important condition for achieving successful implant-supported prosthetic outcomes.[21] Traditionally, 5 or more teeth should remain to obtain an appropriate surface-based registration of an intraoral scan with a CBCT scan.[19] In addition, the distribution of the remaining teeth should form as extensive a triangle as possible to improve registration. If there are fewer than 5 teeth or a fully edentulous jaw, a fiducial marker protocol to register the intraoral scan with a CBCT scan is advised.[22] A major drawback is that small movements of the patients could easily displace those markers, whereas this problem could be easily solved by soft tissue-based registration.

Although these results are encouraging, several limitations should be addressed. As traditional registration methods rely on dental markers to match different imaging modalities, there is no gold standard to compare the results from the edentulous group in the current study. However, previous study results on this topic provide a solid basis for interpretation of our results. First, the reliability of using intraoral scanning for 3D documentation of the palatal soft tissue has been investigated.[23] That study compared intraoral scanning with traditional impression techniques, and the results illustrated that intraoral scanning could be used to perform a 3D documentation of palatal soft tissue in terms of shape, color, and curvature. Secondly, the registration method proposed in the current study was validated on dentate jaws and compared with a triple scan procedure.[5]

As illustrated in this study, intraoral scanning and soft tissue-based registration showed excellent reproducibility. The small cohort in this study necessitates the confirmation of these results in larger study populations. One must be very cautious when comparing the outcome of this study to other results. Extrapolation and comparison to other studies would be difficult due to differences in scanning performance, protocols, and techniques. The reproducibility of intraoral scanning can be affected by many aspects of the intraoral environment.[12] The saliva, moisture, temperature, and movement of soft tissue areas are all factors that need to be taken into account. Future research is imperative to confirm the results of this study. Subsequent research and software optimization are factors that can improve the clinical implementation to incorporate this method into daily practice.

The high reproducibility of the proposed technique is promising, as it could improve patient comfort while avoiding additional scans and costs. Facilitating the entire 3D documentation of the edentulous jaw may clear the path to perform a predictable virtual implant-prosthetic workflow.

In conclusion, this report illustrates the excellent reproducibility of intraoral scanning and the soft tissue-based registration of an intraoral scan with a CBCT scan, which can contribute to consistent and predictable implant-prosthetic outcomes for a fully edentulous upper jaw.

Conflicts of Interest: None

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