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Clinical Research

Accuracy of Buccal Scan Procedures for the Registration of Habitual Intercuspation

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Clinical Relevance

Accurate reproduction of the jaw relationship is important in many fields of dentistry. Maximum intercuspation can be registered with digital buccal scan procedures implemented in the workflow of many intraoral scanning systems.

SUMMARY

Clinical Relevance: Accurate reproduction of the jaw relationship is important in many fields of dentistry. Maximum intercuspation can be registered with digital buccal scan procedures implemented in the workflow of many intraoral scanning systems.

Objective: The aim of this study was to investigate the accuracy of buccal scan procedures with intraoral scanning devices for the registration of habitual intercuspation *in vivo*. The hypothesis was that there is no statistically significant difference for buccal scan procedures compared to registration methods with poured model casts.

Methods and Materials: Ten individuals (full dentition, no dental rehabilitations) were subjects for five different habitual intercuspation registration methods: (CI) poured model casts, manual hand registration, buccal scan with inEOS X5; (BC) intraoral scan, buccal scan with CEREC Bluecam; (OC4.2) intraoral scan, buccal scan with CEREC Omnicam software version 4.2; (OC4.5β) intraoral scan, buccal scan with CEREC Omnicam version 4.5β; and (TR) intraoral scan, buccal scan with Trios 3. Buccal scan was repeated three times. Analysis of rotation (Rot) and translation (Trans) parameters was performed with difference analysis software (OraCheck). Statistical analysis was performed with one-way analysis of variance and the *post hoc* Scheffé test ($p<0.05$).

Results: Statistical analysis showed no significant ($p>0.05$) differences in terms of translation between groups CI_Trans (98.74±112.01 μm), BC_Trans (84.12±64.95 μm), OC4.2_Trans (60.70±35.08 μm), OC4.5β_Trans (68.36±36.67 μm), and TR_Trans (66.60±64.39 μm). For rotation, there were no significant differences ($p>0.05$) for groups CI_Rot (0.23±0.25°),

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BC_Rot (0.73±0.52°), OC4.2_Rot (0.45±0.31°), OC4.5β_Rot (0.50±0.36°), and TR_Rot (0.47±0.65°).

Conclusions: Intraoral scanning devices allow the reproduction of the static relationship of the maxillary and mandibular teeth with the same accuracy as registration methods with poured model casts.

INTRODUCTION

Accurate reproduction of the jaw relationship is important in many fields of dentistry. Jaw relations can be determined either by means of occlusal morphology (ie, maximum intercuspation) or by means of locating the mandibular position (eg, with respect to the position of the centric condyles).[1] Habitual intercuspation or occlusion describes the jaw position that the patient acquires when asked to close the mouth without any deflection caused by external factors, such as tooth contacts. Maximum intercuspation describes the jaw position that the patient acquires when asked to close the mouth with a focus on maximum tooth contact of teeth of the upper and lower jaws. Habitual intercuspation and maximum intercuspation normally describe identical jaw positions as far as there are no premature tooth contacts or relieving postures that the patient is forced to acquire (eg, in the case of craniomandibular dysfunction). Maximum intercuspation can be registered with digital procedures, such as the buccal scan procedure implemented in the workflow of many intraoral scanning systems.[2]

For the registration of habitual intercuspation and its transfer to poured model casts, first impressions of the upper and lower arches are taken and model casts poured. Maximum intercuspation position is taken individually by the patient or can be achieved per hand guidance of the operator.[1] The habitual intercuspation position can be additionally encoded by the use of interocclusal recording materials.[3] Poured model casts are finally mounted into the articulator with respect to the maximum intercuspation taken by the patient *in vivo*. In the literature, several aspects of this *in vitro* registration process for the registration of habitual intercuspation have been described that might be the reason for an inaccurate registration of the jaw relationship.[4,5] The exact determination of the patient's arbitrary hinge axis has been described to be the reason for difficulties.[6] Interocclusal recording materials might result in inaccurate encoding of the maximum intercuspation as a result of specific material characteristics, such as material shrinkage.[7] Hand-guided procedures may be distinctly influenced by the operator's clinical skills and experiences and could be an additional factor for inaccuracies in the registration process.[8]

Maximum intercuspation can be registered with digital buccal scan procedures with intraoral scanning devices with no need for poured plaster models.[2] Buccal scans are defined as intraoral digital scans capturing the buccal surface of approximately three teeth of both upper and lower arches while the patient's jaws rest in maximum intercuspation.[2] By a subsequent software matching process of both buccal scan and intraoral scan of the upper and lower arches, both jaws are automatically aligned, thus representing the exact jaw relationship in the form of the *in vivo* maximum intercuspation.[9,10]

To date, there is no clinical study referring to the accuracy of the buccal scan registration method with intraoral scanning devices in comparison to registration procedures with poured model casts. The aim of this study was to investigate the accuracy of habitual intercuspation registration with intraoral scanning devices on the hypothesis that there is no statistically significant difference compared to conventional registration methods with poured model casts.

METHODS AND MATERIALS

Ten individuals were randomly selected from the clinical staff personnel of the Center of Dental Medicine of the University of Zurich. All participants had full dentition without dental rehabilitation and a good general health status (ASA criteria 1). Individuals suffered from neither periodontitis nor temporomandibular joint dysfunctions. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was conducted as part of an established ethical protocol accepted by the ethical committee of the University of Zurich. Estimation of total sample size for the respective study setup with five test groups, each with 10 individuals, based on a significance level of $\alpha = 0.05$ was performed by means of a power analysis with the statistical power analysis program G*Power version 3.1 (open source; Heinrich-Heine-Universität, Düsseldorf, Germany) with respect to an estimated effect size of 0.3 and an observed power of 0.85.

Habitual Intercuspation Registration With Poured Model Casts

Full-arch impressions of the upper and lower arches were taken with vinylsiloxanether material (Identium, Kettenbach, Eschenbach, Germany) for each patient. Standard metal stock trays (ASA Perma-Lock, ASA Dental, Bozzano, Italy) were used. Impressions were poured after eight hours with scanable Type IV gypsum dental stone (Fujirock EP, GC, Tokyo, Japan). Poured stone models were stored at room temperature for 48 hours and left unmodified. *In vivo* habitual intercuspation for each patient was reproduced on the poured model casts via hand guidance by seating lower and upper arch models into maximum intercuspation. The accuracy of this registration method of maximum intercuspation with poured model casts was analyzed digitally with special software tools and a lab scanner (inEOS X5, Dentsply Sirona, York, PA USA). Scanning accuracy for the inEOS X5 scanner is reported to be less than 5 μm according to the DIN EN ISO 12836 standard. First, poured upper and lower arch models were digitized with the lab scanner (inEOS X5). Second, habitual intercuspation registration was performed by manually seating the poured models into maximum intercuspation with no further manipulation. Third, three teeth of the lower and upper arches were scanned by means of a buccal scan with the lab scanner in the region of the second premolar (inEOS X5). This procedure was repeated three times for each patient.

Habitual Intercuspation Registration With Intraoral Scanning Devices

Registration of habitual intercuspation was performed using the principle of buccal scan with three different intraoral scanning devices: CEREC Bluecam (Dentsply Sirona), CEREC Omnicam (Dentsply Sirona), and Trios3 (3Shape, Copenhagen, Denmark). Four different groups were established: CEREC Bluecam, software version 4.2 (BC); CEREC Omnicam, software version 4.2 (OC4.2); CEREC Omnicam, software version 4.5β (OC4.5β) (beta version); and Trios3 (TR). The buccal scan procedure was identical in each group. First, patients were seated in a comfortable upright position. Second, quadrant scans of the upper and lower arches were taken with respect to actual principles of scanning strategy.[11] Third, patients were asked to individually take their habitual, maximum intercuspation without any further manipulation. Fourth, a buccal scan involving three teeth of the upper and lower arches, ranging from the first molar to the first premolar, was performed. Dusting of tooth surfaces with scan spray was performed prior to scans for group BC with scan spray (VITA Scan Spray, VITA, Bad Säckingen, Germany). Three buccal bite registrations were taken for each patient.

Analysis of Accuracy of Habitual Intercuspation Registration

In this study, the accuracy of the registration of habitual intercuspation was analyzed by means of the relative jaw displacement of the lower jaw. The analysis was performed by determining the relative position of the lower jaw in reference to the upper jaw described by the two parameters, rotation (Rot) and translation (Trans), with special software tools.

First, digital data sets for the upper arch had to be aligned and be transferred to an identical coordinate system. This procedure comprised several steps, all executed with Geomagic Qualify software (version 24, 3D Systems, Rock Hill, USA). First, superimposition of two upper arch data sets was performed via a best-fit algorithm. Second, the transformation matrix generated by this superimposition was applied to the respective lower arch data set. By these means, the two upper arch data sets were positioned within the identical coordinate system, whereas the position of the lower arch data sets differed as a result of the jaw displacement caused by different habitual intercuspation registration procedures. Third, STL data files were exported from Geomagic Qualify software to the 3D difference analysis software OraCheck (Cyfex AG, Zurich, Switzerland) to allow quantitative difference analysis of 3D data sets.

The principle of the OraCheck software tool has recently been described in the literature.[12] First, the origin of the coordinate system was determined by moving the center of gravity of the coordinate system to the lower first molar of the baseline data set (OraCheck software tool "eBIT_ToolOrigin"). Second, baseline and follow-up data sets of the lower arch were superimposed. The relative jaw displacements between baseline and follow-up data sets of the lower jaw represented a quantitative measure for the accuracy of the registration of habitual intercuspation. Quantitative analysis in terms of parameters translation (Trans) and rotation (Rot) was performed by using well-known mathematical procedures.

First, a CSV data file comprising a 4×4 transformation matrix was exported from OraCheck software. On the basis of this transformation matrix, the rotation angle and the all-total translation as the

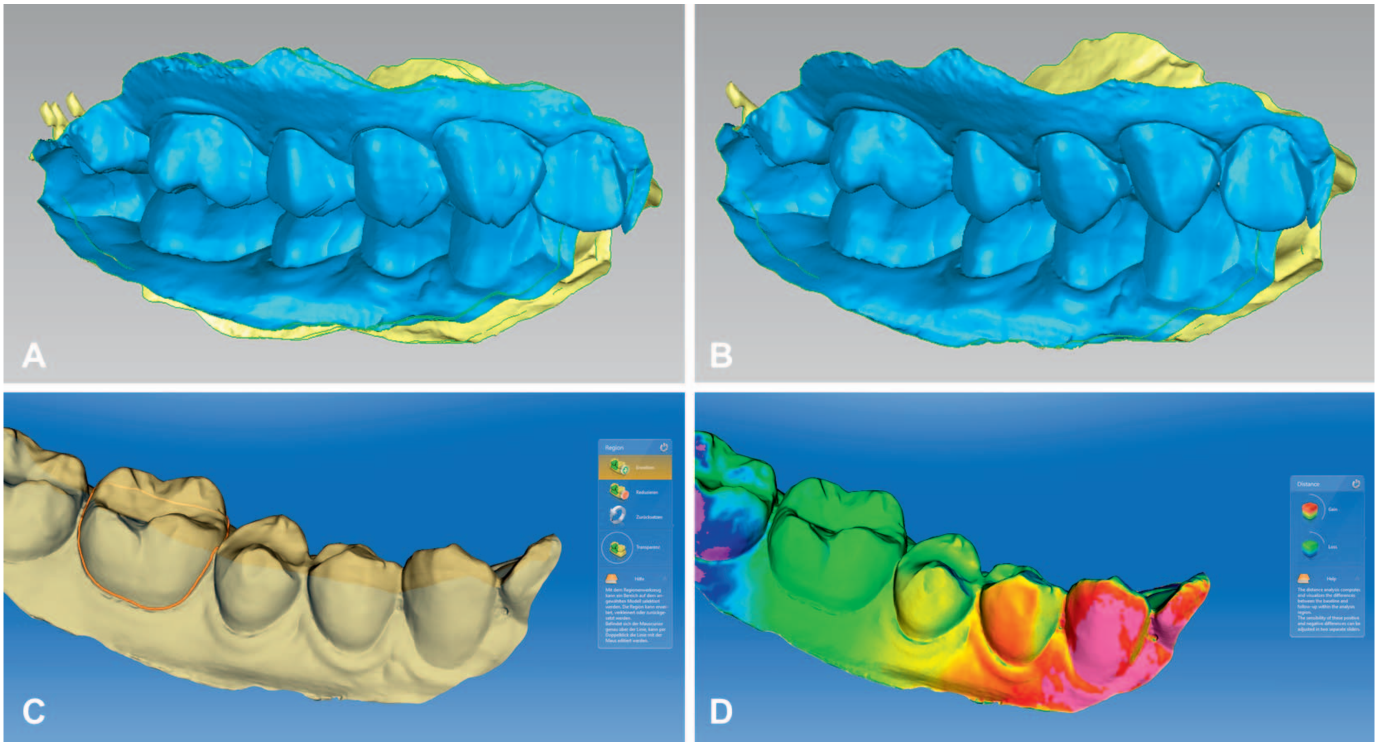

Figure 1. *Step-by-step procedure for the determination of translation and rotation parameters with Geomagic and OraCheck software; example shown for group OC4.2. (1A): Situation after import of STL data files (quadrant scans upper and lower arches) into Geomagic software, displacements of upper arch as a result of nonidentical coordinate system, and displacements of lower arch as a result of different buccal scan registrations in reference to upper arch scans. Three buccal scans were performed in each individual after scanning upper and lower arch quadrants. (1B): Situation after best-fit matching of upper arch quadrant scans. All three quadrants are in the same coordinate system, and respective lower arch quadrant scans were transformed using the transform matrix function of Geomagic software. (1C): Import of STL data files into OraCheck software and selection of the lower first molar in the baseline scan as center of origin for rotation and translation analysis. Three difference analyses were performed in each individual as baseline follow-up difference analysis (data set 1 - data set 2, data set 1 - data set 3, data set 2 - data set 3). (1D): Qualitative analysis of the displacement of the lower jaw as a result of different buccal scan registrations. Differences are color coded with respect to an adjustable scale with green showing the least differences. Quantitative analysis was performed by export of a 4 × 4 matrix and by well-known linear algebra formulas.*

square root of the squared sum of the x-, y-, and z-shifts were extracted by well-known linear algebra formulas.[12,13] Three analyses were performed for each patient in each test group and pooled (data set 1 - data set 2, data set 1 - data set 3, data set 2 - data set 3). The whole procedure is illustrated in Figure 1A-D.

Descriptive statistical analysis of translation (Trans) and rotation (Rot) was performed with SPSS Statistics 22 (IBM Statistics, Armonk, NY, USA), and one-way analysis of variance and the *post hoc* Scheffé test were used for statistical significance analysis ($p<0.05$) after pooling the data for one participant (calculation of the mean).

Table 1: *Values for Parameter Translation (Trans; in μm). Groups: Conventional Impression (CI), CEREC Bluecam (BC), CEREC Omnicam Version 4.2 (OC4.2), CEREC Omnicam Version 4.5β (OC4.5β), and Trios3 (TR). Three Scans per Individual Were Performed (n=30). No Statistically Significant Difference (One-Way Analysis of Variance and* Post Hoc *Scheffé Test,* $p>0.05$*)*

	n	Mean	SD	Min	Max	95% Confidence Interval	
						Lower	Upper
CI_Trans	30	98.74	112.01	5.28	365.33	56.91	140.57
BC_Trans	30	84.12	64.95	20.53	162.61	59.87	108.37
OC4.2_Trans	30	60.70	35.08	16.77	104.15	47.60	73.80
OC4.5β_Trans	30	68.36	36.67	32.83	117.76	54.67	82.06
TR_Trans	30	66.60	64.39	35.22	203.07	42.56	90.64

Table 2: *Values for Parameter Rotation (Rot; in °); Groups: Conventional Impression (CI), CEREC Bluecam (BC), CEREC Omnicam Version 4.2 (OC4.2), CEREC Omnicam Version 4.5β (OC4.5β), and Trios3 (TR). Three Scans per Individual Were Performed (n=30). No Statistically Significant Difference (One-Way Analysis of Variance and* Post Hoc *Scheffé Test,* p>*0.05)*

	n	Mean	SD	Min	Max	95% Confidence Interval	
						Lower	Upper
CI_Rot	30	0.23	0.25	0.07	0.84	0.14	0.32
BC_Rot	30	0.73	0.52	0.13	1.29	0.53	0.92
OC4.2_Rot	30	0.45	0.31	0.08	0.75	0.34	0.57
OC4.5β_Rot	30	0.50	0.36	0.17	1.00	0.37	0.64
TR_Rot	30	0.47	0.65	0.09	1.94	0.22	0.71

RESULTS

Translation of the lower jaw was found to be 98.74 ± 112.01 μm for the conventional habitual intercuspation registration method with poured model casts (CI_Trans). For digital buccal scan registration methods with intraoral scanning devices, the values for translation varied, depending on the intraoral scanning device used. Translation was found to be 84.12 ± 64.95 μm for CEREC Bluecam (BC_Trans), 60.70 ± 35.08 μm for CEREC Omnicam with software version 4.2 (OC4.2_Trans), 68.36 ± 36.67 μm for CEREC Omnicam with software version 4.5β (OC4.5β_Trans), and 66.60 ± 64.39 μm for Trios3 (TR_Trans). Statistical analysis with one-way analysis of variance and the *post hoc* Scheffé test showed no significant differences ($p>0.05$) between all the test groups. Results for translation mean, minimum, and maximum values are shown in Table 1.

Rotation analysis showed no statistically significant different results between different test groups. Rotation was found to be 0.23 ± 0.25° for the conventional habitual intercuspation registration method with poured model casts (CI_Rot). Results for rotation differed, depending on the intraoral scanning device used for the intraoral buccal scan. Rotation was 0.73 ± 0.52° for CEREC Bluecam (BC_Rot), 0.45 ± 0.31° for CEREC Omnicam with software version 4.2 (OC4.2_Rot), 0.50 ± 0.36° for CEREC Omnicam with software version 4.5β (OC4.5β_Rot), and 0.47 ± 0.65° for Trios3 (TR_Rot). Results for rotation mean, minimum, and maximum values are shown in Table 2.

DISCUSSION

The aim of this study was to investigate the accuracy of habitual intercuspation registration with intraoral scanning devices in comparison to conventional methods with poured model casts. The hypothesis was that there is no statistical significant difference between different methods applied for habitual intercuspation registration. Displacements of the relative position of the mandibular arch in reference to the maxillary arch were determined in terms of rotation (Rot) and translation (Trans) parameters with special 3D difference analysis software.

No significant differences were found in terms of translation for all test groups ($p>0.05$). The parameter translation is defined as the position shift of a certain object in the x-, y-, and z-axes, whereas the parameter rotation is defined as the tilt within a defined origin center. In terms of rotation, there were also no statistically significant differences between different test groups ($p>0.05$). Mean values for digital test groups ranged from best 0.50° (OC4.5β_Rot) to worst 0.73° (BC_Rot). The mean value for the conventional method was 0.23° (CI_Rot). Thus, both powder-based and powder-free scanning systems might be able to reproduce habitual intercuspation registration with the same accuracy as conventional habitual registration methods with poured model casts.

Several aspects need to be discussed. First, powder-based intraoral scanning systems require the dusting of buccal tooth surfaces. In order to perform intraoral buccal scans for the registration of habitual intercuspation, at least three single images are needed. If the intraoral scanner is not handled properly, the dust layer is likely to get altered during this procedure. This might lead to inaccuracies in the procedure of habitual intercuspation registration. Second, the data capturing mode and the size of the scanning tip might influence the precision of intraoral habitual intercuspation registration. During the process of habitual intercuspation registration with buccal scans, it is crucial that there are no jaw movements and that single images are matched correctly. If there is any movement of the patient, single images are matched poorly, and the registration process will be inaccurate. This effect might be more crucial if only a few images, such as for the powder-based intraoral scanning system used in this study, are matched. Additionally, if the tip of the intraoral scanner is placed too far distally, artificial involuntary jaw movements of the patient might be more likely to occur. The tip of the CEREC Bluecam powder system is slightly larger than those of the other intraoral scanning systems used in this study. These aspects might explain why the worst results both for parameter rotation (Rot) and for translation (Trans) were found for the powder-based scanning device used in this study (CEREC Bluecam).

In this study, the worst results for the parameter translation were found for group CI with mean 98.74 ± 112.01 μm. The standard deviation was also to be found twice as high for group CI_Trans than for the other test groups. There might be several reasons for this observation. Conventional methods of habitual intercuspation registration may be inaccurate because of alterations in the plaster model, such as bubbles that might occur during the process of model fabrication. In contrast, intraoral buccal scans are directly taken from the patient. Provided that the proper scanning strategy is used, digital models are thus less susceptible to model defects, and buccal scans might lead to a more accurate habitual intercuspation registration of the digital models.

Within the limitations of this study, several aspects need to be discussed. First, there might be the question about the accuracy of intraoral scanning devices. Several published studies show that the intraoral scanning systems used in this study perform with high accuracy. For full-arch digital impressions, our group found an *in vitro* trueness of 56.4 ± 15.3 μm for CEREC Bluecam and 46.1 ± 10.4 μm for CEREC Omnicam.[14] In this study, quadrant scans for the upper and lower arches comprising four to five teeth were performed prior to the buccal scan so that accuracy values for all three scanning systems might in fact be superior. However, scanning artifacts would result in inaccurate model data and thus in a poor buccal bite registration. Scanning artifacts should be cut prior to buccal scan registration with intraoral scanning devices.

In this study, the laboratory benchtop scanner inEOS X5 was used to digitize the plaster models. Scanning accuracy for the inEOS X5 scanner is reported to be less than 5 μm according to the DIN EN ISO 12836 standard. It is important to mention that for ISO standard procedures, standardized geometrical objects and no tooth geometries are used. In terms of optical digitalization processes, however, surface morphology, textural information, and angulation of surface imaging are important. This is why there might be the assumption that scanning accuracy for tooth geometries might be inferior to the ISO standard values. There are no actual studies available addressing the accuracy of the inEOS X5 scanner for tooth geometries. Internal data (not yet published) and pilot tests performed previous to this study revealed the precision of the inEOS X5 scanner to be within a 5- to 10-μm range for full-arch plaster models. It is important to understand that the technical configuration of lab scanners includes an optical imaging from specific, predefined camera positions and model angulations. This is the main reason why the matching process of single images to obtain the final digital model performs better for lab scanners than for intraoral scanners, resulting in a higher accuracy.

There are studies reporting difficulties using digital buccal scan registration procedures.[15,16] One study reports digital model contacts and real model contacts of a full-arch model cast having an accordance for contact distribution of only 30% to 40%. Inaccuracies of the registration occurred mainly at the contralateral side of where the buccal scan registration was performed.[16] This observation might derive from the fact that no ideal scanning strategy had been used and that model deformations might have occurred, resulting in habitual intercuspation inaccuracies. The importance of scanning strategy for the accuracy of digital full-arch impressions has recently been described,[11] although intraoral buccal scans on both sides of the jaw might be beneficial in order to improve the accuracy of habitual intercuspation registration for full-arch scans. In this study, the focus was on the registration of quadrant scan models. A further study might investigate the registration accuracy of full-arch scans.

The disadvantage for conventional habitual intercuspation registration methods might be the manual seating of poured model casts with maximum intercuspation into the articulator. This procedure is reported to be highly dependent on the experience of the dental technician.[17] Boyarksy and others[17] reported that the occlusal refinement of mounted casts before the fabrication of indirect restorations significantly decreased the time needed to adjust the occlusion of the seated restoration. Digital methods such as intraoral buccal scan registrations might be consequently less technique sensitive and more reliable for both the clinician and the dental technician.

In this study, procedures for buccal scans were repeated three times for each patient. For groups BC, OC4.2, OC4.5β, and TR, patients were asked to individually take their habitual, maximum intercuspation three times. For group CI, manual seating of the poured models was repeated three times. For all groups, there might thus be the possibility of some sort of reproducible error. Previous studies that we conducted using a different protocol demonstrated that the mean ± SD value for the location of the habitual intercuspation was 42 ± 34 μm, ranging from 22 ± 9 μm to 77 ± 58 μm for single individuals.[10] In this study, we tried to minimize the reproducible error as much as possible and below the threshold previously observed by systematically standardizing the procedure of determining the maximum intercuspation for patients, such as by defining a specific seating position and exact procedure of intraoral scanning but also by performing the manual seating of plaster models by only a single operator.

Digital procedures for the intraoral habitual intercuspation registration are highly promising, as they might not be limited to reproducing only the static occlusion. In the future, it might be possible to extend the application of the buccal scan registration and simultaneously capture, for example, dynamic movements of the jaw. First attempts to integrate dynamic occlusion into the digital workflow have recently been described.[18,19]

CONCLUSIONS

Intraoral scanning systems with buccal scan procedures allow practitioners to reproduce the static relationship of the maxillary and mandibular teeth with the same accuracy as conventional registration methods with poured model casts. Intraoral scanning devices with different imaging technologies did not show any statistically significant differences for the reproduction of the static relationship. Compared to conventional methods, digital buccal scan registration methods might be less susceptible to errors and be performed more easily and reliably for the determination of habitual intercuspation.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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