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Jaschouz, S ; Mehl, A

Abstract: OBJECTIVES: The aim of this in vivo study was to investigate how reproducible individuals find their habitual intercuspation. METHODS: A new type of highly accurate measuring procedure was involved using an intraoral optical scanning device (Cerec Bluecam). First, a pilot test investigated the accuracy of the procedure within a standardized setting. With regard to the in vivo study, fifteen participants with full dentition were selected. For each of these individuals, eight scans were taken both in the morning and in the afternoon. Furthermore, during each session, scans were taken both in horizontal and upright position. In order to compare this to ubiquitous used processes, plaster replicas of five individuals were investigated as well. The scans were analysed, and the differences in the position of the lower jaw were calculated by a specialized superimposition program (n=570 comparisons/OraCheck). RESULTS: The results showed that there was no significant difference between the time of day and the position of the patient. The overall mean±SD value for locating the habitual intercuspation was 42±34 m, however ranging from 22±9 m to 77±58 m for single individuals. On the other hand, the differences in positioning plaster replicas reached a mean of 135±77 m. CONCLUSIONS: The reproducibility of the habitual intercuspation can be obtained under in vivo conditions by a newly developed and highly accurate measuring procedure. Individuals with full dentition show values in average of 42 m. CLINICAL SIGNIFICANCE: Determining the occlusal jaw relation is an important precondition in restorative dentistry and many methods are proposed for a proper occlusal registration. Although much is known about in vitro accuracy of these techniques, little is known how reproducible the habitual occlusal position itself is found between individuals.

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Reproducibility of habitual intercuspation in vivo

S. Jaschouz[1], A. Mehl[1]

[1]Clinic of Preventive Dentistry, Periodontology and Cariology; Division of Computerized Restorative Dentistry
University of Zurich, Zurich, Switzerland

Keywords: reproducibility; habitual intercuspation; centric occlusion; static occlusion; buccal scan; bite registration

Short title: Reproducibility of habitual intercuspation

Correspondence:
Jaschouz Stella M Dent Med UZH
Division of Computerized Restorative Dentistry
Plattenstrasse 11
CH-8032 Zurich
Switzerland
Phone +41 44 634 32 72
Fax +41 44 634 43 08
stella.jaschouz@zzm.uzh.ch

1 Abstract

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Objectives: The aim of this in vivo study was to investigate how reproducible individuals find their habitual intercuspation.

Methods: A new type of highly accurate measuring procedure was involved using an intraoral optical scanning device (Cerec Bluecam). First, a pilot test investigated the accuracy of the procedure within a standardized setting. With regard to the in vivo study, fifteen participants with full dentition were selected. For each of these individuals, eight scans were taken both in the morning and in the afternoon. Furthermore, during each session, scans were taken both in horizontal and upright position. In order to compare this to ubiquitous used processes, plaster replicas of five individuals were investigated as well. The scans were analysed, and the differences in the position of the lower jaw were calculated by a specialized superimposition program (n=570 comparisons/OraCheck).

Results: The results showed that there was no significant difference between the time of day and the position of the patient. The overall mean ± SD value for locating the habitual intercuspation was 42 ± 34 µm, however ranging from 22 ± 9 µm to 77 ± 58 µm for single individuals. On the other hand, the differences in positioning plaster replicas reached a mean of 135 ± 77 µm.

Conclusions: The reproducibility of the habitual intercuspation can be obtained under in vivo conditions by a newly developed and highly accurate measuring procedure. Individuals with full dentition show values in average of 42 µm.

Clinical significance: Determining the occlusal jaw relation is an important precondition in restorative dentistry and many methods are proposed for a proper occlusal registration. Although much is known about in vitro accuracy of these techniques, little is known how reproducible the habitual occlusal position itself is found between individuals.

2 Introduction

An accurate reproduction of the interocclusal relationship is a daily and important subject in prosthetic dentistry. Specifically, for larger dental restorations and functional analysis, proper recording of the static occlusion is a key for a successful treatment. Many methods and materials can be used to determine the jaw relation. Currently, and in the past, various interocclusal registration materials have been utilized such as wax, resin, zinc oxid paste, plaster, silicone, polyether, polyvinylsiloxane or polysulfide. Several examinations on their properties were the subject of previous investigations.[1-13] Yet, the accuracy of these materials remains questionable. This is evident in various topics such as in processing errors that are possible during registration, during laboratory work or by the shrinking properties within the material itself.[1-5,12,13]

Additionally, only few investigations about the reproducibility and characteristics of the habitual occlusion itself have been done and in these cases using mounted plaster models.[14-16] A study about static occlusion for instance examined the precision of the intercuspation in articulated models with an electronic evaluation by a condymeter.[15] With the use of the interocclusal movement as the lateral leeway, the reproducibility and the hand-held occlusion was measured and quantified. It was assumed that a clear allocation, without tilting of upper and lower cast, does not need an interocclusal registration. The results showed that the median of spatial displacement in the condylar area amounted to 0.07 mm. The repeated measurements showed a median value of 0.16 mm. Both results indicate a lower sagittal and transversal deviation value as described in the concept of “freedom in centric” occlusion. This concept states that the interocclusal positioning varies at a rate of 0.3 - 0.5 mm.[15,17] Another study tested the reproducibility of mounted casts also with a condymeter and the results varied from deviation values from 0 to 1.54 mm, whereas a difference between the various investigators was observed.[16]

One should note, that interocclusal recording is restricted by biologic characteristics of the stomatognatic system.[18-21] By activating mandibular muscles the peripheral and central nervous system controls the occlusal contact of the teeth. Depending on the time of the day, occlusal contacts vary in number, position and intensity.[18] In addition, many external factors can interfere the maxillomandibular relationship for instance different environmental stimuli.[19]

With the developments of intraoral scanning systems, occlusal information can now be derived from buccal scans. This registration technique has enabled a completely new method of defining the jaw relation with an individual measurement.[22, 23] So far, numerous in vitro studies have been conducted on bite registration by using different materials, but few attempts have been made to investigate optical bite registration.[24]

In previous investigations, the accuracy of single tooth data acquisition with intraoral scanning devices was described with 19 μm.[25] However, for buccal registration two additional aligning processes are necessary for the lower and upper jaw data. These superimpositions of the buccal scans are anticipated to be a more challenging process. This fact is shown that the buccal view illustrates more smooth surfaces than an occlusal surface.

Nevertheless, before starting to investigate the accuracy of buccal bite registration processes, it is indispensible to get an idea of the natural range for finding the static occlusion. The aim of this study therefore is to examine the reproducibility of retrieving the habitual intercuspation by individuals using a new optical measuring procedure. In detail, the purpose of this study is to obtain various levels of deviations by conducting the following three investigations:

1) Determination of the accuracy of the measurement method
2) Clinical evaluation of the reproducibility of the habitual occlusion itself and in dependence on the time of day and the position
3) Reproducibility of the static occlusion with plaster replicas in comparison to the in vivo situation

Keywords: reproducibility; habitual intercuspation; centric occlusion; static occlusion; buccal scan; bite registration

3 Materials and Methods

Pilot study

For the pilot test the examination was conducted with the Cerec device (Cerec Bluecam, Sirona, Bensheim, D) and the software version Cerec SW4, such as in the later clinical test. With the use of a mounting device, the camera was fixed above a tooth model. No contact with the stand, camera and the model was made throughout the entire examination (Fig. 1). The scannable plaster model was composed of half of upper and the corresponding lower jaw. Hence, the situation was simulated like the first and fourth quadrant in subsequent clinical trials. A pacemaker-motor (InfiniteFocus, Alicona, Raaba/Graz, AUT) allowed predefined movements (inaccuracy less than 1 μm) of the lower jaw model by translations in the different x, y, z directions, thus moving with a spatial orientation from coronal to apical (x-axis), from mesial to distal (y-axis) and from the buccal to lingual (z-axis). Shifting the model along these three axes in regular intervals (10 μm, 20 μm, 30 μm, 40 μm, 50 μm, 60 μm and 70 μm), it was possible to position the lower jaw in each direction in an accurate well-defined manner. Camera scans were taken at each motor step. The data was saved as a RST-Cerec file and then imported into a superimposition program (OraCheck, Cyfex, Zurich, CH). This program aligns two data sets according to a best fit method: the two 3D-surfaces from the data sets are rotated and shifted as long as a perfect match between unaltered areas is reached. These unaltered areas may be found automatically during the aligning process by the program or defined manually before superimposition. After superimposition a difference image between the two data sets can be calculated showing the deviations between all corresponding surface points. More details of this procedure and of the software are described in Mehl 1997, Mehl 2013. The magnitude of root mean square errors per point have been tested by superimposing both identical and slightly altered objects in random directions. The errors lie far below 5 μm ((Mehl 1997, Mehl 2013), which can be seen negligible in comparison to the inevitable intraoral scanning errors.

With the aid of this superimposition software in this study, the deviations between the various buccal scans could be graphically displayed and numerically analysed. The reference position was defined as the one, where the upper and lower jaw were in start position, i.e. in maximum intercuspation. Then, each shifted bite situation was compared to the reference position. In a first step, both upper jaws of these two buccal scans were marked and superimposed. The result was visually controlled for a proper match. In a second step, the area of the lower jaw of the aligned images were selected and this area then superimposed. As a result, this process gives the transformation parameters (rotation and shift) of the lower jaw in comparison to the reference position. The various images and all the values, including the transformation matrix as an ASCII-readable file for statistical analysis, were saved. (hier gelöscht)(Figs. 2 and 3). From the transformation matrix following values were extracted: the rotation angle by well known linear algebra formulas (Research Methods, Robertson et al 2004) and the total translation as the square root of the squared sum of the x, y and z-shifts. All the experimental arrangements were repeated one week later by the same clinician. The goal of these first pilot tests were to see how accurate the measured values correlated with the movements of the tooth model and thus to create the prerequisite for the clinical test.

Clinical test

Fifteen study participants (eight males and seven females), aged from 18 to 45 years, were selected for this survey. They all agreed to participate in this clinical trial and gave informed consent. The institutional ethics committee of Zurich approved the study design. Inclusion criteria were a good general health status, fully dentulous, few dental restorations, neither periodontitis nor major temporomandibular disorders. The participants came once in the morning and once in the afternoon for the optical registration with the Cerec Bluecam. In each session, four buccal scans were taken in lying (scans 1-4) and four others in upright position (scans 5-8). Dry conditions for the treatment field were achieved by using an aspirator and an auxiliary aid to retract both the cheeks and the lips (OptraGate, Ivoclar Vivadent, Schaan, FL). In addition, for the buccal tooth matting, a non-reflective spray (Cerec Optispray, Sirona, Bensheim, D) was used only in the first and fourth quadrant and was not touched throughout the entire procedure. The view frame corresponded always in height of the first right premolars in maximum intercuspation. The crosshairs were positioned in the height of the cusp tip of the first right premolar and to the plane of occlusion. Between the scans the participant was requested to practice relaxation exercises by moving the mandible in all directions, so that the patient was not too uptight biting in the habitual occlusal position. For each scan the participant was asked to bite in the same habitual intercuspation position again. The different buccal scans were analysed by the same computer program (OraCheck) and the same procedure as described for the pilot study. In order to detect and calculate the deviations, several comparisons have been made (Tab. 1, dividing into groups I to III both for morning (m) and afternoon (a), eg. IIm). In total, for this study 570 detailed comparisons were made from the fifteen subjects.

Comparison test with plaster casts

Dental impressions from five participants were taken with a conventional vinylsiloxanether impression material (Identium, Kettenbach, Eschenburg, D). The impressions were poured in scannable hard gypsum. In a second step, the occlusal surfaces of the plaster models were analysed and checked for blisters, bubbles and other irregularities. Three different operators put the upper und lower plaster casts together. Since the patients had optimal vertical support, the casts were composed hand-held in habitual intercuspation without interocclusal registration material.[15] The models were placed on the table and the camera (Cerec Bluecam) was positioned with the aid of a mounting in front of the first and fourth quadrant without touching the teeth. After each new positioning, one buccal scan was taken. Altogether, five different situations were scanned, three situations positioned by the same dentist and the others from two different clinicians. The deviations of the lower jaw in relation to the upper jaw were calculated with the same method as described in the pilot test by superimposing and comparing each scan pair. In addition, the *in vivo* scans for the corresponding participant were compared to the plaster data, namely the four lying scans which were made in the morning.

Statistical methods

After the determination of the transformation matrices (OraCheck), rotations and translations in each axis were recorded and descriptive statistics were made with

PASW Statistics (Version 18, SPSS Inc., Chicago, USA). Following values were calculated and stored: mean, median, range, standard deviation and 10%, 20%, 80%, 90% percentiles. Scatter and error bar diagrams were made in order to graphically display the results. Statistically significant differences for the clinical measurements were analysed with dependent sample t-test ($p<0.05$) after pooling the data for one individual according to the groups Ia, IIa, IIIa, Im, IIm and IIIm. For the pilot test, correlation analysis with Pearson coefficient was performed to investigate the coincidence of the measured values with the real values. To compare the values of the plaster casts with the clinical data, independent t-test ($p<0.05$) was used. The dependency of the single operators on the values was evaluated with oneway ANOVA and post hoc Bonferroni ($p<0.05$).

4 Results

Pilot study

The results of the pilot test are shown in Figs. 4a, 4b, 4c. The diagrams illustrate the correlations of the translations measured by the new procedure (each in x,y,z-direction) compared to the corresponding real translations from the stepper motor. The linear regression analysis show high correlation coefficents of r^2=0.994 for x-direction, r^2=0.991 for y-direction and r^2=0.997 for z-direction. The mean error between measured and real value is 1.8 ± 1.1 μm and the maximum error is less than 5 μm. This all proves the fact that the measurement method used is able to detect differences in the jaw positions with an uncertainty far below 10 μm.

Clinical case study

Fig. 5 lists all measured translations of the clinical study in dependence of the time of day and the position of each individual. Fig. 6 shows the results for the mean and the standard deviation, respectively. No significant differences were observed neither in the time of day nor in the position (dependent t-test; $p>0.05$). Overall, the positional uncertainty of the lower jaw in the habitual intercuspation amounted on average at 42 ± 34 μm (calculated from groups I and II). 53% (eight patients) of the participants even showed average deviations below 30 μm, with a minimum of 22 ± 9 μm. On the other side, 20% (three participants) of the patients exhibit uncertainties in finding the habitual intercuspation of more than 60 μm, with a maximum of 77 ± 58 μm for one individual.

Plaster cast study

Positioning the upper and lower jaw with the plaster casts resulted in mean dislocations of 135 ± 77 μm (Fig. 7). The displacement compared to the intraoral situation was measured with 162 ± 69 μm. These values were statistically significant different to the clinical situation ($p<0.05$). No significant differences were found between the single dentists positioning the upper and lower casts ($p>0.05$).

5 Discussion

Due to the progress in the last couple of years in the areas of computer-assisted restoration design and manufacturing, the integration of static and functional occlusal relations in such processes are attracting more and more attention. The central question is still the accuracy of transferring the relation into a virtual model. However, before solving this question, the natural positional uncertainty of biting into habitual intercuspation has to be investigated. With the new developments that have been made it is now possible to examine an old theme of static occlusion in a modern and more exact way. The present study was designed to measure intraoral the reproducibility of locating the maximum intercuspation in individuals. Before starting, the measuring procedure was tested in an experimental setup to exactly quantify possible errors. Additionally to the direct in vivo measurement, the corresponding plaster replicas were compared as well. The examined deviations of the lower jaw finding the habitual intercuspation amounted on a total mean of 42 ± 34 μm. In contrast, finding the static occlusion on plaster models showed greater differences with a total mean of 135 ± 77 μm.

The measuring procedure involved optical buccal scans. Despite several previous investigations,[22, 23, 25, 26] which have come to the conclusion that buccal registration with optical measuring systems can be seen as a serious clinical alternative to conventional impression and registration methods, though nothing was stated about the accuracy of these systems. From literature it is known that single tooth scans with intraoral scanning devices can be performed with an accuracy of 19 microns.[25] Such tests evaluated the accuracy by means of single point measurements (RMS/point). In contrast, to detect rotations and translations of a larger area in a single 3D scan like the entire mandibular portion, a high number of measured points will be assessed. For this reason, the accuracy of detecting deviations of jaw positions are expected to be higher due to the larger investigated area. This could be demonstrated in the pilot study here, which allows one to detect the translations with an inaccuracy of less than 4 μm.

The static occlusion was the principal theme of the present study and could be analysed by a modern optical measurement method. Historically, the gnathology has been a central issue in dental scientific research in the period until the early eighties.

In the following twenty years there has been a break in this field of research. At the turn of the 20th century the interest on principles and concepts of occlusion started again.[17] However, not much research has been done in the field on the reproducibility of the habitual occlusion. Possible reasons for that could be a main focus in the literature on the dynamic aspects and concepts about functional occlusion in connection with static investigations.[27-29] Thus, based on this little scientific information, it was difficult to evaluate comparable results. Utz et al.[14] measured the accuracy of the habitual intercuspation in mounted plaster casts. After three repeated tests the average accuracy amounted to the median of 0.16 mm. This value is similar to the means of the present test with plaster replicas. Also Schmid-Schwap et al.[16] tested, how reproducible mounted casts could be positioned in maximum intercuspation. The results showed means among 0.26 mm and 0.73 mm, which are greater than the values in the actual investigation on the plaster replicas. Furthermore, the above-mentioned study shows the distinctions of the results between the different clinicians, which however were not evident within the actual study.
Based on the patient’s dental status, the results of the accuracy measurements can vary and wrong conclusions can be made. Possible causes can be increased tooth mobility or worn out teeth. For this reason, periodontal disease as well as temporomandibular joint disfunction (TMD) were considered exclusion factors in these tests. The criteria set for selecting subjects for this survey were chosen to ensure the presence of a natural dentition. Meaning, patients with few little restorations and not too worn teeth were selected. In addition, the scans were taken once in the morning, and for a second recording some days later in the afternoon, to see if there was a difference in time of day. As mentioned before, the present result showed that time is not of influence. Whereas Berry and Singh showed in a previous study[18] that in the most cases more teeth were in contact in the morning than in the evening. The patients were also analysed in habitual occlusion, which is considered to be a balanced position for the jaw muscles. But in that study the occlusal contacts were marked by articulating paper. In addition, it was noticed that mental and physical stress influences this coordination, thus the occlusion. Because many effects can interfere the occlusal relationship[19], this study design was chosen not only to include different daytimes but also to distinguish between two positions of the

patient. Even the comparison between upright and lying position showed no significant differences.

All in all, because of the controversial discussions in the literature on occlusion, the “healthy and ideal” occlusion remains unexplained. With this study, it was possible to shed a bit light into the dark. Reproducing habitual intercuspation for restorative reconstructions is a daily demand. From this study, it can be assumed that the reproducibility of the terminal occlusion position is a maximum total mean under 77 μm in vivo, for most patients even fewer than 30 μm.

In this study, the following facts have been omitted. Because the main topic of the examination was the reproducibility of the static occlusion functional aspects have been left unconsidered. Meaning that the occlusal relationship has not been observed during functions such as mastication, speech and swallowing. For future investigations, the following cases would be interesting to further explore: patients with TMD, larger restorations, more dental abrasion or higher tooth mobility such as patients with periodontal diseases. It is conceivable that more information about the static occlusion for these specific patient groups may be of interest in restorative dentistry. It is necessary to note that further studies with similar clinical circumstances and test methods should be conducted.

6 Conclusions

The individual reproducibility of the habitual intercuspation could be obtained by a modern measuring procedure under in vivo conditions. The results show a mean reproducibility of 42 µm ± 34 µm. Findings showed that the static occlusion, only with the plaster models, had greater differences with a total mean of 135 µm ± 77 µm. The displacement, compared to the intraoral situation, was measured with 162 µm ± 69 µm. From the clinical point of view, it does not matter when and in which position the patient is biting into habitual intercuspation, meaning that no significant differences were observed either between morning and afternoon or between the horizontal and upright position.

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8 Tables

Tab. 1 – List of comparisons between the single scans within the three groups. The scans are numbered from 1 to 8; scans 1 to 4 correspond to patients in lying position and 5 to 8 in upright position. For each individual, these comparisons were made both in the morning (m) and afternoon (a). With fifteen individuals, this corresponds to a total of n=570 single comparisons.

Group I. Lying positions	Group II. Upright positions	Group III. Lying versus upright positions
Scan numbers: 1, 2, 3, 4 List of superimpositions: 2-1, 3-1, 4-1, 3-2, 4-2, 4-3 Number of comparisons: 6	Scan numbers: 5, 6, 7, 8 List of superimpositions: 6-5, 7-5, 8-5, 7-6, 8-6, 8-7 Number of comparisons: 6	Scan numbers: - List of superimpositions: 5-1, 6-1, 7-1, 8-1, 6-2, 7-3, 8-4 Number of comparisons: 7

9 Figures

Fig. 1 – Schematic figure of the experimental setup of the pilot study: The figure displays the stepper motor and micrometer desk with the fixed tooth model and the corresponding coordinate system. The intraoral scanning system (Cerec Bluecam) was mounted without touching the model. The upper jaw (on the right side) was fixed and the lower jaw moved with the stepper motor in x, y and z direction.

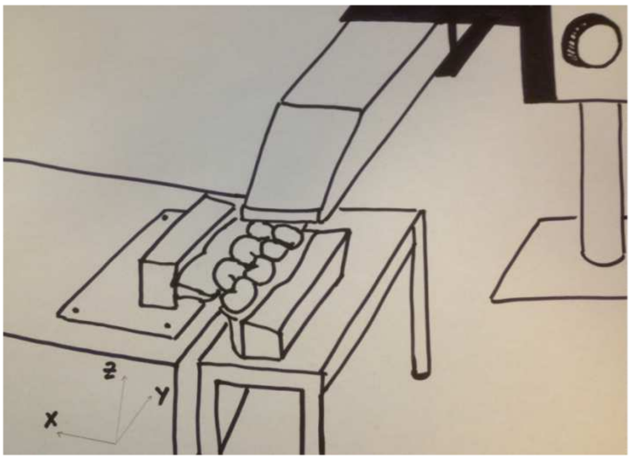

Fig. 2 – An example of two different superimposed buccal scans with a low deviation. The upper jaw is the reference area. The scale on the left shows a range from a red marking of 0.02 mm to a blue marking of 0.02 mm. The corresponding transformation matrices for this graphic shows a x-value of 1.0 μm, a y-value of 7.3 μm and a z-value of -0.1 μm, which corresponds to an accurate reproducibility.

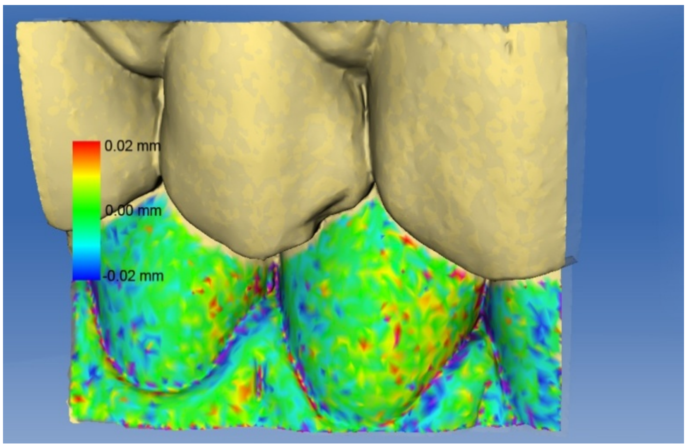

Fig. 3 – Another example of two different superimposed scans, however with a higher deviation. The upper jaw is the reference. The scale on the left shows a different range from a red marking of 0.02 mm to a blue marking of 0.02 mm. The corresponding transformation matrices illustrated a x-value of 10.7 μm, a y-value of -24.6 μm and a z-value of -7.2 μm.

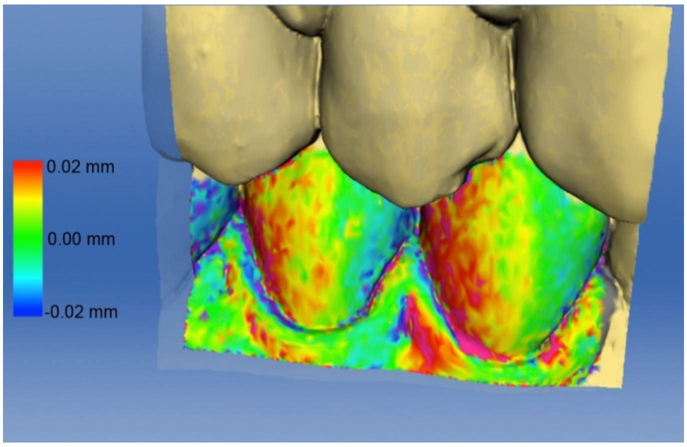

Fig. 4 – Results of the pilot study: The figure illustrates the correlation between values measured with the new procedure and the real values of the shifted jaw model with the stepper motor. The result for each axis (Figs. 4a, 4b, 4c) is shown separately with the linear regression line and Pearson correlation coefficient.

Fig. 4a – x-axis

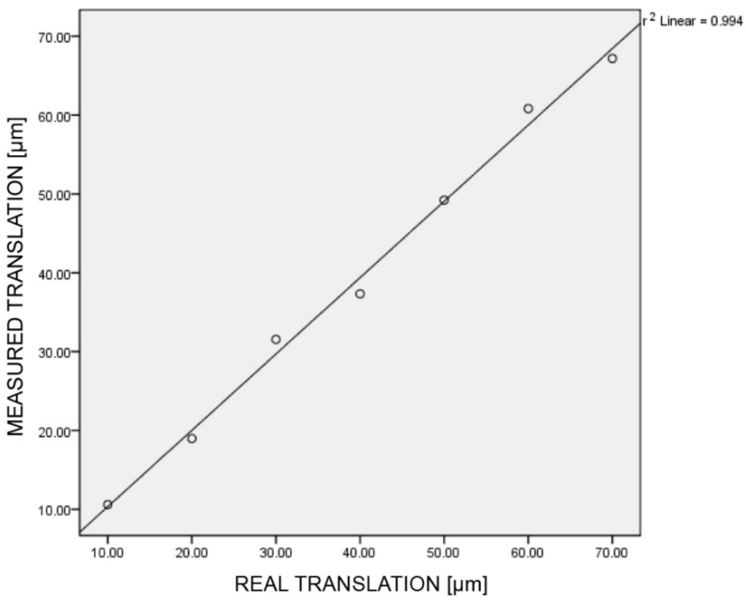

Fig. 4b – y-axis

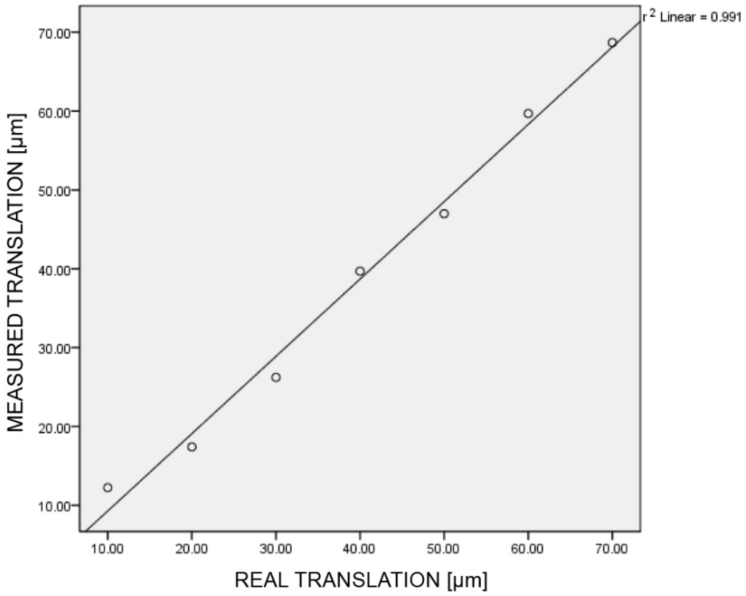

Fig. 4c – z-axis

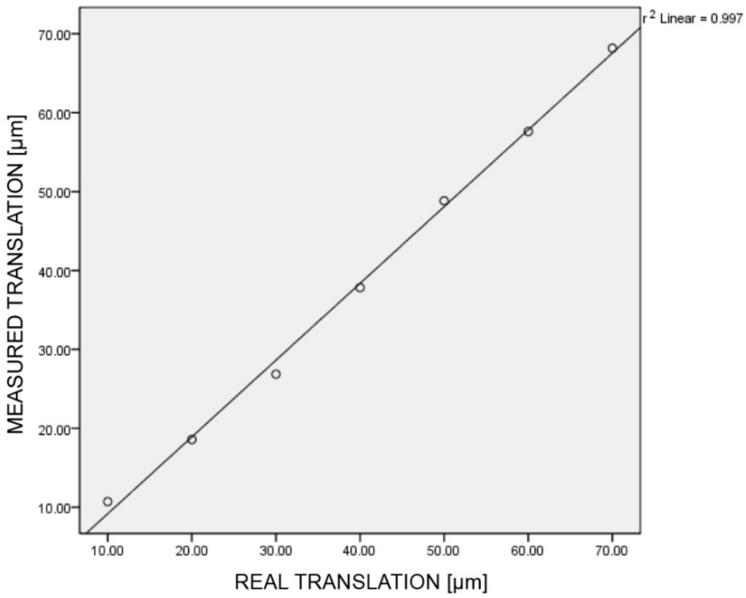

Fig. 5 – A summary overview of the single clinical cases separated by morning scans (a.m.) and afternoon scans (p.m.). The patient`s identity is shown by the numbering on the category axis. The data was analysed in three groups (labelled at the right): lying positions, lying versus sitting positions and sitting positions. Every circle corresponds to one superimposition result of two different buccal scans (n=570).

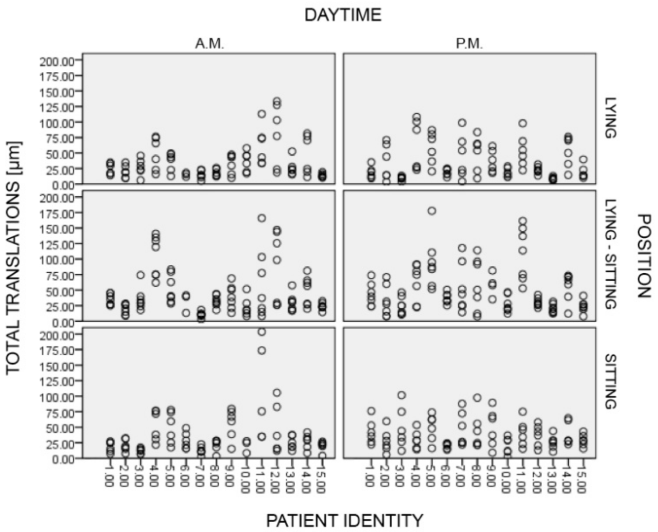

Fig. 6 – Same results as Fig. 5, showing the mean of the total translations and additionally the standard deviations. The patient`s identity is shown by the numbering on the category axis.

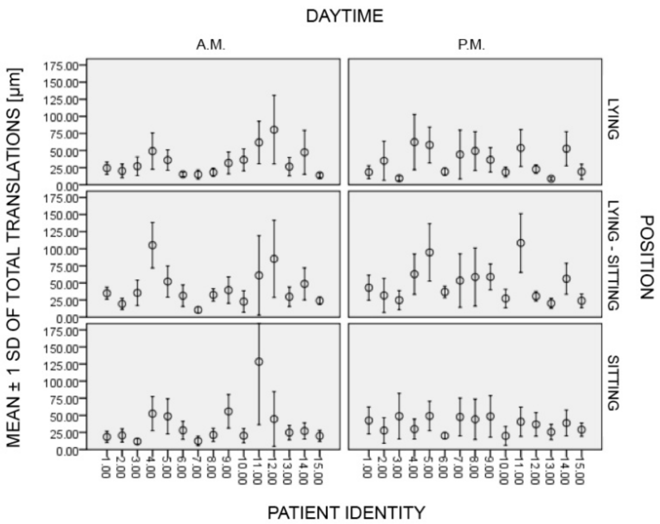

Fig. 7 – The mean and the standard deviation for locating the habitual intercuspation of the five plaster cast cases are displayed.

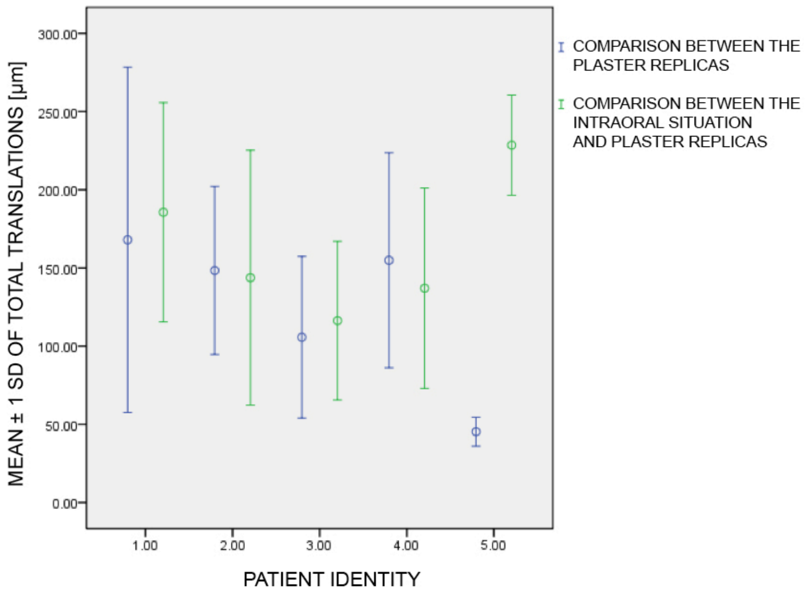

Fig. 8 – The mean and the standard deviation for locating the habitual intercuspation of the five plaster cast cases are shown in dependence of the three operators (ID 1, 2 and 3). No significant difference could be observed between the single operators (p<0.05).