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Transferring Occlusal Anatomy from Worn Temporary Crowns to Zirconium Oxide Crowns

Keywords

In Vitro
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ABSTRACT

Purpose/Aim: To evaluate the accuracy of transferring the occlusal anatomy of provisional crowns to monolithic zirconium oxide crowns. Materials and Methods: From a prepared typodont-tooth (#36), ten CAD/CAM provisional polymethylethacrylate crowns were fabricated with the E4D system. Each provisional crown had its occlusion adjusted. They were scanned (E4D) and the .stl files of the crown preparations were merged with the files from the adjusted crowns (3 shape software) to produce ten polished monolithic zirconium oxide crowns. For comparison, provisional and monolithic zirconium oxide crowns were scanned (True-Definition scanner), the .stl files aligned, converted into a normalized 76x76-matrix, analyzed with ANOVA with repeated measures and Tukey's test. To generate deviation distribution tables and difference plots, .stl files (provisional crowns and monolithic zirconium oxide crowns) were merged with Geomagic software. Results: There were significant differences between provisional crowns and monolithic zirconium oxide crowns. The differences were manly in the fissure area. 86% of the calculated deviations were between + 0.06mm and - 0.04mm, 42.4% of all data points were within ± 0.022mm with a SD of 0.005mm. The main differences were in the fissures, requiring clinically none or only minimal occlusal adjustments for these zirconium oxide crowns.

INTRODUCTION

Clinicians restoring the dentitions of patients with crowns and fixed dental protheses (FDP) must solve, together with the dental technician a multitude of technological and clinical problems. First, the chain from gathering information about the prepared abutments to the manufacturing of the final crown or FDP must yield an object that shows a high trueness of the fit. In classical manufacture of metal or glass based ceramics this is accomplished by matching expansion and contraction of the different materials during the manufacturing process, including to provide a definite space for the cement used for the final cementation. [1-4] The second problem is to create the correct occlusal anatomy, which allows the patent to function without interferences. In the classical way, this is accomplished with complex articulators that allow to reproduce the true movements of the yaws with the master model on which the technician is creating the occlusal anatomy. Very often simpler articulators are used, which may only give information about the centric occlusion, which then may require occlusal adjustment of the crown or FDP during the try in and cementation session. In the digital world, most of the time the anatomy of neighboring teeth is analyzed and either extrapolated to the tooth to be reconstructed or based on the analysis, a tooth form from a digital library is used and adapted to the situation in a static way.[5] This may require occlusal adjustments as well. Extensive research has shown that virtual articulators are very precise in predict the occlusion that should be used for each patient;[6-8] however, these are usually only used in complex cases.

The third problem is, that unless a chairside crown is produced with CAD-CAM, a temporary crown must be produced to protect the pulpal tissues from bacterial contamination, to temporarily maintain the three-dimensional position of the tooth, to keep normal occlusal contact, the ability of the patient to chew and speak, and to restore the esthetics of the patient.[9-12] In the analog world, there are many ways to produce temporary restorations. The common denominator is that a fast process must be used to produce a temporary chairside or reline a previously produced shell usually with inexpensive materials (polymethyl methacrylate [PMMA] or bis-acryl)[13,14] a temporary that more or less fulfills the above mentioned criteria.[9-11,15] Furthermore, these materials lack sufficient mechanical properties to correctly fulfil the task.[15] The consequences are bad, because either the dentist chooses to make them with a correct anatomy, but risking fractures, especially if pontics are involved, or the temporary is designed in a rather bulky version, thus compromising cleansability and subsequently periodontal health. The CAD-CAM technology has changed this dramatically, because, once the data are gathered with an intraoral scan, the file for the final restoration can be generated and used to machine a crown with the same shape as the final restoration, but in a less expensive material (Polymethyl methacrylate blocks).[11,12]

Today, the favorite material used for all ceramic crowns in the posterior area is zirconium oxide ceramic,[5] which must be stabilized with Yttria in order to maintain its tetragoal crystal lattice (Y-TZP). Without stabilization, cooling down below 1100 ˚C ZrO_2 ceramic would go to a crystal lattice change from tetragonal to monoclinic, which has unfavorable mechanical properties. This change called martensitic transformation[16] is accompanied by a 5% expansion of the material, which is attributed to the excellent mechanical properties (see below). In early applications Y-TZP was used to produce frameworks, which were then veneered mainly with feldspathic ceramic for better aesthetics.[17,18] However with this approach many chipping fractures of the veneering materials were reported in its clinical use.[19-21]

To avoid this, the trade has moved to use so called monolithic zirconium oxide crowns,[5,22-24] which take full advantage of the high strength, which depending on the measuring technique is reported to be between 886 MPa and 1526 MPa[25-31] and toughness of 7 – 10 $MPam^{-½}$ [29,32,33] of Y-TZP.

These excellent mechanical properties are due to the fracture toughening mechanism (martensitic transformation) inherent to Y-TZP and preclude a so called hard milling process which requires very robust machining equipment[22] and is not cost effective. Furthermore, this milling results in increased surface roughness, surface damage, crack initiation and higher monoclinic monoclinic phase transformation.[34-36] Therefore, todays favorite process is to machine the Y-TZP in the green state and fire it subsequently, with the result of approximately 20% shrinkage. Therefore, the machining must produce objects that are 20% larger than the desired end product.[37]

As stated above, machining a fully sintered Y-TZP creates microcracks at the surface which triggers locally crack induction followed by martensitic transformation from the tetragonal phase to the monoclinic phase in order to close the cracks due to the volume increase.[34-36] The same applies when adjusting the occlusion of Y-TZP monolithic restorations. Monoclinic phase at the surface increases the low temperature degradation of Y-TZP.[38,39] A high correlation was found between increased monolithic fraction and and the decline in mechanical response.[38] This can only be partially releaved by annealing the ceramic for 15 minutes at 1015 ˚C, which in the clinical situation either requires the dentist to have access to an oven or means that after try in, a further appointment must be scheduled for final cementation. Grinding on a fully sintered ceramic leads to substantial strength degradation, reduced reliability[39] and decreased biaxial flexural strength.[40] Surface and subsurface damage, with formation of microcraters and grain pullout were reported.[41] If this damage remains it could later lead to failure by crack propagation.[41]

Mitov *et al*[42] have shown *in vitro* that diamond ground Y-TZP induces significantly higher wear of enamel antagonists as highly polished Y-TZP. They concluded that after occlusal correction the surface of Y-TZP must be meticulously polished to a high gloss, which is difficult and time consuming.

Based on the facts stated above it would be favorable to have Y-TZP restorations which do not require any occlusal adjustments. The CAD-CAM technology in combination with the availability of PMMA blocks allows theoretically to accomplish this objective. Once an abutment is prepared, the situation can be recorded with an intraoral scan. Then the final reconstruction can be designed and a PMMA temporary crown can be milled. After insertion the occlusal anatomy can be adjusted, and the patient may wear this crown for a short time thus fine tuning the occlusal anatomy from slight wear. During this time adjustments can be made to ensure that the dental occlusion, TMJ wellness and patient satisfaction will be achieved. Thus, provisional treatment is an important step where significant information from the patient occlusion masticatory behavior is collected and subsequently applied to the definitive restorative materials; the exclusion of this essential step can be the difference between oral rehabilitation treatment success and failure.[43,44] Provisional FDPs will provide an ideal template for the final restorations. They will define the occlusion, tooth contour, esthetics, and vertical dimension of the occlusion[45]. Once the Patient is comfortable with the reconstructive situation, the occlusal anatomy can be recorded again with an introral scanner and then be superimposed on the original stl. file.

Currently, chairside intraoral scanners have software features to allow the operator to scan the desired occlusal contours from an existing template, such as a wax-up or provisional restoration, prior to milling the definitive restorations.[46] With a scan of the tooth preparation and an additional scan of the predetermined occlusal anatomy, a definitive restoration can be milled and sintered. With this a final reconstruction should be produced that does not require any adjustments, because all possible errors of static occlusion or virtual articulators are eliminated, and because the patient directly determined the correct occlusion by his/her masticatory movements. To the knowledge of the authors, there is no study that has numerically investigated, if this concept really works so far.

The purpose of this study was to transfer the shape of the occlusal surface of temporary milled PMMA crowns, worn by patients (simulated) to monolithic ZrO_2-crowns. The null hypothesis was that the anatomy of the ZrO_2-crowns is identical with the occlusal anatomy of the temporary crowns.

MATERIALS AND METHODS

MANUFACTURING OF THE SAMPLES

A dental mandibular model (Ivoclar Vivadent) with a 1st molar die tooth preparation (tooth #36) was contrast sprayed (IPS Contrast Spray Chairside),and scanned using an E4D scanner *(Figure 1)*. A crown was virtually designed utilizing the digital library of the Planmeca software (Romexis). Ten identical temporary crowns were milled from CAD/CAM PMMA blocks (Telio CAD), with the E4D milling machine from the tooth preparation scans and labelled P1-P10. To simulate the occlusal adjustment process, all PMMA crowns were modified individually. The high points on the occlusal surface were marked with a pencil by clinically delineating the cusp tips and cuspal slopes. These areas were adjusted with a carbide bur (H251UM.11.060 HP UM Cutter Carbide) on a laboratory motor/hand piece (Forza L50K), arbitrarily at 10,000 rpm. Crowns were finished using rubber points (W1.21 White Flame Universal Silicone Polisher) with a slow speed hand piece at 5,000 rpm. Crowns were polished using medium and fine pumice.

The first PMMA sample (P1) was seated on the die using Fit Checker. Contrast spray was applied to the mandibular left quadrant. The quadrant was scanned using an E4D scanner. This process was repeated for all other samples (P2-P10). These scans were labelled PW1-PW10.

The .stl files of the scan of the models with the “worn” PMMA crowns (PW1-PW10) and the scan of the preparation were imported to the 3 Shape software. Corresponding points on the adjacent teeth were identified and marked to align the images together. By selecting the “manually align” icon, the software automatically morphed the tooth into its place on the tooth preparation. The margin line was then marked on the tooth preparation. The anatomy of the design of the PW1 – PW10 crowns was verified and confirmed. A Zenotec Select Hybrid milling machine was used to mill ZrO crowns (Z1-Z10) out of a ZrO disk (IPS ZirCAD MO) resulting in ten individualized ZrO crowns (Z1-Z10). Sintering of the ZrO crowns was done using a Programat CS4 sintering oven. All ZrO crowns (n=10) were polished with an Optrafine polishing kit using the burs in sequential order from fine to high polish.

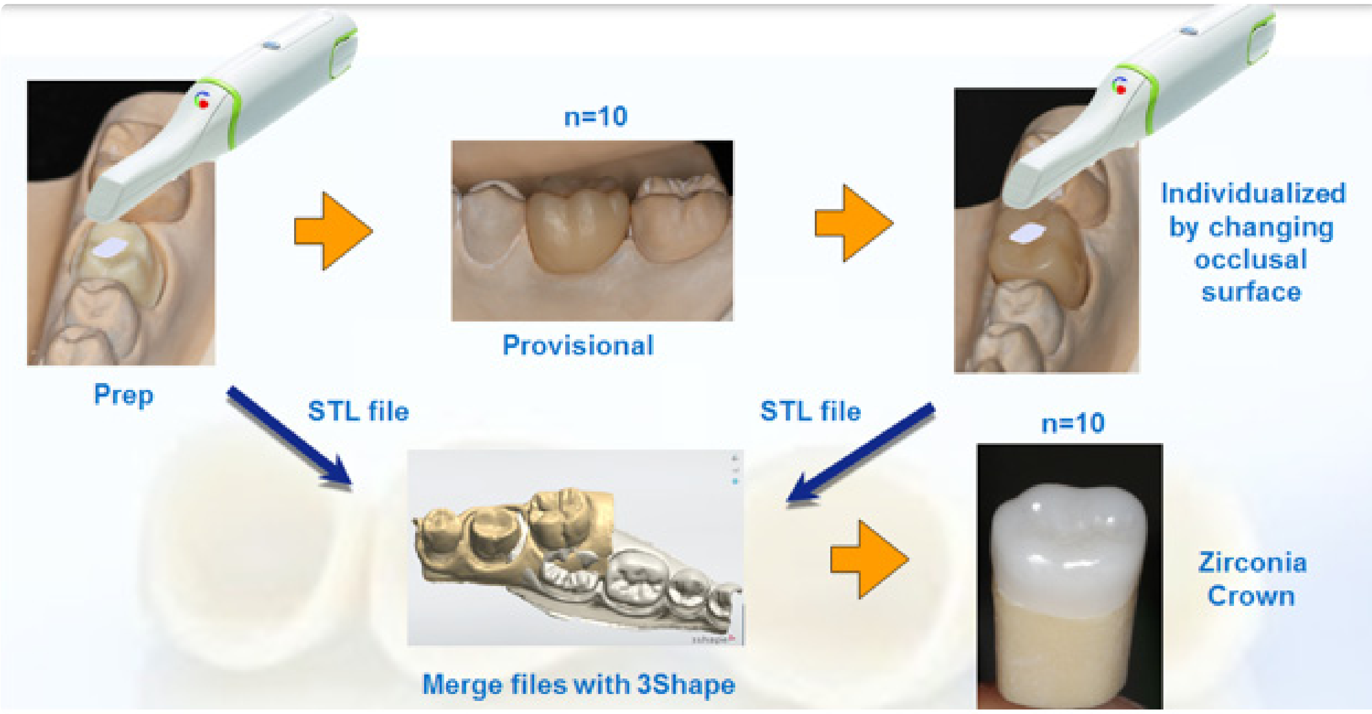

Figure 1: Experimental design 1. Manufacturing the temporary and permanent FDPs: Using a E4D scanner, Telio Cad Temporary FDPs (PMMA) were made and their occlusion adjusted individually. Afterwards the PMMA crowns were scanned and the anatomy of the crowns inserted into the scan of the crown preparation. The resulting .stl-file was used to produce Zir-CAD LT (ZrO_2) crowns.

MEASURING THE CROWNS

The ZrO_2 crowns (Z1 – Z10) were tried on the model to verify the intaglio fit. Fit Checker was applied to the crowns to stabilize them on the molar die. High resolution scanning spray was applied to the crowns along with a portion of the die that incorporated a notch. The assemblies were scanned with a True Definition Scanner. The same procedure was repeated with the temporary PMMA crowns (PW1 – PW10). The .stl files of the ZrO crowns and the ones of the "worn" PMMA crowns were uploaded on the Geomagic software. For the pairwise comparisons (Z1 - PW1, Z2 – PW2, ... Z10 – PW10) the notches of the die were used as a reference to merge the 2 scans together using the Best Fit feature. The merged images were then sliced to eliminate any information below the equator of the crowns. Using the Geomagic compare program, the vertical differences (z-axis) for every x-y point were then determined and displayed in a color-coded 3D map *(Figure 2*). To visualize the important areas, for the most common occlusion points on Class I, II, and III occlusions[47] were superimposed to the 3D pictures.

For the statistical analysis of the data the following steps were performed: First for each pair the .stl files of the "worn" PMMA crowns and the ZrO crowns were merged using the FreeCAD software. Using the Fiji platform and Image J software, the data were converted into x, y, z coordinated mesh voxel (.obj) and converted into a 76 x 76 Matrix of the z values (Origin Pro). The 76x76 matrix file was imported into statistical analysis software (Stata/MP 13). Statistical analyses were performed with a level of significance of $\alpha = 0.05$. Power analysis was conducted to determine the sample size for each experiment to provide a power of at least 0.8 at a significance level of 0.5 (β= 0.2). Data were checked for normality using Shapiro–Wilk's test and for variance homoscedasticity using Lavene's test. The deviation between groups was analyzed using a repeated measurements analysis of variance (ANOVA) where the independent variables were set as between-subject groups for the crowns (PMMA or ZrO Crowns) and as within-subject groups for mesial-distal and buccal-lingual distances.

RESULTS

The frequency distribution plot *(Figure 3*) shows that 86% of the calculated deviations (z-axis) are between + 0.06 mm and – 0.04mm. The mean was calculated to be 0.016 mm ± 0.03 mm *(Table 1*). This was well in the mean deviation over the whole occlusal view of all teeth as shown in Figure 4. The ANOVA Table is shown in Table 2. There were significant differences between the z-values of the PMMA- and ZrO_2-crowns.

However, when a significance plot was generated *(Figure 5*), the statistically significant differences were concentrated in the fissure area and in the periphery, where very steep slopes are compared. When looking at the location of the contact points (black dots in Figures 4 and 5) it is obvious that there were no significant differences in the areas where occlusal contacts would occur.

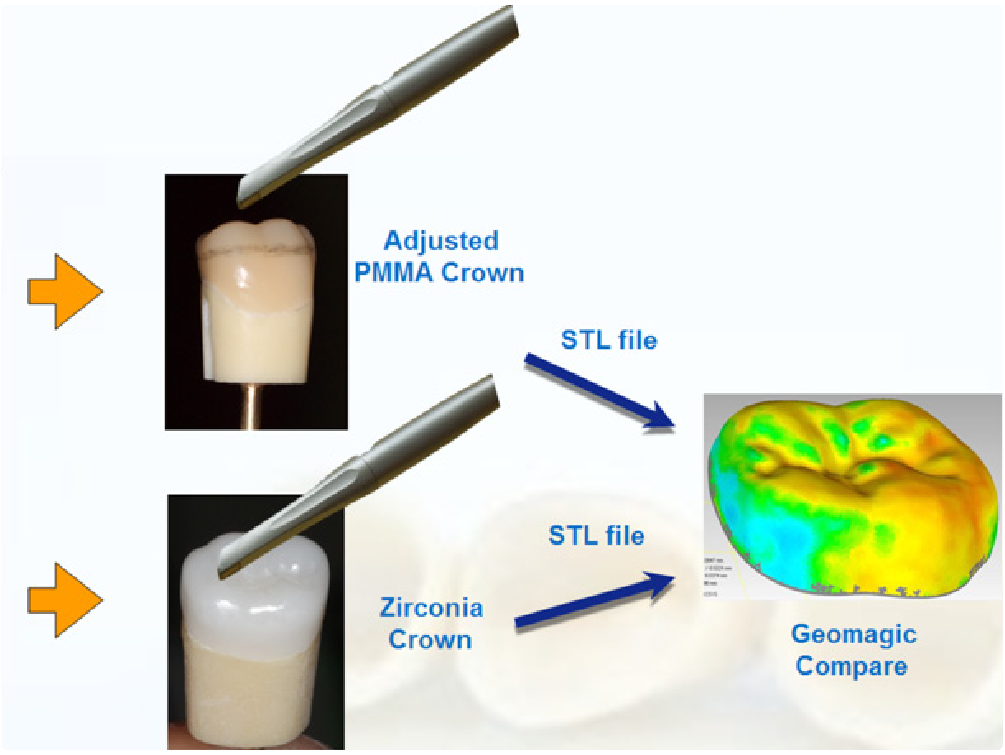

Figure 2: Experimental design 2. Using a True Definition Scanner, the occlusal surface of the PMMA crowns and the ones of the ZrO_2 crowns were scanned. The resulting .stl-files were imported into Geomagic software, superimposed, and trimmed, resulting in color coded difference maps.

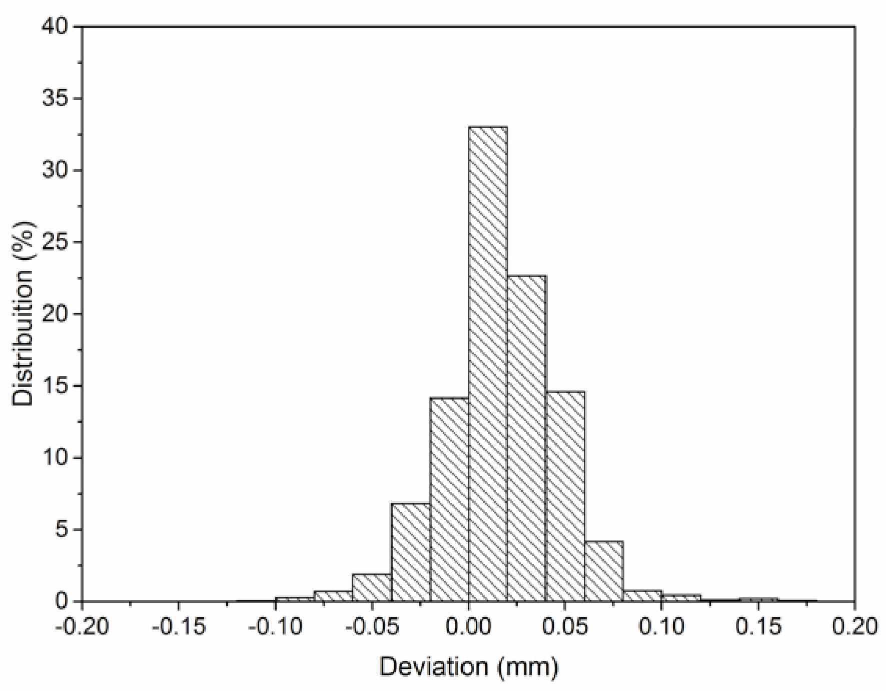

Figure 3: Frequency distribution plot of the deviations between the PMMA- and the ZrO_2-crowns.

Table 1. Average, Standard Deviation, Mode, Minimum and Maximum of the deviation (in mm) from the "worn" provisional crowns and the zirconia crowns.

	Average	SD	Mode	Minimum	Maximum
Deviation (mm)	0.0158	0.0302	0.0002	-0.1300	0.1760

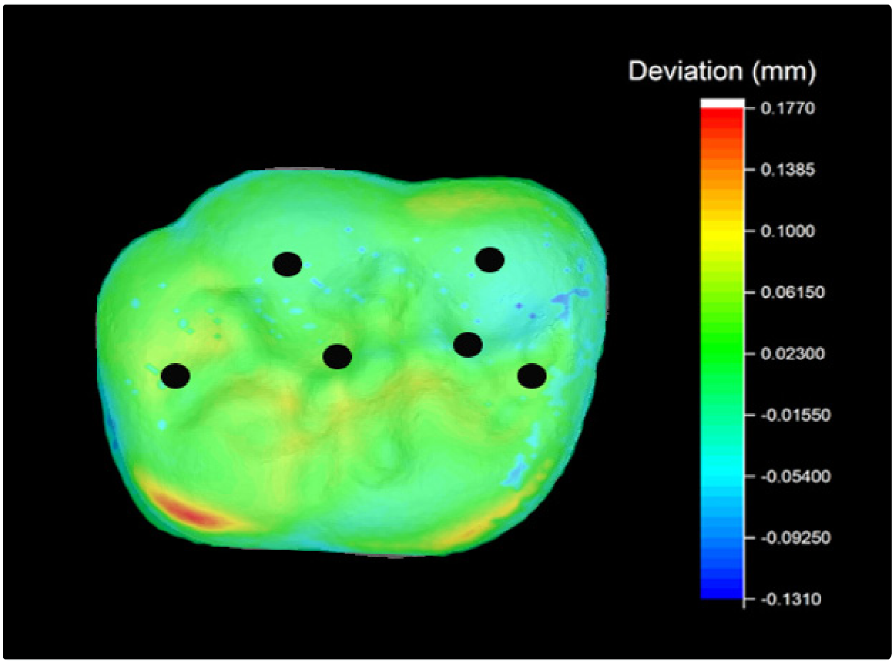

Figure 4: Color coded difference map for the mean differences of 10 ZrO_2 crowns, compared to 10 PMMA crowns. Black dots are the anticipated contact points of a mandibular premolar occlusal surface.

Table 2 - Repeated measurements analysis of variance for the PMMA and ZrO_2 crown. The coordinates x (mesial-distal) and y (buccal-lingual) are set as the within-subject groups nested in the PMMA versus ZrO_2 between subject group set.

		Number of observations = 34,656 Root MSE = 0.297185		R-square = 0.0043 Adj R-squared = 0.0043	
Source	**Partial SS**	**df**	**MS**	**F**	**Prob>F**
Model	13.24	2	6.62	74.98	p < 0.0001
x#y | PMMA#ZrO_2	13.24	2	6.62	74.98	p < 0.0001
Residual	3060.51	34653	0.09		
Total	3073.75	34655	0.09		

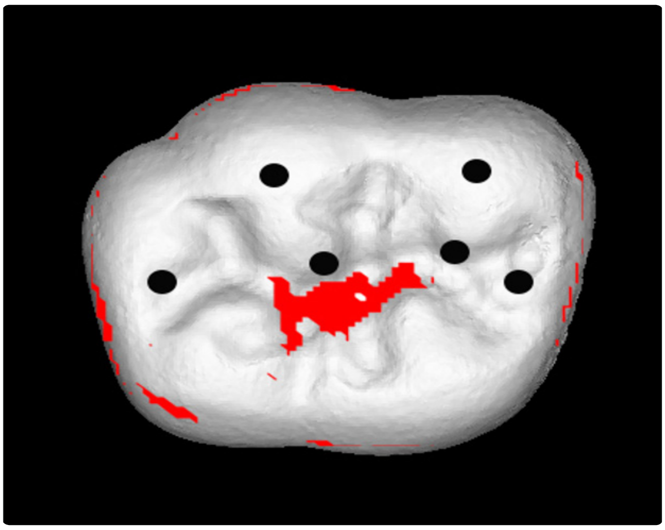

Figure 5: Statistical significance plot of the differences in the occlusal surface between 10 PMMA crowns and 10 ZrO_2 crowns. White = NS, red = p,0.05. Black dots = position of anticipated occlusal contacts of the occlusal surface of a mandibular premolar.

DISCUSSION

Recently, CAD/CAM technologies were used to fabricate temporary restorations. Resin based blanks (PMMA) cured prior under optimal conditions exhibit increased mechanical strength and prevent porosities within the restorations.[11,12,15,48-50] In addition, CAD/CAM fabricated temporaries reportedly reduce the chairside time and produce superior results.[51] Since statistically significant differences were found, the null hypothesis was rejected. However, since these changes occurred not in clinical relevant occlusal areas (mainly fissures) it can be expected that these crowns would have been able to be delivered with no or minimal occlusal adjustments.

To reduce variation, only one crown shape was used. However, the occlusal adjustment of the PMMA crowns was individualized. For manufacturing the crowns, the E4D-system was used *(Figure 1)*, which was familiar to the experimenter (SM) due to its clinical use, and showed sufficient trueness and precision. For sextant scanning, The E4D scanner was found to be the most precise and true scanner.[52] The E4D scanner has a scanner accuracy of 48 microns. In order not to perpetuate the inherent scanner errors of the manufacturing part of the study, a scanner with maximal single tooth accuracy[53-55] was used for the evaluation part of the study *(Figure 2)*. The translucency of the scanned material may influence the accuracy of powderless scans.[56] Since in the present study two different materials with most probably different translucencies were compared, it was decided to use a scanning powder for the evaluation, even knowing that another variable was introduced that might have added to the variability of the results. On the other hand, comparisons of powdered vs non powdered teeth have shown better accuracy if powder had been applied.[57] Therefore, the decision to use powder was not only beneficial for the evaluation, but also for the manufacturing of the crowns.

The week point of the study is that no ZrO_2 crowns manufactured just on the base of a digital impression, using a tooth library were used for a comparison. This was deliberately omitted for the following reasons: Occlusal discrepancies mainly occur due to faulty articulation of models in both worlds (CAD/CAM or conventional manufacture). Furthermore In the CAD/CAM world it is a function as well of the diligence during the construction of the FDPs. To check the accuracy of the occlusion, even with articulated models, errors occur, and therefore there is no way but involving patients. This was deliberately omitted, because an additional variable, being the subjective potential for patients to compensate for faulty occlusion and thus the variability in the assessment of a correct occlusion in the dental chair. Since the present study was set up as a proof of principle the patient's individual "fine tuning" of the occlusion by wearing a PMMA temporary was simulated with a change of occlusion induced with a bur *in vitro*. Based on clinicl experience, the authors are convinced, that wearing new indirect restorations for a few days after insertion helps efficiently to eliminate occlusal interferences.

Since statistically significant differences between the "worn" PMMA crowns and the ZrO_2 crowns were found, formally the null hypothesis must be rejected. However the average deviation was around 0.02 mm with 94% between -0.05 mm and + 0.05 mm, and approximately 70% between -0.03 and +0.03 mm (*Figure 3*), which is clinically acceptable, especially since the significant differences were situated in the fissure area and not in areas where usually the contact points are located (*Figure 5*). If the ideal occlusal balance is taken into consideration, pit, fossae, and fissures are the ending point of the occlusal movement in case of centric relation or maximum intercuspation. However, areas such as scaping sulcus and grooves are critical because any interference during excursive movements can be deleterious to the material mechanical strength and the periodontal ligament. However, the results show that only the central fossae and the non-function area of the marginal ridges, buccal, and lingual cusps had significant statistical differences. Therefore, the occlusal contact areas and the path areas of disocclusion are free from interference, which can be lead to infer that these crowns can be delivered without significant occlusal adjustments.

One of the big advantages of the CAD/CAM approach is the possibility to make chairside crowns in one appointment. However, this holds only for Leucite reinforced or Lithium Disilicate ceramics, where the sintering times are less than 1 hour. Since the sintering process for ZrO_2 FDPs is substantially longer than the ones of Lithium Disilicate ceramic crowns, this advantage disappears. The newest development is that Glidewell has introduced into the market a system for one appointment ZrO_2 crowns, using the hard machining technique, called Bruxcir Now™. Leeson[5] claims that with this approach "The system relies on numerous innovations in machine technology, CAM algorithms and diamond abrasives to process the incredibly hard and difficult to machine material with the bur removing less than 10 microns of material per pass. This creates a surface texture even finer than a lab made crown that has a polished appearance and may be used directly without glazing." Further investigations on this process should be done in order to measure the abrasiveness to enamel of such surfaces and to exclude that the process induces unwanted microcracks or a tetragonal – monolithic transformation at the surface.

On the other side, polishing ZrO_2 after occlusal adjustment is quite time consuming and must be done by the dentist after the cementation. Therefore, the dentist must balance the time effort of occlusal adjustment and subsequent polishing vs a short additional session for scanning the occlusion of the "worn" PMMA temporaries. The authors think that the more restorations are involved the likelier it is that the presented method is useful and time saving. Furthermore, the method presented for the comparison could be used for quality control of the milling/sintering process of zirconium oxide crowns, since .stl files are compared to each other. By scanning the finished crown and comparing the file with the one of the designs would allow to verify the correct dimensions of the final product.

CONCLUSION

A temporary FDP, worn by the patient to his/her satisfaction can be duplicated with precision into a permanent ZrO_2 FDP that could be cemented with no or minimal occlusal adjustment.

MANUFATURERS DETAILS (IN THE ORDER OF APPEARANCE)

- Mandibular model: (Ivoclar Vivadent, Schaan Liechtenstein)
- Contrast spray: (IPS Contrast Spray Chairside, Ivoclar Vivadent
- E4D scanner: (E4D Technologies/Planmeca, Richardson TX, USA)
- Planmeca software: (Romexis, Planmeca USA, Hoffman Estates, IL)
- CAD/CAM PMMA blocks: (Telio CAD, Ivoclar Vivadent)
- E4D milling machine: (E4D Technologies , Richardson TX, USA)
- Carbide bur: (H251UM.11.060 HP UM Cutter Carbide, Brasseler USA, Savannah, GA)
- Laboratory motor/hand piece: (Forza L50K, Brasseler USA),
- Rubber points: (W1.21 White Flame Universal Silicone Polisher, Brasseler USA)
- Fit Checke:r (GC, Tokyo, Japan).
- 3 Shape software: (Trios Design Studio, 3 Shape, Copenhagen, Denmark)
- Zenotec Select Hybrid milling machine: (Wieland Dental + Technik GmbH & Co KG, Pforzheim, Germany)
- Zirconium oxide disk: (IPS ZirCAD MO): Ivoclar Vivadent
- Programat CS4 sintering oven: (Ivoclar Vivadent)
- Optrafine polishing kit (Ivoclar Vivadent)
- High resolution scanning spray: (3M, St. Paul, MN USA)
- True Definition Scanner (3M)
- Geomagic software: (3D Systems Corporation, Rock Hill, SC, USA)
- FreeCAD software: (https://www.freecadweb.org
- Image J software: (Fiji, Nature Methods, National Institutes of Health, Bethesda, MD, USA)
- Origin Pro software: (OriginLab Co., Northampton, MA, USA)
- Stata/MP13 software: (Stata Corp. College Station, TX, USA).

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