Three-Dimensional Digital Evaluation of the Fit of Endocrowns Fabricated from Different CAD/CAM Materials

Zimmermann, Moritz ; Valcanaia, Andre ; Neiva, Gisele ; Mehl, Albert ; Fasbinder, Dennis

Abstract: Purpose A wide variety of CAD/CAM materials are available for single-tooth restorations. CAD/CAM material characteristics are different and may influence CAM fabrication accuracy. There is no study investigating the influence of different CAD/CAM materials on the final fit of the restoration. The aim of this study was to evaluate the fit of endocrowns fabricated from different CAD/CAM materials using a new 3D evaluation method with an intraoral scanning system. The null hypothesis was that there are no significant differences for the fitting accuracy of different CAD/CAM materials. Materials and Methods Preparation for an endocrown was performed on a maxillary right first molar on a typodont, and restorations were fabricated with a chairside CAD/CAM system (CEREC Omnicam, MCXL). Three groups using three different CAD/CAM materials were established (each n = 10): zirconia-reinforced lithium silicate ceramic (Celtra Duo; CD), leucite-reinforced silicate ceramic (Empress CAD; EM), resin nanoceramic (Lava Ultimate; LU). A 3D digital measurement technique (OraCheck, Cyfex AG) using an intraoral scanner (CEREC Omnicam) was used to measure the difference in fit between the three materials for a master endocrown preparation. The preparation scan and the endocrown fit scan were matched with special difference analysis software OraCheck. Three areas were selected for fitting accuracy measurements: margin (MA), axial (AX), occlusal (OC). Statistical analysis was performed using 80% percentile, one-way ANOVA, and post-hoc Scheffé test. Significance level was set to $p = 0.05$. Results Results varied from best 88.9 ± 7.7 m for marginal fit of resin nanoceramic restorations (LU_MA) to worst 182.3 ± 24.0 m for occlusal fit of zirconia-reinforced lithium silicate restorations (CD_OC). Statistically significant differences were found both within and among the test groups. Group CD performed statistically significantly different from group LU for marginal fit (MA) and axial fit (AX) ($p < 0.05$). For occlusal fit (OC), no statistically significant differences were found within all three test groups ($p > 0.05$). Deviation pattern for differences was visually analyzed with a color-coded scheme for each restoration. Conclusions Statistically significant differences were found for different CAD/CAM materials if the CAM procedure was identical. Within the limitations of this study, the choice of CAD/CAM material may influence the fitting accuracy of CAD/CAM-fabricated restorations.

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TITLE

Three-Dimensional Digital Evaluation of the Fit of Endocrowns Fabricated from Different CAD/CAM Materials

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ABSTRACT

Purpose: A wide variety of CAD/CAM materials are available for single-tooth restorations. CAD/CAM material characteristics are different and may influence CAM fabrication accuracy. There is no study investigating the influence of different CAD/CAM materials on the final fit of the restoration. The aim of this study was to evaluate the fit of endocrowns fabricated from different CAD/CAM materials using a new 3D evaluation method with an intraoral scanning system. The null hypothesis was that there are no significant differences for the fitting accuracy of different CAD/CAM materials.

Materials and Methods: Preparation for an endocrown was performed on a maxillary right first molar on a typodont, and restorations were fabricated with a chairside CAD/CAM system (CEREC Omnicam, MCXL). Three groups using three different CAD/CAM materials were established (each n = 10): zirconia-reinforced lithium silicate ceramic (Celtra Duo; CD), leucite-reinforced silicate ceramic (Empress CAD; EM), resin nanoceramic (Lava Ultimate; LU). A 3D digital measurement technique (OraCheck, Cyfex AG) using an intraoral scanner (CEREC Omnicam) was used to measure the difference in fit between the three materials for a master endocrown preparation. The preparation scan and the endocrown fit scan were matched with special difference analysis software OraCheck. Three areas were selected for fitting accuracy measurements: margin (MA), axial (AX), occlusal (OC). Statistical analysis was performed using 80% percentile, one-way ANOVA, and post-hoc Scheffé test. Significance level was set to $p = 0.05$.

Results: Results varied from best 88.9 ± 7.7 µm for marginal fit of resin nanoceramic restorations (LU_MA) to worst 182.3 ± 24.0 µm for occlusal fit of zirconia-reinforced lithium silicate restorations (CD_OC). Statistically significant differences were found both within and among the test groups. Group CD performed statistically significantly different from group LU for marginal fit (MA) and axial fit (AX) ($p < 0.05$). For occlusal fit (OC), no statistically significant differences were found within all three test groups ($p > 0.05$). Deviation pattern for differences was visually analyzed with a color-coded scheme for each restoration.

Conclusions: Statistically significant differences were found for different CAD/CAM materials if the CAM procedure was identical. Within the limitations of this study, the choice of CAD/CAM material may influence the fitting accuracy of CAD/CAM-fabricated restorations.

CAD/CAM technology represents an acceptable technique for the fabrication of indirect restorations.[1] In recent years, several new types of CAD/CAM materials have been introduced for clinical application.[2] Most commonly used CAD/CAM materials are ceramics and polymer-based composites. Both material classes have significantly different characteristics and physical properties.[3,4] Different material characteristics may result in different machinability with CAD/CAM milling machines. Resin-based CAD/CAM blocks have been shown to have a higher margin stability compared to ceramic materials.[4] To ensure well-fitting restorations, ceramic-based materials may require certain material thicknesses, as they are more brittle and thus more susceptible to fracture.

The fitting accuracy of restorations has been shown to influence the clinical long-term success of restorations. Marginal misfits are reported to result in increased microleakage and the dissolution of the luting cement.[5] Wettstein et al demonstrated that loading fracture of restoration decreases with increasing cement gap thickness.[6] Additionally, the joint bend strength on luting cement and restoration material joint is negatively altered for poorly fitting restorations.[7]

The material characteristics of CAD/CAM materials may be different, thus influencing their CAM machinability. Particle-filled composite resin materials such as Lava Ultimate (3M ESPE, St Paul, MN) have a polymer matrix with embedded filler particles of different size. Ceramic materials such as Empress CAD (Ivoclar Vivadent, Schaan, Liechtenstein) or Celtra Duo (Dentsply Sirona, York, PA) are built of a ceramic glass framework with embedded crystals. Lava Ultimate has a resin framework with embedded ceramic particles of 4 to 11 nm.[2,8] For Empress CAD there is a glass matrix with embedded leucite crystals with 100 to 500 nm diameter.[9] For Celtra Duo the glass matrix consists of embedded particles with a diameter of 500 to 800 nm.[10] Zirconia-reinforced lithium silicate ceramics and leucite-reinforced silicate ceramics are available from the manufacturer as a completely crystallized block. This is in contrast to lithium silicate ceramics such as e.max CAD (Ivoclar Vivadent). For e.max CAD a firing process under vacuum is needed to complete the crystallization process once the restoration has been fabricated. The post-processing procedure for particle-filled composite resin CAD/CAM materials such as Lava Ultimate may be hand polishing.

Many factors influencing the final fit of restorations have been described in literature. These factors include preparation form, parameter setting, and cement type.[11-13] CAM machinability is a crucial factor and important especially for the aspect marginal area. The marginal fit of a restoration is crucial for a high clinical long-term success of the restoration. If too much material is left due to insufficient milling, the restoration cannot be seated correctly and may be seated with occlusal discrepancy. This may result in intense occlusal adjustments and marginal chippings. If too much material is milled around the marginal area, microleakage is possible.

Restoration of endodontically treated teeth is usually performed with crowns and post-and-core abutments in the case of complete loss of coronal hard tissue. So-called endocrown restorations represent a less-invasive, alternative approach to restore non-vital endodontically treated teeth. The preparation for an endocrown normally comprises a circular butt margin preparation and the preparation of a central retention cavity of the entire pulp chamber. CAD/CAM-fabricated endocrowns have been intensively investigated in recent literature.[14,15]

The fitting accuracy of CAD/CAM fabricated restorations is crucial for clinical long-term success. Because of different material characteristics the fitting accuracy may be significantly influenced by the type of CAD/CAM material chosen; however, there is no study available addressing the fitting accuracy of CAD/CAM restorations as a function of material type. The aim of this study was to investigate the influence of different CAD/CAM materials for fitting accuracy with a new 3D method. The null hypothesis was that there are no significant differences for the fitting accuracy if different CAD/CAM materials are used.

MATERIALS AND METHODS

A master endocrown preparation was completed on a maxillary right first molar on a typodont complying with the general guidelines for an all-ceramic preparation.[16] Parameters for the preparation were 1.5 mm anatomical reduction of all cusps, circumferential butt-joint margin with a central retention area representing the pulp chamber (2.0 mm depth). All internal angles were rounded. The endocrown preparation followed the guidelines published in recent literature and is illustrated in Figure 1.[14,15] The fabrication of the CAD/CAM restorations was performed with a chairside CAD/CAM system (CEREC; Dentsply Sirona). A powder-free intraoral scanning system (CEREC Omnicam; Dentsply Sirona) was used to make quadrant scans of the master preparation in respect to principles of scanning strategy.[17] CAD design was done with CAD Software (CEREC SW v.4.0; Dentsply Sirona) using biogeneric individual design mode. Parameter settings for endocrown restorations were set to the manufacturer's recommendations, with 80 µm spacer, 0 µm margin thickness, 400 µm minimum thickness radial, and 1500 µm minimum thickness occlusal. The milling unit CEREC MCXL (Dentsply Sirona) equipped with step bur 12S and cylinder pointed bur 12 was used for the fabrication of endocrowns. Milling mode was set to fine. Three groups were established based on different CAD/CAM materials: CD = zirconia-reinforced lithium silicate ceramic (Celtra Duo), EM = leucite-reinforced silicate ceramic (Empress CAD); and LU = resin nanoceramic (Lava Ultimate). Ten endocrowns of each material were fabricated for each test group (n = 10). Milling instruments and water were changed after ten restorations. No internal adjustment and no post-processing were performed after milling.

The method for the evaluation of fit applied in this study was a special 3D subtractive analysis technique using a proprietary software program (OraCheck, Cyfex AG, Zurich, Switzerland). The master crown preparation was scanned using an intraoral scanner (CEREC Omnicam) and saved as the master digital file of the preparation. Each of the test crowns was seated onto the master preparation, and a polyvinylsiloxane (PVS) impression technique was used to record the space between the surface of the master preparation and the internal surface of the crown, essentially the space available for the cement and the mismatch of the endocrown and the preparation surface.

First, the inner surface of the test endocrown was wiped with an ultra-thin layer of lubricant (Vaseline). Second, a thin layer of light-body PVS impression material (Aquasil Ultra LV; Dentsply Sirona) was inserted into the crown. The endocrown was seated on the master preparation with slight finger pressure for 15 seconds with approximately 250 N. Excess PVS material was carefully removed from the margins. The endocrown was carefully removed from the preparation after a setting time of 2 minutes for the PVS material. There was no manipulation done to the PVS material inherent to the preparation. For all endocrowns, clear adhesion of PVS material was diligently verified visually prior to the following steps to exclude any interference or bias for the method. Multiple pilot testing of the method prior to this study demonstrated high repeatability and precision of the steps described for this method. After removing the endocrown restoration from the preparation, a second quadrant scan with the intraoral scanning device was performed with the PVS material covering the preparation.

A proprietary 3D digital software program (OraCheck) was used to measure the dimensional differences between the two recorded quadrant scans for each test endocrown.[18] The two standard tessellation language (STL) data files were digitally matched in the software program. The digital scan of the PVS material/preparation represented a replica of the adhesive cement space and thus the internal (axial and occlusal) and marginal fit of the restoration within all three dimensions. The two quadrant scans were superimposed with the software´s best-fit algorithm. The subtractive analysis was accomplished by calculating the distances from each surface point of the first data set to the surface points of the second data set. Approximately 20,000 points per surface matching were selected. Three specific areas of interest for difference analysis were selected in the software using selective tools: group MA = margin fit, the circumferential area within 0.5 mm of the preparation margin line; group AX = axial fit, the circumferential area of the axial wall next to the occlusal top of the preparation with 0.5 mm diameter, group OC = occlusal fit, the circular area with 3.0 mm diameter in the middle of the occlusal top. The respective areas of the endocrown preparation selected are shown in Figure 1.

Difference values between the two matched STL files were measured by calculating the 80% percentile value. This indicates that 80% of the surface of the first scan (preparation scan) has less deviations compared to the second scan (PVS preparation scan). Values were exported as a CSV file and imported into statistical analysis software (SPSS; IBM Statistics, Armonk, NY). Kolmogorov Smirnoff test was used to test for normal distribution of the data. Levène test was used to test for homogeneity of variances. Descriptive statistics with calculation of mean, median, standard deviation and 95% confidence interval were calculated for each group. Statistical analysis was performed with one-way ANOVA and post-hoc Scheffé test ($p = 0.05$).

RESULTS

Equality of variances was found for the values of this study with a normal distribution of data. Results for different test groups of this study are shown in Table 1. Boxplots with median values are shown in Figure 2.

Statistically significant different values were found both within and among the test groups ($p < 0.05$). The best fit in all test groups was found for margin area ranging from 88.9 ± 7.7 µm for group LU_MA to 131.0 ± 26.5 µm for group CD_MA. The poorest fit in all groups was found for occlusal area ranging from 158.0 ± 8.1 µm for group LU_OC to 182.3 ± 24.0 µm for group CD_OC. The maximum value for restorations milled from leucite-reinforced silicate ceramic blocks (group EM) was found for the occlusal area with 177.0 ± 28.6 µm. The maximum value for restorations milled from resin nanoceramic blocks (group LU) was found for the occlusal area with 158.0 ± 8.1 µm. The maximum value for restorations milled from zirconia-reinforced lithium silicate ceramic blocks (group CD) was found for the occlusal area with 182.3 ± 24.0 µm.

Endocrown restorations fabricated from resin nanoceramic (LU) performed statistically significantly better than restoration from group CD ($p < 0.01$) in margin fit but did not perform statistically significant different in margin fit from group EM ($p = 0.99$). For occlusal fit (OC), no statistically significant differences were found within all three test groups ($p > 0.05$).

Homogenous subsets after one-way ANOVA and post hoc Scheffé test for all test groups are shown in Table 2.

DISCUSSION

The aim of this study was to evaluate the fit of endocrowns fabricated from different CAD/CAM materials. Based on the results found in this study, the null hypothesis that there are no significant differences for the fitting accuracy of different CAD/CAM materials has to be rejected. Statistically significant differences were found for the margin fit within the different test groups ($p < 0.05$). Resin-based composite materials performed statistically significantly better for aspect marginal fit than ceramic CAD/CAM materials. Results found for all groups showed relatively low standard deviations.

Many methods have been described for the evaluation of the marginal and internal fit of restorations.[19-21] Despite the method applied, there is a consensus about the clinically acceptable marginal gap for restorations with 120 µm.[22] Except for restorations from group CD (131.0 ± 26.5 µm), all values found in this study were below this threshold, which is in accordance with the literature published.

In this study, occlusal areas were found to be the worst fitting areas for all types of CAD/CAM-fabricated endocrown restorations. This is in accordance with recently published literature about the fit of CEREC restorations.[23,24] Because of the size of milling instruments, flat surfaces such as pulpal retention areas for endocrowns may be not milled precisely, as overmilling might occur.

In this study, a 3D evaluation method was applied with special statistical interpretation. Therefore, comparison of the results with other 2D fit evaluation methods cannot easily be made. In contrast to well-established 2D methods with distance measurement between artificially set reference points, the method described in this study uses a 3D circumferential analysis.

In this study, statistically significant differences were found for the marginal fit among the different test groups. One potential explanation for this may be that the marginal area with its very thin structure is the most difficult to mill. Both the pressure of the milling instruments and the resistance of the material itself may contribute to fractures at the margin. This effect is more likely to occur for brittle materials such as ceramic. In this study, it could be demonstrated that a resin-based material had better marginal accuracy compared to glass-ceramic materials. This observation is in accordance with the literature recently published showing the high margin stability of resin-based CAD/CAM restorations.[4]

Material characteristics may influence margin stability. Resin-based materials with a polymer matrix may allow the milling of thinner structures. In contrast, the glass matrix of ceramic materials is brittle, and ceramic crystallites may easily break out if pressure of milling instruments is applied. The larger the crystallites the more probable this effect may occur. In this study, the material with the largest crystal size (CD) also has the worst marginal fit with 182.3 ± 24.0 µm. The best marginal fit was found for group LU with 88.9 ± 7.7 µm. Results found in this study are in accordance with the material characteristics described in literature. Resin-based composite material restorations have a higher margin stability than ceramic materials.[4]

The material characteristics may influence CAM machinability. The material composition directly influences the wear of milling machine tools. The stronger the CAD/CAM material, the higher the wear rate of milling instruments. In this study, instruments were changed after every ten restorations. It is very likely that the longer instruments are used, the worse the results for the fit of the restorations could be. A recent study shows the influence of CAD/CAM tools and materials on tool wear and roughness of prostheses after milling.[23]

In this study, endocrowns were chosen as a restoration type to evaluate the fitting accuracy of different CAD/CAM materials. The design of an endocrown has been intensively described in literature.[26] Endocrowns are restorations for endodontically treated teeth and consist of a circular margin and a central retention cavity inside the pulp chamber. In general, studies to test the fitting accuracy of restorations are conducted with full-contour crown restorations. The design of an endocrown is far more complex, with many internal angles that may be difficult to mill for CAD/CAM milling units with their specific instrument geometries; however, it may be interesting to compare results of this study with other restoration types.

In this study, the CAM procedure was identical for all test groups. The milling unit CEREC MCXL was equipped with step bur 12S and cylinder pointed bur 12. Milling mode was set to fine. Recent studies have shown the influence of different CAM parameters such as instrument diameter and milling paths as well as 4-axis and 5-axis milling strategies for the accuracy of milled restoration.[27] To obtain best results for each type of material, CAM procedures may be optimized for different types of materials. For brittle surfaces such as ceramics not too much pressure should be applied on the margins.

CONCLUSION

Within the limitations of this in-vitro study, the following conclusions may be drawn:

1. The choice of CAD/CAM material may influence the fitting accuracy of CAD/CAM-fabricated restorations.
2. Specific material class-dependent milling strategies may improve the fitting accuracy of CAD/CAM-fabricated restorations.

TABLES AND FIGURES

Table 1: Results for fitting accuracy of endocrowns fabricated from three CAD/CAM materials; three areas were selected for 3D analysis: margin (MA), axial (AX), occlusal (OC); difference values were calculated as 80% percentile; (µm)

	Group	n	Mean	SD	Min	Max	95% confidence interval	
							Lower	**Upper**
Empress CAD (EM)	EM_MA	10	99.6	23.7	68.5	154.0	82.6	116.6
	EM_AX	10	123.8	20.4	102.6	161.7	109.1	138.4
	EM_OC	10	177.0	28.6	141.1	226.7	156.6	197.5
Lava Ultimate (LU)	LU_MA	10	88.9	7.7	79.2	106.7	83.4	94.4
	LU_AX	10	133.9	16.0	117.1	172.3	122.5	145.4
	LU_OC	10	158.0	8.1	144.0	168.6	152.1	163.8
Celtra Duo (CD)	CD_MA	10	131.0	26.5	105.5	184.9	112.0	149.9
	CD_AX	10	160.8	12.9	139.8	184.0	151.6	170.1
	CD_OC	10	182.3	24.0	141.0	216.3	165.2	199.5

Table 2: Results for homogenous subsets for test groups; no statistically significant difference for values within a column; statistical analysis with one-way ANOVA and post-hoc Scheffé test; significance level (p = 0.05); (µm)

Material_Area	n	Subsets for alpha = 0.05				
		1	2	3	4	5
LU_MA	10	88.9				
EM_MA	10	99.6	99.6			
EM_AX	10	123.8	123.8	123.8		
CD_MA	10		131.0	131.0	131.0	
LU_AX	10		133.9	133.9	133.9	
LU_OC	10			158.0	158.0	158.0
CD_AX	10				160.8	160.8
EM_OC	10					177.0
CD_OC	10					182.3
Sig.		0.073	0.083	0.086	0.215	0.504

Figure 1: Three-dimensional evaluation of the fit of Lava Ultimate (group LU) endocrown; three areas were selected following standardized protocol: (A) margin; (B) axial; (C) occlusal; difference analysis with software OraCheck; deviation pattern color coded with (+100 µm) (red).

Figure 2: Boxplots for evaluation of fit of endocrowns fabricated from different CAD/CAM materials (Empress CAD; EM), (Lava Ultimate; LU), (Celtra Duo; CD); three areas were selected for 3D analysis: margin (MA), axial (AX), occlusal (OC); mean precision for test groups is represented by the bar; circles represent outliers; difference values were calculated as 80% percentile; (µm).

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