Marginal Fit Evaluation Trough Micro-CT Technology of Pressed *vs* Milled Ceramic Inlays

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The goal of the present study is to compare the marginal fit using microCT of ceramic inlays obtained using two different technologies: pressing technique (lithium disilicate) and milling technique (milled leucite glass-ceramic). After extraction of four caries-free mandibular first molars, first class inlay cavities were prepared. For each tooth two inlays were manufactured- one by using pressed lithium disilicate (Emax) (n=4) and one by using milled leucite glass-ceramic (n=4). The marginal gap was analyzed circumferentially at the occlusal margin using a table-top Bruker micro CT, by measuring the distance at the occlusal limit of the cavities, between the restoration and the tooth in several points for every surface of each tooth before cementing. Data were analyzed statistically using One –way ANOVA with Tukey's Multiple Comparison Test performed using 5.00 for Windows (GraphPad Prism 5.00 Software, San Diego, California USA). When the marginal gaps of the inlays made out of different materials on the same tooth were compared, only one result had no statistical significance. The program expressed also results by comparing the gaps of pressed vs milled restorations on different teeth. 11 out of 16 results had statistical significance. Although statistical significance between the two studied materials, we can conclude that both used materials offer a good marginal adaptation within the acceptable limits. By summing up the gathered data we can conclude that the milled ceramic shows a better marginal fit than the pressed ceramic.

Keywords: marginal adaptation, pressed ceramic inlay, milled ceramic inlay, MicroCT

The marginal discrepancy of fixed restorations is one of the main factors which lead to failure of the prosthetic treatment. The accuracy of the restorations depends on many factors: a precise impression, a correct pouring technique of the dies, an accurate wax pattern [1, 2], as well as a flawlessly cementation technique.

The purpose of the present study is to compare the marginal fit of two different kind of ceramic materials: lithium disilicate pressed ceramic and milled leucite glass-ceramic using a three dimensional evaluation method, namely micro CT.

Experimental part

Materials and method

For our research we used four caries free molars, extracted for orthodontic reasons. The teeth were stored in artificial saliva at 4æ%C for less than 6 months. As part of a larger study we tried to standardize the preparation method and used the same preparation steps following the general guidelines for inlay preparations, as we used in our previous study. First class inlay cavities were prepared using a high speed carbide bur FG271(iSmile, Sacramento,Canada) with a 0.3 mm tip, which was used for entry and establishing the pulpal floor at a depth of 2.5 mm. Then a FG169L (SS White, New Jersey, USA) high speed bur with a tip thickness of 0.5 mm, was used to extend the occlusal outline mesio-distally along the central groove, at a 3-5 degree divergence to the facial and lingual walls, as well as to accomplish the final extension in the triangular grooves. The final step of the cavity preparation was performed using a 6862 (Komet Dental, Lemgo, Germany) high speed diamond bur which was used to correct the enamel margins and to perform the rounding of the internal edges [3[. All preparation steps were made under constant water-cooling. For each tooth two inlays were manufactured- one inlay out of lithium disilicate pressed ceramic (n=4) (Emax Press -Ivoclar Vivadent Inc., Amherst, USA) and one out of milled leucite glass-ceramic (n=4) (Empress CAD).

After taking the impression of the cavities and obtaining the dies, the morphology was reestablished modeling full contour wax patterns for the Emax inlays which were attached to the base of the IPS Multi investment ring using 2.5 mm wax wires, at an angle of 45 degrees. At least 10 mm were kept between the waxed-up inlays. As investment material we used IPS PressVest (Ivoclar Vivadent Inc., Amherst, USA). Processing was carried out imediatly after 60 min the complete setting time. Preheating and heating of the investment was done raising the temperature of the furnace up to 850^{o}C degrees. were used for the For the pressing procedure we used a cold IPS Alox-Plunger (Ivoclar Vivadent Inc., Amherst, USA) and a cold IPS e.max Press HT ingot (Ivoclar Vivadent Inc., Amherst, USA). After complete cooling, the length of the Alox plunger was marked on the ring and the investment ring was sectioned with a diamond disk. Divestment was completed by blasting using first higher and then lower

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Fig. 1 Laboratory steps for fabricating pressed and milled inlays

pressure as we got closer to the pressed objects and then IPS Invex Liquid was used to remove the reaction layer. The technical steps were completed with the application of stains (IPS E.max Ceramic Shades, Essence) and glazing materials [3].

For the milled Empress inlays, the impression was made using duplicating silicone Duplicast. The dies were obtained out of a scanable die material - Shera Hard Rock which prevents an uneven refection of the light. For the image aquisition we used the scanner InEos X5 (Sirona). This scanner has a light source with structured blue light, which provides an automatic emission of the incident light beam at 45°. HDR scanning mode was used in order to make multiple exposures and to enable shot selection. The disign of the inlays was established with the InLab 4.2.5 software and with the use of a draw margin tool. The restoration's parameters were: spacer 80µ, occlusal milling offset = 0, minimal radial and occlusal fittness 800µ, marginal fittness 70µ. The morphology was reestablished using the biogeneric individual function. For milling the HT - B2- I8 Empress CAD blocks, In Lab MCXL milling unit was used. Normal milling mode was used with a cilindric pointed bur 12 and a step bur 12.

The obtained inlays were placed into the cavities without cementation and the marginal gap was analyzed using a Skyscan 1172 desktop µCT scanner (Skyscan Bruker, Kontich, Belgium) again using the same parameters as in our previous study ([1,2]. The scanning was carried out at 80 kV, 100µA using an aluminum and copper filter. The specimens were rotated 180° with a rotation step of 0.4° and an exposure time of 500 ms. The overall scanning time was approximately 75 min per specimen. The x-ray beam was irradiated perpendicularly to the preparation long axis, and the image pixel size was 6.92µm. The x-ray projections were reconstructed using SkyScan's volumetric reconstruction software (Nrecon) that uses the set of acquired angular projections to create a set of cross section slices through the object. Reconstructed slices were saved as a stack of BMP-type files. The CTAn software (Skyscan, Aartselaar, Belgium) was used to obtain cross-section images through the center of the teeth (Z-axis) and also to perform measurements using the line measurement tool. The images were inspected and the marginal gap of each inlay was analyzed in horizontal sections, at the occlusal margin of each restoration, circumferentially, by measuring the distance between the restoration and the tooth in 100 µm steps.

We measured the lowest and the highest values for the E max pressed inlays as well as the average values and standard deviation, for each type of material on each tooth.

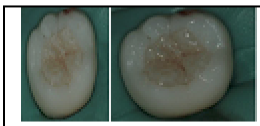
Statistical analysis was carried out on 8 columns of values (in two sets of 4). The results for the 8 inlays on the 4 molars were compared with One–way ANOVA with Tukey's Multiple Comparison Test performed using 5.00 for Windows (GraphPad Prism 5.00 Software, San Diego, California USA).The statistical program also expressed values by comparing each molar with others, displaying data for the same and different materials of the restorations.

Results and discussions

The lowest gap measured was found on the first molar with an Emax reconstruction (13.3 µ). The highest score was found on the second molar with an Emax reconstruction. The results were compared as shown in thetable 1.

For E max inlays we obtained the following average values: 59.576 (M1), 64.115 (M2), 73.417 (M3) and 71.165(M4) and the following standard deviations: 30.087 (M1), 29.966 (M2), 31.786 (M3) and 27.634 (M4) - (table 5). For Empress CAD the average values were: 78.51(M1), 78.75(M2), 82.72 (M3) and 87.03 (M4) and the standard deviations were: 30.52 (M1), 31.68 (M2), 22.33 (M3), 21.69 (M4).

For the statistical analysis One–way ANOVA with Tukey's Multiple Comparison Test was performed. When the marginal gaps of the inlays made out of different materials on the same tooth were compared, only one



Nr. measurments	Emax Press	Empress CAD
M1	168	106
M2	144	174
M3	178	180
M4	121	121

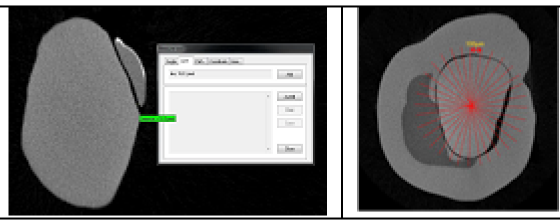


Fig. 2. Pressed and milled inlays inserted in the cavities. Comparison of measurements for pressed/ milled inlays MicroCT image-horizontal

Table 1
MINIMAL AND MAXIMAL GAP VALUES OBTAINED FOR E MAX AND EMAX CAD INLAYS SECTION

E max	M1	M2	M3	M4	Empress CAD	M1	M2	M3	M4
Min value(µ)	13.3	19.9	23.4	23.6	Min value (µ)	20.8	18.4	28.4	41.5
Max value(µ)	116.8	139.0	133.8	133.7	Max value (µ)	138.4	134.7	131.5	124.5

Table 2
AVERAGE AND STANDARD DEVIATION VALUES FOR PRESSED AND MILLED INLAYS

E max	Average	Std dev	Empress CAD	Average	Std dev
M1	59.576	30.087	M1	78.51	30.52
M2	64.115	29.966	M2	78.75	31.68
M3	73.417	31.786	M3	82.72	22.33
M4	71.165	27.634	M4	87.03	21.69

Parameters				
Are means signif. different? (P < 0.05)	Yes			
F test	16.14			
R squared	0.08724			
Bartlett's test for equal variances				
Bartlett's statistic (corrected)	41.09			
P value	P<0.0001			
Do the variances differ signif. (P < 0.05)	Yes			
ANOVA	SS	df	MS	
Treatment (btw columns)	91250	7	13040	
Residual (within columns)	954800	1182	807,8	
Total	1046000	1189		
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P < 0.05?	95% CI of diff
M1- Pressed vs Milled	**-18.93**	**7.551**	**Yes**	**-29.80 to -8.065**
M2- Pressed vs Milled	**-14.56**	**6.432**	**Yes**	**-24.38 to -4.750**
M3- Pressed vs Milled	-9.202	4.332	No	-18.41 to 0.006498
M4- Pressed vs Milled	**-16.23**	**6.283**	**Yes**	**-27.43 to -5.035**

Fig 5. Onle-way analysis of variance. Comparison gaps of pressed and milled inlays

result had no statistical significance (M3 pressed vs milled - fig. 3). The program expressed also results by comparing the gaps of pressed vs milled restorations on different teeth, for example M1CAD CAM vs M3Emax. 11 out of 16 results had statistical significance (fig.3).

Many studies use either subjective or inaccurate methods to evaluate the marginal and internal gaps of crown restorations,including the use of the explorer, mirror and a probe -visual examination, and radiographic techniques. Other studies use conventional score-based stereomicroscopic quantification [3], light body silicone [4] or epoxy replicas analized with the scanning electron microscope, sectioning the tooth-restoration sample for direct evaluation under a microscope. Some studies need embedding of the restorations and sectioning [5], steps that can lead to different errors. Other researches needed thermocycling and immersing of the specimens in basic fuchsin previous to sectioning, digitally photographing microscope analysis [6]. Compared to these methods the microCT scanning method we used, provides 3D images which enhance accurate results at a micrometric scale. When scanning entire tooth, the use of an Al + Cu filter is required in order to correct for the beam-hardening effect.

There are also others more reliable equipments as the atomic force microscope (AFM) which allows the scanning of dental tissues at a nanometric scale level [7].

In ceramic failure theory, the point of crack initiation area is considered to be the cement interface of all-ceramic restorations. If a ceramic layer is well supported and correctly luted to a material with less stiffness, tensile stresses forces develop in the ceramic layer as well as at the cement interface, especially when occlusal forces are applied. In our research we wanted to eliminate all possible error factors which can occur also during cementation [6].

ANOVA Table	SS	Df	MS			
Treatment (between columns)	91250	7	13040			
Residual (within columns)	954800	1182	807,8			
Total	1046000	1189				
Tukey's Multiple Comparison Test	Mean Diff.	q	Significant? P <0.05?	Summary	95% CI of diff	
Molar1Emax vs Molar1CadCAm	-18.93	7.551	Yes	***	-29.80 to -8.065	
Molar1Emax vs Molar2CadCAm	-19.18	8.821	Yes	***	-28.60 to -9.753	
Molar1Emax vs Molar3CadCAm	-23.15	10.74	Yes	***	-32.49 to -13.80	
Molar1Emax vs Molar4CadCAm	-27.82	11.61	Yes	***	-38.21 to -17.44	
Molar2Emax vs Molar1CadCAm	-14.32	5.538	Yes	**	-25.53 to -3.112	
Molar2Emax vs Molar2CadCAm	-14.56	6.432	Yes	***	-24.38 to -4.750	
Molar2Emax vs Molar3CadCAm	-18.54	8.249	Yes	***	-28.27 to -8.796	
Molar2Emax vs Molar4CadCAm	-23.21	9.365	Yes	***	-33.95 to -12.47	
Molar3Emax vs Molar1CadCAm	-4.989	2.011	No	ns	-15.74 to 5.763	
Molar3Emax vs Molar2CadCAm	-5.23	2.441	No	ns	-14.52 to 4.057	
Molar3Emax vs Molar3CadCAm	-9.202	4.332	No	ns	-18.41 to 0.006498	
Molar3Emax vs Molar4CadCAm	-13.88	5.861	Yes	**	-24.14 to -3.614	
Molar4Emax vs Molar1CadCAm	-7.345	2.733	No	ns	-18.99 to 4.303	
Molar4Emax vs Molar2CadCAm	-7.586	3.189	No	ns	-17.90 to 2.725	
Molar4Emax vs Molar3CadCAm	-11.56	4.892	Yes	*	-21.80 to -1.317	
Molar4Emax vs Molar4CadCAm	-16.23	6.283	Yes	***	-27.43 to -5.035	

Fig 6. Tukey’s Multiple Comparison Test. Comparison of gap values between all samples

Another reason for analyzing the marginal fit without cementation is that the radio-opacity of the luting agent can obstruct the microCT measurements.

Optical coherence is an evaluation method which provides real-time qualitative and quantitative information of the oral tissue to aid in performing diagnostics for early detection and evaluation of the oral microstructures. This new imaging technology is safe, versatile, inexpensive and readily adapted to a clinical dental environment. OCT images exhibit microstructural detail that cannot be obtained with current imaging modalities. Using this new technology, visual recordings of internal aspects and marginal adaptation of porcelain restorations can be visualized [8].

There are also studies [9] which evaluate the capability of en-face optical coherence tomography (efOCT) to detect and analyze the possible defects at the interface of several FPPs. Validation, was carried out through laser micro-spectral analysis- a punctual method of analysis, which allows the investigation of small quantities of materials of around 0.1 μg. and allows to establish the content of atoms and molecules and to perform semi-quantitative and quantitative analysis ensuring the establishment of trace elements, with concentration of ppm (parts per million). The advantages of the OCT method consist in non-invasiveness and high resolution. En-face OCT investigations permit to visualize a more complex stratified structure at the interface metallic framework /veneering material.

This noncontact imaging modality (OCT) that provides cross-sectional images of biological structures, in-vivo and non-invasively, by detecting light backscattered from tissue. Contrast agents can also be used. They are substances designed to alter the detected signal of a biological image in a way that allows the region containing the agent to be discernible. This way it enhances the examination of gaps at a nanometric scale at the limit of inlay preparations [10].

The measurements made at 100 μ steps insured a higher number of results compared to other studies (C, F). The results were included in the statistical analysis using One–way ANOVA with Tukey's Multiple Comparison Test (table 3) performed using 5.00 for Windows (GraphPad Prism 5.00 Software, San Diego, California USA). No problems occurred when results were expressed as in other studies [11] using the same statistical method, because of the violation of the assumption of equal variances among groups. In our research, the statistical analysis had significant values ($P<0.05$) in three of the 4 examined samples, so no nonparametric testing was undertaken.

Conclusions

According to some authors, no consensus exists concerning the acceptable ranges of marginal fit for lithium disilicate restorations fabricated with heat-pressing techniques [12].

Most authors agree that generally the marginal openings below 120 ìm are clinically acceptable [11]. Recent studies consider an acceptable gap around the value of 100 micrometers. There is a large range of marginal fit values related to the location of a crown and type of restoration [13]. An internal gap value of 200 to 300μ also may be clinically acceptable, but this requires in vivo confirmation [11].

By summing up the gathered data we can conclude that within the limits of this study, the null hypothesis is rejected and there is a statistically difference among groups.

We can also conclude that all measured gaps were within clinically acceptable values and that both types of ceramic materials (lithium disilicate as well as leucite glass-ceramic) and both types of processing methods (milled and pressed) provide reliable prosthetic treatments.

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