UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

FERNANDA FURTADO PIRAS

Cement space of all-ceramic crowns

Espaço de cimentação de coroas totais cerâmicas

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Tese constituída por artigos apresentada a Faculdade de Odontologia de Bauru da Universidade de São Paulo para obtenção do título de Doutora em Ciências no Programa de Ciências Odontológicas Aplicadas, na área de concentração de Prótese Dentária.

Orientador: Prof. Dr. José Henrique Rubo

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*“Você nunca sabe a força que tem. Até que
a única alternativa é ser forte”.*

Johnny Depp

ABSTRACT

Cement space of all-ceramic crowns

A ceramic system's ability to provide a restoration well adapted and fulfilling the patient's clinical and esthetic requirements is its most important technical feature. A CAD / CAM machine unit must be able of designing and milling different restorative materials, such as: resin-matrix ceramics, polycrystalline ceramics and glass-matrix ceramics. The purpose of this study was to present two articles that evaluated whether or not the milling strategy of different all-ceramic crown materials has an influence on the final cementation space. Specifically, the two articles evaluated: article I - The cementation space assessed by the most commonly used method- silicone replica technique- correlating stereomicroscope analysis with micromotomography (μ -CT); article II: The two-dimensional measures of cementation space were correlated with volume values by using μ -CT analysis, to better understand the behavior of 2D values in a tridimensional view. In both articles, single crowns were milled in lithium-disilicate, resin nanoceramic and zirconia. In article I, one hundred twenty measurements of each material were used to correlate the methodologies: stereomicroscope and μ -CT. The Pearson correlation coefficient test showed a correlation between the methods ($p=0.000$, $r=+0.455$). A similarity in the pattern of statistically significant differences among the regions evaluated (axial, occlusal, marginal) for both methodologies seems to exist. The positive correlation between the methods of measurements of cement space suggests that the internal dimensions of the materials varied because the different strategies after milled of them. In article II, twenty-eight slices were evaluated in three regions: marginal, axial and occlusal, totaling eighty-four measurements for each specimen. Axial and Marginal region showed positive correlation ($p=0.000$, $r=+0.656$; $p=0.000$, $r=+0.677$, respectively), while occlusal space presented negative correlation ($p=0.003$, $r=0.526$). The correlation between 2D and volumetric analysis allow to achieving as more information as possible to improve CAD/CAM systems.

Key Words: Replica technique. 3D imaging. CAD/CAM. Internal fit. Marginal adaptation.

RESUMO

Espaço de cimentação de coroas totais cerâmicas

As principais características dos sistemas cerâmicos é a capacidade de abranger estética e boa adaptação clínica. A tecnologia CAD/CAM é capaz de projetar e fresar diferentes materiais, como: cerâmicas de matriz resinosa, policristalinas, e ainda, cerâmicas de matriz vítrea. O objetivo deste trabalho é apresentar dois artigos que avaliam se a estratégia de fresagem de diferentes materiais cerâmicos influenciam no espaço final de cimentação. No primeiro artigo, especificamente, o espaço de cimentação foi avaliado pela metodologia mais utilizada, réplica de silicone. A película de silicone foi mensurada através da estereomicroscopia e microtomografia computadorizada (μ -CT) e as metodologias foram correlacionadas. No segundo artigo, através da metodologia de μ -CT, as medidas bidimensionais do espaço de cimentação foram correlacionadas com o volume obtido, a fim de compreender melhor o comportamento dos valores 2D numa visão tridimensional. Em ambos artigos, coroas unitárias foram fresadas em dissilicato de lítio, resina nanocerâmica e zircônia. No artigo I, cento e vinte medidas foram utilizadas para correlacionar as metodologias empregadas, estereomicroscopia e μ -CT. O teste de correlação de Pearson apresentou correlação entre os métodos ($p=0.000$, $r=+0.455$). Uma similaridade no padrão de diferenças estatisticamente significantes nas regiões avaliadas (axial, oclusal, marginal) parece existir entre as metodologias. A correlação positiva entre os métodos de mensuração do espaço de cimentação sugerem que as dimensões internas variam por conta dos diferentes processos que as coroas são submetidas após a fresagem. No artigo II, oitenta e oito fatias obtidas pelo μ -CT foram avaliadas em três regiões: marginal, axial e oclusal, totalizando oitenta e quatro medidas por espécime. A correlação positiva entre os métodos de mensuração do espaço de cimentação sugerem que as dimensões internas variam por conta dos diferentes processos que as coroas são submetidas após a fresagem. Artigo II, oitenta e oito fatias foram avaliadas em três regiões: marginal, axial e oclusal, totalizando oitenta e quatro medidas por espécime. Houve correlação positiva entre as regiões axial e marginal ($p=0.000$, $r=+0.656$; $p=0.000$, $r=+0.677$, respectivamente) e negativa na oclusal ($p=0.003$, $r=-0.526$). A correlação entre as

avaliações bi e tridimensionais permitem obter mais informações possíveis para aprimorar o sistema CAD/CAM.

Palavras-chave: Adaptação. Silicona. Microtomografia por Raio-X. Cerâmicas.

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1 Introduction

1 Introduction

The ceramic crowns are the first choice when the goal is to achieve natural appearance with the best aesthetic result associated with the biocompatibility (CONRAD; SEONG; PESUN, 2007). The success of these restorations is influenced by the resistance to fracture, aesthetic result and the marginal fit (GARDNER, 1982). Biologically, the misfit can contribute to the development of caries lesions (KARLSSON, 1986), plaque accumulation (SALTZBERG et al., 1976) and cement dissolution COOPER et al., 1971).

It is known that predefined cement space can influence in ceramic crown fit (CONTREPOIS et al., 2013). In CAD/CAM systems, the cement space was set through the software interface. Reviewed studies showed the impact of different setting in internal and marginal crown fit (NAKAMURA et al., 2003; 2005; IWAI et al., 2008; HMAIDOUCH; NEUMANN; MUELLER, 2011). The small cementation space may cause premature contacts between internal surface of the crown and the abutment tooth (NAKAMURA et al., 2003), as also a greater width layer of cement in occlusal region, thus widening the marginal gap (HMAIDOUCH; NEUMANN; MUELLER, 2011). Thicker cement contributes to polymerization shrinkage (tensile stress in the intaglio surface of crowns), and this factor could cause debonding of ceramic restorations (MAY et al., 2012).

A CAD / CAM machine unit must be able of designing and milling different restorative materials, such as resin-matrix ceramics, polycrystalline ceramics and glass-matrix ceramics (GRACIS et al., 2015). Consequently, different designing and milling strategies must be used to obtain the best result of each material. Biomaterials available for CAD/CAM have their own features regarding mechanical properties, chemical properties and machinability (LUTHARDT et al., 2004). Considering that different material properties can result in different wear of the milling tools, it would be relevant if suppliers could provide additional information regarding the lifespan of

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milling tools based on the amount of wasted material, since the fit of crowns may be affected by the abovementioned factors (LEBON et al., 2016).

Lithium disilicate, for example, consists of a glass matrix ceramic that presents fracture strength, color and translucency similar to enamel, which undergoes through a crystallization process, whereby the milled restoration is brought to a furnace at 840°C for 25 min to ensure that material properties reach a flexural strength of 360 MPa (± 60 MPa) and fracture toughness between 2 e 2.5 MPa $\cdot$ m^{0.5} (WIEDHAHM, 2007). After crystallization, a shrinkage of 0.3% is expected, which implies in the production of a slightly larger restoration soon after milling (REICH et al., 2011).

A resin of nanoceramic material (Lava Ultimate, 3M Oral Care) was introduced in an attempt to combine the advantages of a ceramic material and the ease of milling the composite resins. This material is intended to better absorb masticatory forces, reducing restoration internal stresses, providing wear resistance combined with a highly polished surface, color stability and accurate and well adapted margins (AWADA; NATHANSON, 2015).

Another material, the zirconia (Y-TZP), a polycrystalline ceramic, presents relevant properties for a restorative material such as high flexural strength (900 a 1200 Mpa), fracture toughness (9 MPa $\cdot$ m^{0.5}), hardness (13,5 GPa) and wear resistance (REKOW; ZHANG; THOMPSON, 2007; VAGKOPOULOU et al., 2009). The advantages of faster production, low cost and ease of machining pre-sintered zirconia blocks have led to this system gaining popularity. However, high temperature sintering is required after the milling to achieve the final hardness and strength. The final sintering is followed by a shrinkage of 25% in volume (DENRY; KELLY, 2008), which means that a larger restoration must be milled for compensation, which may eventually influence the fit (COLPANI; BORBA; DELLA BONA, 2013).

Although there are several methods available for quantification of crown misfit and cement internal space, the replica technique has been validated and used in several studies because is a non-destructive technics, such in vivo and in vitro researches, with accuracy and reliable (LAURENT et al., 2008; REICH et al., 2011) ability to reproduce the thickness of the cement pellicle (RAHMÉ et al., 2008). A light-body elastomeric impression material is used to simulate the thickness of the cement

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space, which is then measured either two-dimensionally using an optical microscope, scanning electron microscope (SEM) or three-dimensionally, by means of microcomputed tomography analysis (μ -CT) (SHAMSEDDINE et al., 2016).

Acceptable values of marginal and internal space of prosthetic restorations are known and have been reported to be around 100 and 150 μ m (HUANG et al., 2015), but information about volume is lacking. It may be clinically more relevant to have a three-dimensional view of the internal space to better understand the misfit of the crowns. In this context, microcomputed tomography (μ -CT) is a nondestructive method could be useful to quantify and qualify the cement space in the buccolingual and mesiodistal direction of crowns and to measure the average internal space by means of three-dimensional reconstruction (de PAULA SILVEIRA et al., 2017).

Based on the thickness of the cement layer should be as uniform and as thin as possible (DE JAGER et al., 2004), the overall aim of this study was to investigate if the CAD could transfer the cement spaces for each material considering their process after milled and the same stl. (the standard file type used) parameter. Each article had specifically evaluated:

According to the literature, the thickness of the cement layer should be as uniform and as thin as possible (DE JAGER et al., 2004). Thus, the general objective of this study was to investigate if the CAD could transfer the cement spaces for each specific material, considering the process after milling and the same stl. parameter. The present thesis will be presented in two separate articles, which had specific objectives:

- Article I: The aim of this study was to evaluate the cement space by μ -CT analysis, compared to the optical analysis of the silicone replica, since the latter is the most commonly used method.
- Article II: The aim of this study was to correlate two-dimensional measurements with volume values by μ -CT analysis.

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Articles

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2 Articles

The articles presented in this thesis were written according to the instructions and guidelines for article submission of the corresponding journals.

2.1 ARTICLE 1 – Analysis of correlation between optical and microcomputed tomography measurements of cementation space in all-ceramic crowns. (Submitted to *The Journal of Prosthetic Dentistry*)

2.2 ARTICLE 2 – Two-dimensional measurements and volumetric analysis of cement space in all-ceramic crowns. (Submitted to *The Journal of Prosthetic Dentistry*)

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2.1 Article¹ Analysis of correlation between optical and microcomputed tomography measurements of cementation space in all-ceramic crowns.

ABSTRACT

Statement of problem. The same stl. parameter, considering the materials with different process after milled, could reproduce by CAD for all ceramic materials. Some methodologies were used to evaluate the cement space, but no single method has proven to be superior.

Purpose. This study used three different all ceramic materials to correlate the stereomicroscope and the microtomography 2D analysis of the cementation space by silicone replica.

Material and methods. The specimens were milled in lithium disilicate, resin nanoceramic and zirconia. The cement space was measured at the cervical margin, axial walls and occlusal surface. One hundred twenty measurements of each material were used to correlate the methodologies. The Pearson correlation coefficient was found to be statistically significant, showing a correlation between the methods ($p=.000$, $r=.455$).

Results. The similarity in the pattern of statistically significant differences among the regions evaluated (axial, occlusal, marginal) for both methodologies seems to exist. Although, in μ -CT all the region studied showed differences between all the materials, only occlusal region in stereomicroscope analysis all the materials were different between them.

Conclusions. A positive correlation between the stereomicroscope and the microtomography in 2D evaluation of cement thickness was observed for ceramic crowns. Although the same spacings were set in the CAD software, final internal dimensions varied among milled crowns.

CLINICAL IMPLICATIONS

¹Analysis of correlation between optical and microtomography measurements of cementation space in all-ceramic crowns. The Journal of Prosthetic Dentistry (Submitted)

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The positive correlation between the methods of measurements of cement space suggests that the internal dimensions varied because the different process after milled.

Key Words: Replica technique, 3d imaging, CAD/CAM, internal fit, marginal adaptation.

INTRODUCTION

A well-adapted restoration is one prerequisite for the success and longevity of the restoration.¹ Considering the diversity of available restorative materials, different designing and milling strategies are used to obtain the best result for each material. An important step with regard to the fit of the restoration is the fabrication process.² Ceramic crowns can be distorted during fabrication, negatively affecting the fit and compromising the success of the restoration.^{3,4} Cement space, as well as firing parameters after milling directly affect marginal and internal adaptation of ceramic restorations.^{4,5,6}

Different measurement methods have been used to evaluate cementation space, including the direct measurement, cross-sectional measurement and impression replica technique.⁷ Other methods used are laser videography,⁸ profile projection,⁹ microcomputed tomography.^{10,11,12,13} The most widely used method is the replica technique,¹⁴ because of its nondestructive characteristic and its ability to estimate internal and marginal discrepancies.^{15,16,17,18} It is an accurate and reliable method that has been used in vivo and in vitro.^{16,17} A light-body elastomeric impression material is used to simulate the thickness of the cement space,¹⁹ which is then measured either two-dimensionally using an optical microscope,²⁰ scanning electron microscope (SEM), or three-dimensionally by means of microtomography analysis (μ -CT).^{21,22,23,24}

It has been reported that among the different methods to determine the fit accuracy of prosthetic restorations no single method has proven to be superior, suggesting that the combination of at least two measurement methods may be useful to verify and validate the

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cementation space characterization.¹⁴ In order to elucidate this question, the purpose of this study is to correlate the 2D evaluation of the pellicle obtained by the replica technique by stereomicroscope and μ -CT. The null hypothesis is that the cement space is not influenced by the measurement method.

MATERIAL AND METHODS

Specimens' preparation

An artificial mandibular first molar positioned in a mannequin received a full crown preparation. The preparation comprised a 2.0 mm occlusal reduction, 1.5 mm axial reduction and a 1.2 mm shoulder finish line with rounded internal and external angles.

The prepared molar received an impression with polyvinyl siloxane material (Express; 3M Oral Care) using the double impression technique and the plaster model was made with type IV special CAD/CAM stone (CAM-base). The model was scanned, the crown design was provided following the same spacing parameters for all materials (InEos Blue – Sirona Dental) and milling performed (Cerec InLab MC XL2, Sirona).

Materials for Crowns fabrication

Ten crowns per group were milled from lithium disilicate glass-ceramic blocks (IPS e.max; Ivoclar Vivadent), resin nanoceramic (Lava Ultimate Restorative; 3M oral Care) and Zirconia Y-TZP (inCoris ZI; Sirona). A uniform 50 μ m cement spacer was set for all groups. This has been done because a pilot study showed that no frictional retention and even some crown rotation onto the preparations was present when the spacer recommended by the manufacturers of the materials was used. After milling, crowns were sintered and/or glazed according to the manufacturer's instructions and material's requirement.

Replica technique

Each crown was seated on the master model with a light body silicone layer (Express VPS Impression Material; 3M Oral Care) representing cementation material. No internal

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adjustments or grindings were performed. A 50 N load was applied using a loading device and 5 kg weight for 10min.^{25, 26} Excess impression material around the crown was removed before the final setting to avoid material tearing. After polymerization, the crown was carefully removed.

Then, the master model with the light body silicone pellicle was seated on squared box containing heavy body silicone (Express VPS Impression Material; 3M ESPE Dental).(Figure 1) The master model was removed after silicone polymerization leaving the pellicle inside. Then a new portion of heavy body silicone was introduced to support the film of light body silicone.^{4,7} Replicas were sectioned perpendicular to its surface with a blade into four parts determined with the assistance of the device: mesial, distal, facial and lingual areas.²⁷

Micro-CT scanning

Micro-CT measurements of cement space were performed by x-ray microtomography. Each crown was seated on the master model with a light body silicone layer (Express VPS Impression Material; 3M Oral Care) representing cementation material.

The pellicle of silicone positioned on the prepared tooth was scanned using a desktop X-ray microfocus CT scanner (SkyScan 1174v2; SkyScan). Images were acquired using 50 kV X-ray tube voltages, 800 μ A anode current and voxel size of 16 μ A.

After scanning, scans were reconstructed using NRecon v1.6.10 (SkyScan) software. The SkyScan DataViewer 1.5.1.2 software generated 3 views: coronal (x-z plane), sagittal (y-z plane), and transaxial (x-y plane). They were used to locate the mesiodistal and buccolingual positions of the crown in order to evaluate the measures.

Cementation space measurements

All specimens were evaluated for marginal and internal cementation space using micro-CT and stereomicroscope images.

Micro-CT measurements

CTAn software (Skyscan) was used to choose a region of interest (ROI). The center of the prepared tooth was located and provided a starting point for the measurements. Measurements of marginal and internal space were performed at the center and both mesiodistal and buccolingual directions. As shown in the schematic, measurements were performed in other six slices 0.8 mm apart from each other in the mesiodistal and buccolingual directions, totaling twenty-eight slices; (Fig 1.) eighty-four measurements were taken for each specimen. All measurements were performed by a single examiner. All measurements were taken manually, and the measuring points were standardized to minimize errors.

Stereomicroscope measurements

Film thickness was imaged in a stereomicroscope (MZ6, Leica) at 50x magnification, with a built-in charge-coupled camera (Hitachi CCTV HV-720E, Hitachi). Image analysis software (Image J) was used to measure the cement space in three ROIs: cervical margin, axial walls and occlusal surface. The most external margin of the pellicle, and the occlusal surface were observed on each side of the crown for measurements. Each side of the crown was measured twice, resulting in twenty-four measurements for each specimen.

Statistical analysis

Preliminary data analyses showed indistinguishable variances in the study of the dependent variable (Levene test, all $p > 0.398$). Data were statistically evaluated through two-way analysis of variance (ANOVA) with fixed factors of Material (lithium disilicate, resina nano, zirconia) and region of cement space (axial, marginal and occlusal) following post-hoc comparisons by Tukey test. Data are presented as a function of mean values with the corresponding 95% confidence interval (CI). All analyses were accomplished using SPSS (IBM SPSS 23, IBM Corp). Subsequently, the Pearson correlation coefficient was used between μ -CT and optical microscopy methodologies.

RESULTS

Table 1 shows two-way (ANOVA) for values obtained by stereo evaluation and table 2 represent two-way analysis of variance (ANOVA) for μ -CT results. Then, the Tukey test was applied, separately for both techniques, to detect any interaction between the regions (Fig 2. and Fig 3.).

Regarding stereomicroscope measurements, for occlusal region all materials were statistically different, in which zirconia showed the lowest values of occlusal space ($122.064\mu\text{m}$, CI: ± 13.49), lithium disilicate the highest ($200.852\mu\text{m}$, CI: ± 13.49) and resin nanoceramic presented intermediate values ($156.333\mu\text{m}$, CI: ± 13.49). For axial region, lithium disilicate ($87.023\mu\text{m}$, CI: ± 13.49) was statistically similar to zirconia ($97.210\mu\text{m}$, CI: ± 13.49 , $p=.295$) and resin nano ($68.796\mu\text{m}$, CI: ± 13.49 , $p=.061$). In marginal space, zirconia ($58.327\mu\text{m}$, CI: ± 13.49) showed no significant differences relative to lithium disilicate ($75.887\mu\text{m}$, CI: ± 13.49 , $p=.071$) and resin nano ($54.211\mu\text{m}$, CI: ± 13.49 , $p=.672$).

However, in μ -CT analysis all the ROIs showed statistically significant differences among materials. For axial and marginal region, zirconia showed the highest values (axial space= $185.81\mu\text{m}$, CI: ± 13.46 ; marginal space= $129\mu\text{m}$, CI: ± 13.46), lithium disilicate presented intermediate values ($161.23\mu\text{m}$, CI: ± 13.46 ; $103.69\mu\text{m}$, CI: ± 13.46 , respectively axial and marginal values) and resina nano the lowest values (axial space= $112.31\mu\text{m}$, CI: ± 13.46 ; marginal space= $75.90\mu\text{m}$, CI: ± 13.46). For occlusal space, the same trend of stereomicroscope occurred, where zirconia showed the lowest value ($171.10\mu\text{m}$, CI: ± 13.46), resina nano presented intermediate values ($205.55\mu\text{m}$, CI: ± 13.46) and lithium disilicate the highest space ($229.41\mu\text{m}$, CI: ± 13.46).

For correlation evaluation, each region (axial, marginal, occlusal) was evaluated according to tooth surfaces (mesial/ distal/ lingual/ buccal); therefore, 40 measurements were

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taken for each region, totaling 120, and these were correlated according to the evaluation method (μ -CT and stereo). Pearson's correlation coefficient was found to be statistically significant, showing a correlation between the methods ($p=.000$, $r=.455$).

DISCUSSION

The null hypothesis of this study was accepted because a significant correlation was found between both methodologies used to evaluate cement space. The use of low viscosity impression materials is a technique commonly used by clinicians as a guide to where adjustments must be done to improve seating of fixed restorations.¹⁹ In addition, it is also an *in vitro* evaluation technique capable of recording the pre-cementation space three-dimensionally.²¹

Although the replica technique is a widely used method for the evaluation of the cement space, the handling of the silicone, dispensing or the crown settling, as well as varied ways of sectioning the pellicle of silicone, comprise factors that introduce errors.²⁸ Other limitations of the replica technique include difficulty in identifying the crown margins and finishing lines, the differences in number of slices evaluated in stereo as compared to micro-CT, as well as mistakes in the sectioning plane, that could lead to overestimated measurements.^{29,30} In attempt to reduce error sources, a larger number of measurements per sample has been suggested,³¹ as performed in this study.

Considering that no consensus exist as to the best methodology for fit accuracy¹⁸ it has been recommended that the combination of two measurement methods should be performed in order to verify and validate results.¹⁴ The applicability of the stereomicroscope 2D evaluation of the silicone pellicle can also be verified by μ -CT,^{20, 4} which is an innovative, noninvasive and nondestructive technique.^{12, 13} μ -CT technique can be useful to evaluate cement space of the ceramic crowns and shows several advantages over other methods, as 3D and 2D evaluation:

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it is easy to perform²² and very thin sections may be imaged from close proximity to one another.¹³ The main disadvantages of this method are that it is expensive and time-consuming,²¹ and also the possible formation of radiation artifacts caused by the differences of radiation absorption coefficients between different materials²³ during the evaluation of the cement space volume.^{23, 4}

The positive correlation between the replica technique and the μ -CT evaluation observed in this study makes this latter methodology an incremental, but not mandatory technique to replace conventional optical microscopic 2D observation. Although not identical measurements were collected, a trend was observed for the statistical differences among the observed regions of interest and materials evaluated for both methodologies.

Past studies reported that the optical microscopic reading of the replica shows high accuracy measurements for under 15 μ m thicknesses, whereas above 100 μ m the accuracy decreases. In contrast, the μ -CT is capable of resolving thicknesses to approximately 10 μ m.²¹ The differences between the measurement techniques for axial and marginal region, which the lowest values was found, could be explain by the fact that in a single surface (axial, marginal or occlusal) twenty-eight measurements were performed in μ -CT scans, compared to only eight measurements in the silicone pellicle for stereomicroscope evaluation, which suggests that measurements of the scanned pellicles may be more reliable when thinner sections are under measurement.

Although materials were subjected to different processing methods after milling, such as crystallization or sintering, it was expected that the use of one .stl parameter for all groups would eventually result in similar internal fit. However, as previously reported, large internal spaces can occur as a result of milling processes,⁵ as well as different marginal spaces result from differences in CAD/CAM systems.¹³ The ‘spacer’ appears to be a semi-quantitative tool

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that interactively counterbalances errors within the process chain such as powdering, manufacturing or sintering shrinkage.⁶

CONCLUSION

From the results of this in vitro study, the following conclusions were drawn:

- A positive correlation between the stereomicroscope and the μ -CT in 2D evaluation of cement thickness was observed for ceramic crowns. Although the same spacings were set in the CAD software, final internal dimensions varied among milled crowns.

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TABLES

Table 1. Two-way ANOVA was used to detect any significant difference between the fixed factors materials and region and their interactions for stereomicroscope analysis. The level of significance was set at $P < .05$.

Source of Variation	Sum of Squares	df	Mean Square	F	<i>P</i> value	Observed Power
Material	129368.403	2	64684.202	17.121	.000	1.0
Region	1243804.933	2	621902.466	164.606	.000	1.0
Material*Region	174693.331	4	43673.333	11.559	.000	1.0
Total	11769172.991	720				

$R^2 = 0.366$ (corrected $R^2 = 0.358$)

Table 2. Two-way ANOVA was used to evaluate any significant difference in μ -CT evaluation using fixed factors materials and region and their interactions. The level of significance was set at $P < .05$.

Source of Variation	Sum of Squares	df	Mean Square	F	P value	Observed Power
Material	82649.554	2	41324.777	22.037	.000	1.0
Region	589957.067	2	294978.534	157.304	.000	1.0
Material*Region	153265.896	4	38316.474	20.433	.000	1.0
Total	9869203.302	360				

$R^2 = 0.556$ (corrected $R^2 = 0.546$)

LEGENDS

Figure 1. Illustration of the measurements performed in the scanned pellicle. The measurements were performed in six slices 0.8 mm apart from each other in the mesiodistal and buccolingual directions, totaling twenty-eight slices.

Figure 2. Space values using stereomicroscope analysis as a function of mean values with the corresponding 95% confidence interval (CI).

* Different lowercase letters indicate statistical difference between the materials ($P < .05$)

*Different uppercase letters indicate statistical difference between the regions inside the material ($P < .05$)

Figure 3. Space values using μ -CT evaluation as a function of mean values with the corresponding 95% confidence interval (CI).

* Different lowercase letters indicate statistical difference between the materials ($P < .05$)

* Different uppercase letters indicate statistical difference between the regions inside the material ($P < .05$)

2.2 Article² Correlation between two- and three-dimensional measurements of cement space in all-ceramic crowns.

ABSTRACT

Statement of problem. Although the two-dimensional (2D) analysis of prostheses cementation space has been vastly used, its correlation with volumetric comparison (three-dimensional data) of cement space still requires investigation.

Purpose. To correlate two-dimensional measurements of cement space of CAD/CAM crowns with their corresponding three-dimensional values (volume of cement space), using micro-computed tomography analysis at selected regions of interest.

Material and methods. Ten molar crowns were milled in lithium disilicate (LD), resin nanoceramic (RN) and zirconia (Z) ceramics. Silicone replicas were produced and used as the cement layer analog and scanned using a desktop X-ray microfocus CT scanner. Twenty-eight slices were evaluated in three regions: marginal, axial and occlusal (n=84 measurement points/specimen). After three-dimensional reconstruction of cement space, the volume was calculated. Data were statistically evaluated through ANOVA and Tukey test ($p<.05$). Pearson correlation test was used to investigate the correlation between 2D and 3D data.

Results. RN (20.98 mm^3 , $CI:\pm 1.23 \text{ mm}^3$) presented significantly lower volume of cement space, followed by LD (26.15 mm^3 , $CI:\pm 1.31 \text{ mm}^3$) and Z (47.10 mm^3 , $CI:\pm 1.16 \text{ mm}^3$) (all, $p=.000$). The same trend was observed when considering the marginal and axial regions. Conversely, while LD showed the highest values for occlusal region, Z presented the lowest and RN showed intermediate values (statistically different from Z; $p=.000$). While axial and marginal region showed a significant positive correlation with volume values, a negative correlation between occlusal space and volume of cement space was found.

² Correlation between two- and three-dimensional measurements of cement space in all-ceramic crowns. The Journal of Prosthetic Dentistry (Submitted)

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Conclusions. The correlation between the two-dimensional analysis and the volume was observed for ceramic crowns.

CLINICAL IMPLICATIONS

The correlation between 2D and volumetric measures of cement space allows understanding the issues of all-ceramic crowns, achieving as more information as possible to improve CAD/CAM systems.

Key Words: Replica technique, 3d imaging, CAD/CAM

INTRODUCTION

Dental ceramics are the most studied material for CAD-CAM systems in Dentistry, mainly because of their esthetic features.¹ Ceramics differ considerably with respect to their mechanical, chemical, and machinability properties² and can be classified as resin-matrix ceramics, polycrystalline ceramics and glass-matrix ceramics.³ Theoretically, all-digital systems allow for better control of restoration fit because of the possibility to standardize *stl* parameters. However, multiple factors could contribute to introduce errors, such as die spacer,⁴ size and shape of milling burs⁵ and processing methods after milling, such as crystallization or sintering shrinkage.

Acceptable values of marginal and internal space of prosthetic restorations are known and have been reported to be around 100 and 150 μ m,⁶ but information about cementation space volume is limited.⁷ It may be clinically more relevant to have a three-dimensional view of the internal space to better understand potential misfit of the crowns. Microcomputed tomography (μ CT) is a nondestructive method used for two-dimensional (2D) measurement of cement space in the buccolingual and mesiodistal direction of crowns and to measure the average internal space by means of three-dimensional reconstruction.⁵

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The question remains whether values found by two-dimensional analysis correlate with volumetric 3D analysis of the cement space. Once the thickness of the cement layer should be as uniform and as thin as possible,⁸ the values of volume should follow the same trend. Therefore, the purpose of this study is to compare 2D measurements of cement space of CAD/CAM crowns with the 3D volume, and evaluate if there is a correlation between the two measurements. The null hypothesis is that two- and three- dimensional measurements for quantification of the cement space do not correlate.

Material and Methods

An artificial mandibular first molar was prepared considering a 2.0mm occlusal reduction, 1.5mm axial reduction and a 1.2mm shoulder finish line with rounded internal and external angles. An impression was taken using polyvinyl siloxane material (Express; 3M Oral Care) to obtain a plaster model (type IV special CAD/CAM stone - CAM-base; Dentona AG). After the model was scanned (InEos Blue – Sirona Dental), a milling unit was used to produce the crowns (Cerec InLab MC XL2, Sirona), considering a standard cement space of 50µm for all groups.

Ten crowns were produced from three different materials: (a) lithium disilicate glass-ceramic blocks (IPS e.max; Ivoclar Vivadent) [LD]; (b) resin nanoceramic (Lava Ultimate Restorative; 3M oral Care) [RN] and zirconia Y-TZP (inCoris ZI; Sirona) [Z]. After milling, to attend material's requirements, the crowns were submitted to specific strategies (sintered and/or glazed) according to the manufacturer's instructions.

To evaluate the cement space, each crown was seated on the master model with a light body silicone layer (Express VPS Impression Material; 3M Oral Care), under 50 N load applied using a loading device for 10min.^{9, 10} The excess of impression material around the crown was removed before the final setting to avoid material tearing at the margins. The crowns were removed while the thin silicone film remained on the outer surface of the master model, as the

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cement layer analog. Then, each silicone film covering the prepared tooth was scanned using a desktop X-ray microfocus CT scanner (SkyScan 1174v2; SkyScan). Images were acquired using 50 kV X-ray tube voltages, 800 μ A anode current and voxel size of 16 μ A.

After scanning, images were reconstructed using NRecon v1.6.10 (SkyScan) software. The measurements were made on planes constructed as follows: one point on each of the mesial, distal, buccal, and lingual surfaces was chosen in the SkyScan DataViewer 1.5.1.2 software for the construction of mesiodistal and lingual fitting planes. CTAn software (CTAn v1.14.4; Bruker m-CT, Skyscan) was used to choose a region of interest (ROI) to take the measurements: the central section was defined as the symmetric plane. Additional measuring points were gathered by constructing parallel planes 0.8 mm bilateral to the symmetric planes, totaling twenty-eight slices. Each slice was evaluated in three ROIs: marginal, axial and occlusal, totaling eighty-four measurements for each specimen. All measurements were performed by a single examiner. After three-dimensional reconstruction, CTVol (CTVol v.2.2.1; Bruker Micro-CT, CTAnalyser software, Skyscan) was used to obtain the volume of cementation space.

Data from three-dimensional measurements (volume) and two-dimensional measurements were statistically evaluated through one-way analysis of variance (ANOVA) followed by post-hoc comparisons by Tukey test. The level of significance was set at $P=.05$. Data are presented as a function of mean values with the corresponding 95% confidence interval (CI). Also, the Pearson correlation test was used to assess the correlation between the measurement methods (2D and 3D) used in this study for fit evaluation. All analyses were accomplished using SPSS (IBM SPSS 23, IBM Corp.).

RESULTS

The three-dimensional (3D) analysis, one-way ANOVA showed a significant difference between materials with respect to volume of cement space ($F=640.422$, $P=.000$) (Table 1).

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Tukey post hoc test showed that RN (20.98 mm³, CI:±1.23 mm³) presented significantly lower volume of cement space, followed by LD (26.15 mm³, CI:±1.31 mm³) and Z (47.10 mm³, CI:±1.16 mm³), which were significantly different from each other (P=.000)(Fig. 1). Qualitative 3D image analysis of cement space depicted higher internal space for Z, which can be observed due to thicker silicone layer and fewer empty spaces compared to other materials (Fig. 2).

Results from two-dimensional measurements of the cement space in all ceramic crowns are shown in Figure 3 and Table 1. For the marginal region, zirconia (129 µm, CI:±12.87) showed the highest values and resin nanoceramic the lowest values (76.47µm, CI:±16.88) (significantly different from each other; P=0.000) and lithium disilicate (103.69 µm, CI:±22.33) presented intermediate values (statistically similar to Z and RN; P=.077 and P=0.053, respectively). For axial region, RN (112.76 µm, CI:±14.29) presented the lowest values (P<.004), while no difference was found between Z (185.33 µm, CI:±15.56) and LD (161.23 µm, CI:±31.10; P=.197). For occlusal region, while LD (229.41 µm, CI:±24.96) showed the highest values, Z (171.10 µm, CI:±10.28) presented the lowest and RN (204.80 µm, CI:±16.76) presented intermediate values (statistically different from Z; P=.000).

The Pearson correlation test was found to be statistically significant, showing a correlation between the cementation space analyses methods (volume and 2D analysis). Axial and marginal region showed a positive correlation with volume values (p=.000, r=+.656; p=.000, r=+.677, respectively), which means that the lower the axial and marginal space the lower the volume of cement space. Conversely, a negative correlation was observed between occlusal space and volume of cement space, where the higher the occlusal space, the lower the volume (p=.003, r= -.526).

DISCUSSION

The correlation between two- and three-dimensional (volume) measurements through micro-computed tomography (µCT) analysis for quantification of the cement space was

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confirmed for milled all-ceramic crowns, thus the null hypothesis was rejected.

The 2D analysis allows quantification of the cement space, but the three-dimensional analysis seems to be relevant since it provides a more thorough assessment of available cement space. Information about the volume of cement space is scarce ⁷ and there no reference values seem available thus far, as in two-dimensional measurements.⁷ All materials showed statistical difference in volume, probably because the restorative materials differ considerably with respect to their mechanical, chemical, machinability properties, and milling process. ²

A similarity in the pattern of statistically significant differences among the regions evaluated (axial, occlusal, marginal) for both measurements was observed. For axial and marginal regions, a positive correlation with volume where the higher the volume the greater the 2D measurements was confirmed. The opposite was observed for the occlusal region: the higher the volume, the lower the 2D measurements. These findings could suggest that limited cement space may lead to incomplete crown seating and eventually in increased marginal gap.¹¹

The larger occlusal space makes more difficult to seat the crown, because less cement flows to the axial and marginal regions. ^{11, 12} The poor occlusal space of glass-ceramic restorations may result in an increased risk of fractures because of the compromised support and stabilization of the ceramic through adhesion to the tooth substrate.¹³ Additionally, as the occlusal cement layer become thicker, the clinical performance of bonded restorations might decrease due to the polymerization shrinkage.¹⁴ The effects of water sorption by resin cements may also play a role in clinical failures of all-ceramic crown systems. ¹⁵ Conversely, thinner cement space associated to loading application onto the surface of the crown could lead to tensile fracture of the ceramic at the cementation surface, due to the low modulus of resin cements (4-6GPa) compared with glass-ceramic (70GPa).¹⁵ Then, the resin nano was contraindicated by the manufacturer as a crown material due to debondings that occurred at

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higher rates than commonly expected, which could be explained by the above-mentioned factors.

Zirconia showed the lowest value on occlusal region, but the highest mean volume for all materials studied. In the three-dimensional analysis, the lowest value of occlusal region result in higher volume in axial and marginal region, likely due to the flowing of the cement simulated in the silicone replica technique. It is known that thicker layer of cement reduces the effectiveness of bonding, may hinder the seating of the crown jeopardizing its fixation, consequently leading to higher risk of marginal polymerization shrinkage stress.^{14, 16} Cement shrinkage result in tensile stress in the intaglio surface of crowns, following in microcracks, debonding and fracture.¹⁴ This could justify Y-TZP debonding to remain an issue likely associated with its polycrystalline structure and difficulties in bonding techniques.¹⁷

The two-dimensional measurement is an important tool to quantify the cement space, but the three-dimensional view allows analyzing the entire space. It seems to be interesting to associate the two measurements to achieve as more information as possible to improve CAD/CAM systems. The correlation between them allows understanding the main issues related to the investigated all-ceramic systems, such as the requirement to adjustment of lithium disilicate to permit the complete seat of the crown¹⁸ and prevent flaking of surface,¹⁹ and the loss of retention of zirconia.²⁰

CONCLUSION

Within the limitations of this study, the following conclusion were drawn:

- The correlation between the two-dimensional analysis and the volume was observed for ceramic crowns.

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TABLES

Table 1. One-way ANOVA was used to find any significant difference between volume and cement space of the different materials. The level of significance was set at $P < .05$.

Variable	Source of Variation	Sum of Squares	df	Mean Square	F	P value
Volume	Between materials	3827.647	2	1913.823	640.422	.000
	Within materials	80.686	27	2.988		
	Total	3908.333	29			
Marginal	Between materials	13810.594	2	6905.297	11.164	.000
	Within materials	16700.979	27	618.555		
	Total	30511.572	29			
Axial	Between materials	27322.660	2	13661.330	14.835	.000
	Within materials	24864.218	27	920.897		
	Total	52186.878	29			
Occlusal	Between materials	17138.486	2	8569.243	13.028	.000
	Within materials	17759.806	27	657.771		
	Total	34898.293	29			

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Figure 1. Results from three-dimensional measurements of the cementation space using CTscan v1.11.10.0 (SkyScan) software analysis. Volume values as a function of mean values with the corresponding 95% confidence interval (CI).

Figure 2. Three-dimensional reconstruction of one representative sample of each ceramic material: A) Lithium disilicate (LD), B) Resin nanoceramic (RN), C) Zirconia Y-TZP (Z).

Figure 3. Results from two-dimensional measurements of the cementation space using CTscan v1.11.10.0 (SkyScan) software analysis. Cementation space values as a function of mean values with the corresponding 95% confidence interval (CI).

*Different lowercase letters indicate statistical difference between materials (P<0.05)

3 Discussion

3 Discussion

For a better understanding of the ideas, the discussion of this thesis was divided into the following topics: “methodology”; “results” and “clinical relevance”.

3.1 Methodology

The present study proposed to evaluate the cementation space of all ceramic materials. Cement space, as well as fabrication technique, directly affects marginal and internal adaptation of ceramic restorations (MOUSLY et al., 2014). The use of a single space parameter was chosen to allow evaluation of the milling strategies on different CAD/CAM restorative materials, because a pilot study showed that no frictional retention and even some crown rotation onto the preparations was presented when the spacer recommended by the manufacturers of the materials was used. Although materials were subjected to different processing methods after milling, it was expected that the use of one stl. parameter for all groups would eventually result in similar internal fit. However, as previously reported, the different setting could impact in marginal and internal space (NAKAMURA et al., 2003; 2005), the large internal spaces can occur as a result of milling processes (Lee, 2008), as well as different marginal spaces result from differences in CAD/CAM systems (BRAWEK et al., 2013; CONTREPOIS et al., 2013). The “spacer” appears to be a semi-quantitative tool that interactively counterbalances errors within the process chain such as powdering, manufacturing or sintering shrinkage (MOLDOVAN et al., 2011).

The replica technique was used first for measure the gap space, as described by Molin and Karlson (RAHMÉ et al., 2008). The technique allowed in vivo and in vitro measurement of internal and marginal gaps, repeated any times, not time consuming

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and relatively not expensive (LAURENT et al., 2008). When using silicone replica, the space can be evaluated from a thin section of silicone pellicle (REICH et al., 2005). It is possible to observe marginal and internal space in one (1D), two (2D) and three dimensional (3D) (OKA et al., 2016), depends on the technology used, such as the optical microscopy, scanning electron microscopy, optical comparator screen and microcomputer tomography (μ -CT) (SHEMBESH et al., 2016).

Despite these advantages, certain difficulties can arise on measuring the thickness of the pellicle (LAURENT et al., 2008), the mixing, dispensing, handling of the silicone for the cement replica (DAHL; RØNOLD; DAHL, 2017). However, the replica technique combined with optical microscopy has been shown to be a practical and established method (LAURENT et al., 2008), although there is the difficulty in identifying reference points (CONTREPOIS et al., 2013) and limited number of slices to measure.

The last technique used was microcomputer tomography (μ -CT), which allows evaluating 2D and 3D the cement space, could provide great number of measurements sites (CONTREPOIS et al., 2013). This is noninvasive and nondestructive methodology (KIM et al., 2016), whose major disadvantage is the formation of radiation artifacts caused by the different radiation coefficient of the materials during the volume evaluation (BORBA et al., 2011), also this technique is considered expensive and time-consuming (RUNGRUANGANUNT; KELLY; ADAMS, 2010).

Yet among the different methods to determine the fit accuracy of prosthetic restorations, no single method has proven to be superior, suggesting that the combination of at least two measurement methods may be useful to verify and validate the cementation space characterization (NAWAFLEH et al., 2013). Owing to this, in article 1, the cement space was evaluated two-dimensionally by two methods, stereomicroscope and μ -CT, aiming to correlate the measurements. Previous studies reported that the optical microscopic replica reading showed high accuracy measurements for under 15 μ m thicknesses, whereas above 100 μ m the accuracy decreases. In contrast, the μ -CT was capable to resolve thicknesses to approximately 10 μ m (RUNGRUANGANUNT; KELLY; ADAMS, 2010).

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As previous showed, the defined space was not exact, as expected. The cement constitutes a certain thickness, which result in crown intaglio surface contact with the prepared tooth, consequently increasing marginal space (PRUDENTE et al., 2017; YILDRIM et al., 2017). Although, the acceptable marginal and internal values may be known (MCLEAN; VON FRAUNHOFER, 1971), the exact volume of that space is not (YILDRIM et al., 2017). More than accuracy value, 3D measurement allowed qualify the cement space (YILDRIM et al., 2017). Due to this, in second article, 2D measurements of cement space of CAD/CAM crowns was compared with their internal volume, trying to establish a correlation between the two measurements, aiming to achieve as more information as possible to improve CAD/CAM systems. Considering that in the first article, the correlation between in 2D analysis by stereomicroscope and μ -CT showed the possibility to apply the μ -CT in two-dimensionally for all-ceramic crowns.

3.2 Results

In this study, the CAD/CAM system used a 2-step workflow. In Step-1, large diameter burs reduce the block up to 0.3 mm larger than the final dimensions of the restoration. In Step-2, finer grit burs refine the milling process. There is limited information in the literature regarding the wear of burs as a result of material properties, what certainly would help better understand the results of cement space obtained. In the system used, material hardness did not seem to affect the milling speed and regardless of milled material, the replacement of burs is indicated by the software (CHAVALI et al., 2017).

The classes of restorative materials differ considerably with respect to their mechanical, chemical and machinability properties (LUTHARDT et al., 2004). However, our study question was whether the CAD-CAM system used would reproduce the cement space from the .stl to the milled restorations, yet adjusting post processing alterations during crystallization or sintering. Most ceramic materials seem to present clinically acceptable marginal and internal adaptation values

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(CONTREPOIS et al., 2013). Gaps of up to 150 μm are commonly considered as being clinically tolerable (BOENING et al., 2000).

The resin nanoceramic presented the lowest values of marginal and axial discrepancy, as previously reported (de PAULA SILVEIRA, et al., 2017,) probably because no dimensional alterations are expected after milling in an already processed block. In this study, the negative correlation showed between volume and occlusal space, could suggest that limited cement space may lead to incomplete crown seating and eventually in increased marginal gap (HMAIDOUCH; NEUMANN; MUELLER, 2011). The lowest volume, but the larger occlusal space turns more difficult to seat the crown, because less cement flows to the axial and marginal regions (HMAIDOUCH; NEUMANN; MUELLER, 2011; MAI; LEE; LEE, 2017). The manufacturer is no longer indicated this material as a crown material, by due to debonding issues that occurred at higher rates than commonly expected. This finding may be due to the low modulus of elasticity of the material and resiliency that results in deformation during occlusal contacts. Also, the high content of polycrystalline material zirconia at the nanoscale may hinder long-term adhesion at the intaglio surface.

Lithium disilicate presented the highest value of occlusal space, in accordance with literature studies (NAN et al., 2017; SHAMSSSEDINE et al., 2016). This can be the result of the crystallization process (0.3% of shrinkage) or because of burs of reduced diameter used for refinement (REICH et al., 2011; SHAMSSSEDINE et al., 2016). The poor occlusal fit of glass-ceramic restorations may result in an increase in the risk of fractures because of the reduced support and stabilization of the ceramic through adhesion to the tooth substrate (ZELTNER et al., 2017), the clinical performance of bonded restorations might decrease due to the polymerization shrinkage (MAY et al., 2012). Conversely, thinner cement space associated to loading application onto the surface of the crown could lead to tensile fracture of the ceramic at the cementation surface, due to the low modulus of resin cements (4-6GPa) compared with glass-ceramic (70GPa) (SILVA et al., 2008).

On the other hand, the smallest value of occlusal space and the greater volume was presented by Y-TZP, the negative correlation between them allows to understand that the insufficient space for the luting agent in occlusal space, may hinder the seating

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of the crown eventually leading to higher risk of marginal leakage (QUINTAS et al., 2004). Zirconia showed the greater marginal value between the materials studied. Although cement space values observed are within acceptable ranges, debonding of Y-TZP prostheses remain an issue likely associated with its polycrystalline structure and difficulties in bonding, but also on preparation and milling parameters that should not be overlooked.

3.3 Clinical relevance

An inadequate marginal fit can lead known biological and mechanical issues, such as plaque retention, washout of the luting agent, caries, pulpal inflammation, periodontal disease (CONTREPOIS et al., 2013) and loss the restoration retention. As possible consequences of an internal misfit, no frictional retention and even some crown rotation onto the preparations resulting in reduced fracture toughness (REICH et al., 2013) and sometimes debonding of the all-ceramic crowns.

Although, this study concerned about the same .stl parameter and CAD/CAM system to milled all the material used, the results showed the “spacer” appears to be a semi-quantitative tool that interactively counterbalances errors within the process chain such as powdering, manufacturing or sintering shrinkage (MOLDOVAN et al., 2011). This tool requires more studies to better comprise and, consequently, improve all digital restorations.

The article 1 showed the correlation between optical and μ -CT. The measurements of the scanned pellicles may be more reliable when thinner sections are under measurement, and the stereomicroscope allow limited number of measures, while μ -CT allow two and three-dimensional analysis. In addition to, in article 2 the correlation between 2D and volumetric measures of cement space allows understanding the main issues related to the investigated all-ceramic systems.

4 Conclusion

4 Conclusions

Considering the hypothesis raised before, it is possible to conclude that:

- Article 1: A positive correlation between the stereomicroscope and the microtomography in 2D evaluation of cement thickness was observed for ceramic crowns. Although the same spacings were set in the CAD software, final internal dimensions varied among milled crowns.
- Article 2: The correlation between the two-dimensional analysis and the volume was observed for ceramic crowns.

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Appendixes

APPENDIX A - DECLARATION OF EXCLUSIVE USE OF ARTICLE IN THESIS

DECLARATION OF EXCLUSIVE USE OF ARTICLE IN THESIS

We declare to be aware that the study entitled ***“Analysis of correlation between optical and microtomography measurements of cementation space in all-ceramic crowns”*** will be included in the Thesis of the student Fernanda Furtado Piras and may not be used in other works of Graduate Programs at the Bauru School of Dentistry, University of São Paulo.

Bauru, January 8th, 2019

Fernanda Furtado Piras

Fernanda Ferruzzi

Brunna Mota Ferrairo

Estevam Augusto Bonfante

José Henrique Rubo

APPENDIX B - DECLARATION OF EXCLUSIVE USE OF ARTICLE IN THESIS

DECLARATION OF EXCLUSIVE USE OF ARTICLE IN THESIS

We declare to be aware that the study entitled ***“Correlation between two- and three-dimensional measurements of cement space in all-ceramic crowns”*** will be included in the Thesis of the student Fernanda Furtado Piras and may not be used in other works of Graduate Programs at the Bauru School of Dentistry, University of São Paulo.

Bauru, January 8th, 2019

Fernanda Furtado Piras

Fernanda Ferruzzi

Brunna Mota Ferrairo

Ilana Santos Ramalho

Estevam Augusto Bonfante

José Henrique Rubo

Annexes

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ANNEX A – Manuscript submission letter confirmation from The Journal of Prosthetic Dentistry

Submission Confirmation

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ANNEX B – Manuscript submission letter confirmation from The Journal of Prosthetic Dentistry

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