UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

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Analysis of marginal chipping of monolithic lithium disilicate crowns produced by four CAD-CAM systems

Análise do lascamento marginal de coroas monolíticas de dissilicato de lítio confeccionadas por quatro sistemas CAD/CAM

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Orientador: Prof. Dr. Accácio Lins do Valle

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“Aquele que tem uma profissão tem um bem; aquele que tem uma vocação tem um cargo de proveito e honra. ”

Benjamin Franklin

ABSTRACT

ABSTRACT

Analysis of marginal chipping of monolithic lithium disilicate crowns produced by four CAD-CAM systems

Statement of the problem. The marginal integrity of monolithic crowns is an essential factor for longevity. Due to the wide application of CAD/CAM systems, evaluation of production accuracy is of great clinical interest.

Purpose. Evaluating the marginal chipping of monolithic lithium disilicate crowns produced by four different CAD-CAM systems.

Material and methods. Four CAD-CAM systems were selected: Ceramill (Ceramill Motion 2), Cerec (Cerec inLab MC XL), EDG (CAM5-S1 SmartDent) and Zirkonzahn (M5 Heavy). An artificial lower first molar was prepared for a full crown, duplicated in plaster, scanned and a crown was designed following standardized parameters. Ten lithium disilicate crowns (IPS e.max CAD) per group were milled. Images were obtained using a scanning stereomicroscope Stemi 2000-C (Zeiss), overlapped (Adobe Photoshop CS6 software) and measurents of the marginal perimeter and chipping area were performed (ImageJ software). To evaluate the degree of marginal chipping, the Chipping Factor (CF) of each crown was calculated and the data were subjected to Kruskal-Wallis One-way test followed by Dunn's method ($p< 0.05$).

Results. Based on SD and absolute mean values, the CF of Ceramill (14,5 ± 8,3) and Cerec (13,4 ± 9,4) groups was statistically higher than EDG (3,4 ± 1,2) and Zirkonzahn (2,8 ± 1,3).

Conclusion. The data demonstrated the influence of selected parameters during the design, parameters settings and manufacturing tools of CAD/CAM systems on the marginal integrity of monolithic crowns.

Key words: CAD/CAM. Dental Crowns. Dental Marginal Adaptation. Ceramics.

Resumo

RESUMO

Análise do lascamento marginal de coroas monolíticas de dissilicato de lítio confeccionadas por quatro sistemas CAD/CAM

Afirmação do problema. A integridade marginal de coroas monolíticas é um fator essencial para sua longevidade. Devido a ampla aplicação dos sistemas CAD-CAM disponíveis, a avaliação da precisão de sua produção é de grande interesse clínico.

Finalidade. Avaliação do lascamento marginal de coroas monolíticas de dissilicato de lítio produzidas por quatro sistemas CAD-CAM diferentes.

Material e métodos. Foram selecionados quatro sitemas CAD-CAM: Ceramill (Ceramill Motion 2), Cerec (Cerec inLab MC XL), EDG (CAM5-S1 SmartDent) e Zirkonzahn (M5 Heavy). Um primeiro molar inferior artificial foi preparado para coroa total, duplicado em gesso, digitalizado e a coroa foi projetada seguindo parâmetros padronizados. Dez coroas de dissilicato de lítio (IPS e.max CAD) foram fresadas por grupo. Para cada grupo o sistema foi utilizado em sua totalidade: scanner, software do design e unidade de fresagem. Imagens foram obtidas usando o estereomicroscópio Stemi 2000-C (Zeiss), sobrepostas (programa Adobe Photoshop CS6) e medidas do perímetro marginal e área de lascamento foram realizadas (programa ImageJ). Para avaliar o grau de lascamento da margem, o Fator de Lascamento (FL) de cada coroa foi calculado e os dados foram submetidos ao teste de Kruskal-Wallis, seguido pelo método de Dunn ($p < 0,05$).

Resultados. Com base nos valores médios absolutos e DP, o FL dos grupos Ceramill (14,5 ± 8,3) e Cerec (13,4 ± 9,4) foram estatisticamente maiores do que os grupos EDG (3,4 ± 1,2) e Zirkonzahn (2,8 ± 1,3).

Conclusão. Os dados demonstraram a influência dos parâmetros selecionados durante o design, das configurações e ferramentas de confecção dos sistemas CAD / CAM sobre a integridade marginal das coroas monolíticas.

Palavras chave: CAD/CAM. Coroas dental. Adaptação Marginal Dentária. Cerâmica.

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1 INTRODUCTION

Dental ceramics have been the mainstay of esthetic dentistry for decades, since they present satisfactory mechanical properties such as flexural strength, fracture toughness, thermal and electrical conductivity, great optical properties, high biocompatibility and reduced plaque accumulation.[1-4] These characteristics are determined by the ceramic microstructure and consequently are subject to changes. [3] The increase in the demand for aesthetic procedures in anterior and posterior regions has directly influenced the improvement of the optical and mechanical properties of dental ceramics.

Although ceramic materials demonstrate desirable properties, cohesive failures in veneer ceramic were reported as the most common complication. For this reason, monolithic restorations were introduced in recent years with the purpose of reducing the failures on veneer layer.[5-7] Because of lithium disilicate excellent chemical durability, height flexural strength, high fracture load and improved translucency, it has become widely used for veneers, inlays, onlays, single crowns and multiple unit bridges.[8-10]

Monolithic lithium disilicate ceramic restorations have a cumulative survival rate of 100% after 5 years and 87,9% after 10 years showing similar survival rate of conventional metal-ceramic crowns.[8] The longevity is influenced and dependent of many factors: tooth preparation characteristics, crown shape and thickness, elastics modulus of the restoration material, material selection, cement thickness, quality of laboratory processing and marginal and internal fit.[11-13] Regardless of improvements in monolithic materials, complications can still affect the survival rates.[8, 14-15]

Among these complications, the marginal and internal accuracy has been considered as a crucial factor for the success and survival of all-ceramic crowns. Deficiencies of marginal fit in the restoration may lead to the luting resin to be exposed to the oral environment, which would favor the material natural dissolution and leave the region more susceptible to bacterial infiltration, altering the composition of the subgingival microflora.[16-18] This would result in marginal microleakage, which may increase susceptibility to plaque retention, marginal discoloration, dentin sensitivity, secondary caries, irritates the vital pulp and beginning of periodontal disease. In addition, the tooth cannot support properly restorations poorly adapted, inducing complete failure of ceramic restorations and affecting the restoration longevity. Therefore, marginal and internal accuracy are related to marginal integrity, and are considered key factors for the clinical quality of ceramic restorations.[11, 16-23]

The method of laboratorial processing is also influenced by demand and receives constantly modifications. Although conventional dental ceramic manufacture presents an established high quality of production, the laboratory steps are still laborious and experience-dependent.[24-29] Since ceramic materials are technically sensitive, new advanced processing technologies and automated systems have been introduced to improve their manufacture. The CAD/CAM (computer-aided design/computer-aided manufacturing) systems have a fundamental participation at this perspective.[30] It allows restorations of high strength polycrystalline ceramics blocks to be fabricated[31-34] and make possible restorations with optimal esthetic and functional outcomes to be made.[11, 35]

CAD/CAM systems should ensure the ability to produce prosthetic restorations (1) with improved fit, (2) with adequate strength, (3) to decrease labor, (4) to enhance quality control, (5) with cost effectiveness and (6) that meets optical properties compared to conventional manufacturing processes using pressing or casting techniques. In addition to facilitate the process, making them faster and more accurate.[24, 36-37]

Scanning process may undermine the precision, especially when an intra-oral scanner is used. However, companies have invested heavily in improving this technology to minimize errors.[38] After scanning, the design setting of the restoration is essential. During this stage, it is possible to control parameters and modify the restoration morphology, considering the limits based on the mechanical properties of the selected material. Marginal gap, cement space, emergence profile, proximal contact strength, occlusal offset and marginal thickness are some of the adjustable parameters and variations will influence the quality of the final product. The last phase consists in the milling operation and it has a potential for generation of machining induced flaws. It could reduce the accuracy of restorations and consequently affect marginal adaptation and internal fit.[39]

The accuracy of the CAD/CAM system is paramount to control, improve, and maintain the quality of the product delivered. The success of the restoration is directly related to the clinical standards of strength, biocompatibility, marginal adaptation and color stability.[12, 40] However, the main challenge faced by the use of a CAD/CAM system is the marginal adaptation and the internal fit of restorations. As already mentioned, this problem has been identified as a vulnerable point of the system due the association with wear of the luting resin which may lead to wash-out and material collapse. The poor adaptation leads to a higher luting space resulting in dissolution of the luting resin, polymerization shrinkage, contraction gaps and leakage.[41,42] Furthermore, it may complicate prosthesis cementation and final adjustment.

For this reason, margin quality has been described as an essential aspect considering the longevity of ceramic restorations manufactured by CAD/CAM.[19-23] Marginal chipping, even small ones, may lead to biologic and mechanical complications, since marginal weaknesses can become stress concentration sites resulting in cracks, besides causing marginal gaps and disadjustments.[41-43]

Considering all these factors, the importance of properly understanding marginal chipping is demonstrated. However, there are few researches about this subject on the literature. Previous studies investigated the marginal integrity of ceramic crowns produced by CEREC CAD/CAM system. The results indicated increase of marginal chipping with acute bevel finishing lines showing that brittleness of a material increases the chipping factor.[44] Another research evaluated the effect on the marginal integrity of copings using different CAD/CAM systems and different finishing lines. They found different amount of marginal chipping related with the CAD/CAM systems and with finishing lines.[45]

It is uncertain what factors are related to chipping of marginal region and their consequences. Therefore, the purpose of this *in vitro* study was to investigate the degree of marginal chipping of lithium disilicate crowns manufactured with four different CAD/CAM systems and the accuracy of their production. The null hypothesis is that there are no differences in the marginal chipping of the restorations among the systems.

2 Article

2 ARTICLE

The article presented in this Dissertation was written according to The Journal of Prosthetic Dentistry instructions and guidelines for article submission (Annex A).

ANALYSIS OF MARGINAL CHIPPING OF MONOLITHIC LITHIUM DISILICATE CROWNS PRODUCED BY FOUR CAD-CAM SYSTEMS

ABSTRACT

Statement of the problem. The marginal integrity of monolithic crowns is essential factor for their longevity. Due the wide application of CAD/CAM systems, evaluation of the accuracy of its production is of great clinical interest.

Purpose. Evaluating of marginal chipping of monolithic lithium disilicate crowns produced by four different CAD-CAM systems.

Material and methods. Four CAD-CAM systems were selected: Ceramill (Ceramill Motion 2), Cerec (Cerec inLab MC XL), EDG (CAM5-S1 SmartDent) and Zirkonzahn (M5 Heavy). An artificial lower first molar was prepared for a full crown, duplicated in plaster, scanned and the crown was designed following standardized parameters. Ten lithium disilicate crowns (IPS e.max CAD) per group were milled. For each group the complete system was used: scanner, design software and milling unit. Images were obtained using a scanning stereomicroscope Stemi 2000-C (Zeiss), overlapped (Adobe Photoshop CS6 software) and measures of the marginal perimeter and chipping area were performed (ImageJ software). To evaluate the degree of marginal chipping, the Chipping Factor (CF) of each crown was calculated and the data were subjected to Kruskal-Wallis One-way test followed by Dunn's method ($p < 0.05$).

Results. Based on SD and absolute mean values, the CF of the Ceramill (14,5 ± 8,3) and Cerec (13,4 ± 9,4) groups were statistically higher than EDG (3,4 ± 1,2) and Zirkonzahn (2,8 ± 1,3).

Conclusion. The data demonstrated the influence of selected parameters during the design, parameters and manufacturing tools of CAD/CAM systems on the marginal integrity of monolithic crowns.

INTRODUCTION

Monolithic all-ceramic crowns have been widely used, since they present satisfactory mechanical properties, minimizing the presence of residual stress and cohesive failures in veneer ceramic.[1-4] The high flexural strength, improved esthetics and possibility of using in anterior and posterior regions has become the lithium disilicate an excellent material option for monolithic dental crowns.[5-7]

Monolithic lithium disilicate ceramic restorations have a cumulative survival rate of 100% after 5 years and 87,9% after 10 years showing, similar survival rate of conventional metal-ceramic.[5] The prosthesis longevity is influenced and dependent of many factors, such as tooth preparation characteristics, crown shape and thickness, cement thickness, quality laboratory processing and marginal and internal fit.[8-10] Regardless of all improvements in monolithic materials, complications can still affect the survival rates.[5, 11,12]

Among the complications, the marginal and internal accuracy has been considered a crucial factor for success and survival of all-ceramic crowns. Deficiencies of marginal fit in the restoration may lead the luting resin exposed to the oral environment, which would favor the material natural dissolution and leave the region more susceptible to bacterial infiltration.[13-15] This would result in marginal microleakages, which may increase susceptibility to plaque retention, marginal discoloration, secondary caries, irritates the vital pulp and beginning of periodontal disease. In addition, the tooth cannot support properly restorations poorly adapted, inducing complete failure of ceramic restorations and affecting the restoration longevity.[8, 13-20] The method of laboratorial processing is also influenced by demand and receives constantly modifications. The CAD/CAM (computer-aided design/computer-aided manufacturing) systems allows restorations of high strength polycrystalline ceramics blocks to be fabricated and make possible restorations with optimal esthetic and functional outcomes.[21-24] However, the abrasive machining processes used by CAD/CAM systems induce surface damages, which could reduce the accuracy of restorations and consequently affect marginal adaptation and internal fit.[25] This, can result in serious implications related to integrity of monolithic lithium disilicate ceramic restorations.

Considering all of these factors, margin quality has been described as an essential aspect regarding the longevity of ceramic restorations manufactured by CAD/CAM systems.[16-20] The marginal chipping, even the small ones, may lead to biologic and mechanical complications, since marginal weakness can become a stress concentration site, resulting in cracks, causing marginal gaps, disadjustments and any other problems arising from this.[26-28] Previous research indicates the relation between the amount of marginal chipping with CAD/CAM systems and tooth preparation design.[29,30] Despite the importance of properly understanding marginal chipping, there are few researches about this subject on the literature. Since these questions are already unstudied and it is remain uncertain, the purpose of this *in vitro* study was to investigate the degree of marginal chipping of lithium disilicate crowns manufactured with four different CAD/CAM systems and the accuracy of their production. The null hypothesis is that there are no differences in the marginal chipping of the restorations among the systems.

MATERIALS AND METHODS

To determine the marginal integrity of the crowns through the degree of marginal chipping, forty lithium disilicate crowns produced by four CAD/CAM systems were obtained and analysed with a stereomicroscope.

Tooth preparation and cast fabrication

An artificial lower first molar positioned in a mannequin was prepared for a complete crown. 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 angles (Fig. 1).

An impression was taken using the double impression technique with polyvinyl siloxane material (Express; 3M ESPE, St Paul, USA). A plaster model was made with type IV special CAD/CAM stone (CAM-base; Dentona AG, Dortmund, Germany) (Fig. 2), scanned and the crown design was produced according to standardized parameters. For each group, the complete system was used: scanner, design software and milling unit.

Standardized parameters

In each CAD-CAM system the same parameters where selected and stablished according to the ceramic manufacturer's indication.

For the evaluation of marginal integrity, the following parameters are highlighted as the most capable of influencing the outcome:

- Margin Thickness: allows to increase the material amount in restoration margins. It prevents chipping of the porcelain during the milling process. Set up to 120 µm.
- Margin Ramp Width: allows to determine the length of the area with which the restoration rises from the preparation margin. Set up to 50 µm.

- Margin Ramp Angle: allows to define the angle at which the restoration rises from the margin. Set up to 60º.

Crowns fabrication

Ten crowns per group were milled from lithium disilicate glass-ceramic blocks (IPS e.max CAD; Ivoclar-Vivadent, Amherst, NY) (Fig. 3). As standard, a wax-up model was used to determine the occlusal anatomy.

Four CAD-CAM systems were selected and the groups were named:

1. CERAMILL - Ceramill Motion 2 (Amann Girrbach AG, Koblach, Austria)
2. CEREC - Cerec inLab MC XL (Sirona Dental Systems GmbH, Bensheim, Germany)
3. EDG - SmartDent CAM5-S1 (EDG Equipamentos e Controles Ltda; São Carlos, Brazil)
4. ZIRKONZAHN - Milling Unit M5 Heavy (Zirkonzahn, South Tyrol, Austria)

After milling, crowns were sintered and glazed according to the manufacturer's instructions.

Image Acquisition

The marginal perimeter and integrity were examined using a scanning stereomicroscope Stemi 2000-C (Zeiss, Oberkochen, Alemanha; magnification: 0,8x-1,6x) connect to a computer (Fig. 4). The images were reproduced by assistance of AxionVision 4.9.1 imaging software.

Images standardization was ensured dividing the edge of the crown in 8 sections:

1. B (buccal)
2. BM (buccal-mesial)
3. BD (buccal-distal)
4. M (mesial)
5. D (distal)
6. L (lingual)

7. LM (lingual-mesial)

8. LD (lingual-distal)

This segmentation allowed proper observation with adequate focus in all the intended extension, facilitating the subsequent analysis, and ensuring that the entire perimeter was considered.

To enable the standardized positioning of the crown for the analysis, 8 bases were manufactured of polyvinyl siloxane (Express; 3M ESPE, St Paul, USA) (Fig. 5) dividing the sections of interest and named according to sessions (Fig. 6).

Marginal Chipping Analysis

The images were imported to Adobe Photoshop CS6 software which allowed the recognition of the chipping areas.

An ideal selected image, without marginal chipping, of each section was considered the baseline for overlapping the other imagens of the same section and group. This overlapping ensures the observation of the chipping area and, consequently, the perimeter for analysis (Fig. 7). After overlapping, the images obtained were imported to ImageJ software providing the perimeter measurements for each section by a single examiner and, thus calculated (Fig. 8).

An ideal margin was defined by the absence of interruption of continuity (Fig. 9), while the marginal chipping was defined as the interruption of this continuity (Fig. 10). Based on this principle, the margin of the selected region was initially outlined in all its length, disregarding eventual launches, characterizing the perimeter measure (P). If there was marginal chipping, its extent was measured (L).

To find the degree of marginal chipping, the Chipping Factor (CF) of each crown was calculated. The equation was applied by region. The mean CF of each region was considered the total CF for each crown.

The following equation was used to calculate CF. [29]

$CF = [L / P] \times 100$

The benefit of this approach is to ensure a better quality of observation of the entire margin of the crown, allowing to measure chipping with greater accuracy.

Statistical analysis

The chipping values were imported into Statistica software (Statsoft®, Tulsa, Ok, USA). The means and standard deviation of the eight section were analyzed for each of 4 groups. Kruskal-Wallis One-way analysis test was used to find any difference of the CF among the groups and the data were submitted to the Dunn's method to multiple comparisons between-group, at a statistically significant differences at $p < 0.001$.

RESULTS

The means and standard deviation (SD) for chipping factor (CF) of each CAD-CAM system were obtained from Kruskal-Wallis one-way analysis of variance on ranks, at a significance level of 5% and were summarized in Table 1. The Ceramill (14,5 ± 8,3) and Cerec (13,4 ± 9,4) groups showed higher values than EDG (3,4 ± 1,2) and Zirkonzahn (2,8 ± 1,3) groups, demonstrating a heterogeneous distribution. This inconsistency in distribution could be related to inaccuracy of monolithic lithium disilicate crowns ($p<0,001$).

Pairwise multiple comparison procedures (Dunn's Method) was used to compare discrepancies among groups and indicated significant differences among them. The results obtained are shown in Graphic 1.

Data from this graphic demonstrate the differences between Ceramill and EDG, Ceramill and Zirkonzahn, Cerec and EDG and Cerec and Zirkonzahn. On the other hand, there was no disparities between Ceramill and Cerec and EDG and Zirkonzahn. The results indicate variations in the median values distribution among the treatment groups, highlights a statistically significant difference ($p<0,05$).

Overall, these results suggest the presence of differences in manufacturing process among the CAD-CAM systems. Zirkonzahn group showed a more uniform distribution of marginal chipping and higher accuracy in crown fabrication followed by, EDG, Cerec and Ceramill. Therefore, the null hypothesis was rejected.

DISCUSSION

Marginal adaptation, internal fit and the quality of laboratory process are considered the essential factors for the longevity of all-ceramic crowns.[8-10] The marginal integrity when presents discrepancies or gaps, it will directly influence the marginal adaptation and might result in higher susceptibility to secondary caries, plaque retention, marginal discoloration and also prevent the final adjustment.[13-20]

In this *in vitro* study, the marginal integrity of monolithic lithium disilicate (IPS e.max CAD) crowns manufactured by four different CAD/CAM systems was evaluated by quantitative image analysis, in order to determine if there is a difference in this characteristic among manufacturing systems.

The index used to determine the marginal integrity was chipping factor (CF). The results showed an increase of the CF in CEREC (13,35%) and Ceramill (11,84%) groups. On the other hand, the EDG (3,02%) and Zirkonzahn (2,33%) groups presented lower rate of the CF. Multiple comparison analyses presented statistically significant differences between the groups with high and low CF ($p<0,05$).

The data obtained in CEREC and Ceramill groups are opposite to a previous study using copings, which present lower values of CF.[30] Direct comparison can be realized in CEREC group with 0º bevel angle copings, where the mean CF was 2,8% compared with 13,35% found by this study. It is important to emphasize that the difference of design between copings and crowns may affect the results, since the CAD-CAM manufacturing process produce in copings a collar at the margins, which function as a support while the crowns are milled until final shape, increasing the possibility of marginal chipping.[30]

The previous study correlated the machinability of glass ceramic materials through the chipping factor and brittleness calculation by single CAD/CAM system. They used the CEREC system to mill lithium disilicate crowns finding 69.8% of marginal chipping, which was significantly greater than present study. Moreover, their results showed a perfect positive correlation between brittleness and CF, however, in this study only one glass ceramic was used, which standardized the samples.[29] Another finding that emerge from the analysis is related to occurrence of difference in milling process of CAD/CAM systems which have different effects on the quality of the restorations.

The machinability of CAD/CAM systems may be the reason of the variations between groups. The machining processes create, through the milling burs contact, trace lines inducing few microscopic defects. Although microscopic, these defects promote surface damages that enables stress concentration increasing the susceptibility for crack initiation that, in turn, may increase with mastication. Therefore, microscopic flaws lead to small cracks, which can grow and result in larger cracks reducing strength and fatigue life or even causing catastrophic failure.[31-34]

Other relevant issues that requires attention apply to the marginal thickness and marginal ramp width. According to the manufacturing companies, the amount of ceramic present at the margin of the restoration can vary without affecting the adaptation. However, a smaller thickness of material in margin may turn the margin restoration more susceptible to damage derived from milling process. The margin ramp width establishes the length of the area that the restoration rises from the dental preparation. Minimally invasive preparation can reduce the width of finish lines producing restorations with low thickness, which may hamper the marginal integrity. Furthermore, the burs diameter of CAD/CAM systems cannot be compatible with the thickness restoration and provide damages in milling resulting in margins defects.[35]

The extension of damage can be influenced by size of the bur, wear of cutting tool, number of axes, applied load and grinding speed.[7,20,36,37] The size of the burs limits the accuracy of the milling process, since the crowns fine details can be incompatible with them.[37] In this study, the burs indicated by each system were used considering the fabrication of a monolithic lithium disilicate crown.

Regarding to number of axes, all systems presents 5 axes that enable linear movement and rotations in three spatial directions X, Y, Z. The ceramic block rotates around X axes and milling spindle rotation around Y axes. These freedom of rotation allows higher accuracy of the milled restorations.[20,27]

Another factor that could influence the final aspect of the margin is the time consuming for the milling operation. The shorter is the process time, the greater is the production rate, although the probability for inaccuracy and marginal chipping will be higher, resulting in reduced success rate.[27, 37] In present research, the time spent for manufacturing was 14 min (CEREC), 30 min (Ceramill), 30 min (EDG) and 40 min (Zirkonzahn). The CAD/CAM systems have the option of changing the milling time, speeding up or not the process. Often, this decision is determined by the operator. Further studies, that considers these variables, need to be undertaken.

The CF method analysis was initially described by Tsitrou et al.[29] however in the present study, modifications was realized for allowing a detailed observation of crown margins. The equation was also adapted to guarantee that the chippings were measured and belonged to the right perimeter. Therefore, the perimeter extent was unique for each section. Furthermore, the setting of measures were performed after overlaying the images allowing all of the chipping areas to be involved, opposed to what happens in this previous study.

The correlation between the amount of degree of marginal chipping and longevity of all-ceramic restorations remain unknown. Consequently, we cannot be assertive of what chipping percentage is necessary to affect the survival rates.[30] However, previous researches have suggested the possibility of structural surface flaws acting as stress concentration sites. The stress magnitude will depend on the severity of the surface defect, thus the greater the surface defect, the higher the stress concentration. Consequently, the potential of flaws to become crack initiation sites, affecting survival probability.[31] Furthermore, flaws may assume the form of micro cracks and are unlikely to allow visual detection, due their sub-millimeter scale.[32]

Therefore, understand the damages produced by CAD/CAM milling, it is important to highlight the marginal integrity role in success of ceramic restorations. It is necessary greater emphasis in parameters selections during design process, materials choice and milling time process, given the impact of marginal integrity role in success rates of all-ceramic restorations. Future investigations could clarify questions about the theme.

CONCLUSIONS

The present study was designed to determine the degree of marginal chipping of lithium disilicate crowns manufactured by four different CAD/CAM systems and evaluate the accuracy of its production.

Within the limitations of this *in vitro* study and the lack of detailed information about some CAD/CAM systems, it was concluded that the chipping factor of monolithic lithium disilicate crowns exhibit statistical differences among the test groups ($p<0.001$). Zirkonzahn showed the uniform distribution and the lowest percentage of chipping in marginal region. The current data highlight the influence of the restorations design, settings and tools of CAD/CAM systems have in final integrity of the prosthesis margin.

Furthermore, the clinical importance of chipping margin remains unclear, which suggests future *in vivo* studies to evaluate the marginal chipping and clinical performance of monolithic crowns made from different CAD-CAM systems.

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LEGENDS FOR ILLUSTRATIONS

Figure 1 - Prepared artificial tooth positioned in a mannequin.

Figure 2 - Master die.

Figure 3 - Lithium disilicate glass-ceramic crowns.

Figure 4 - Stereomicroscope Stemi 2000-C (Zeiss, Oberkochen, Alemanha).

Figure 5 - Bases of polyvinyl siloxane (Express; 3M ESPE, St Paul, USA).

Figure 6 - Crowns positioned in base

Figure 7 - Image overlapping on Adobe Photoshop CS6 software.

Figure 8 - Measures of ImageJ software.

Figure 9 - Example of perfect margin

Figure 10 - Example of marginal chipping

Figure 11 - Chipping Factor (CF) analysis

Fig 1

Fig 2


CE 0123
Made in Liechtenstein
FL-9494 Schaan
IPS e.max CAD
for CEREC and inLab
HT A3 / C 14
ivoclar vivadent
5 pcs.
LOT U26854
CE 0123
Made in Liechtenstein
FL-9494 Schaan
IPS e.max CAD
for CEREC and inLab
HT A3 / C 14
ivoclar vivadent
5 pcs.
LOT T10337

Fig 3

Fig 4

Fig 5

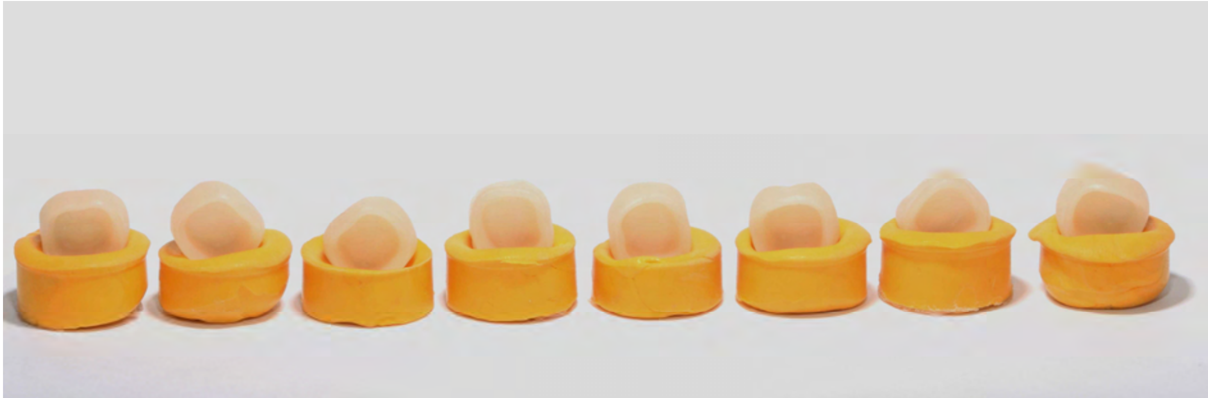


Fig 6

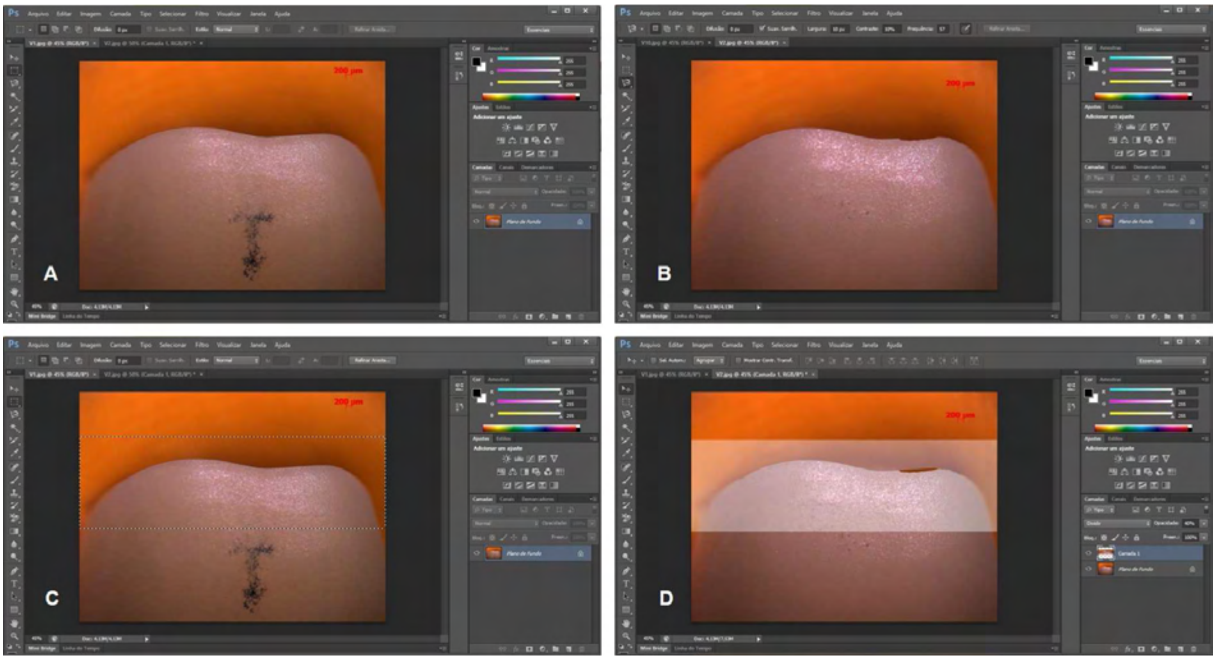
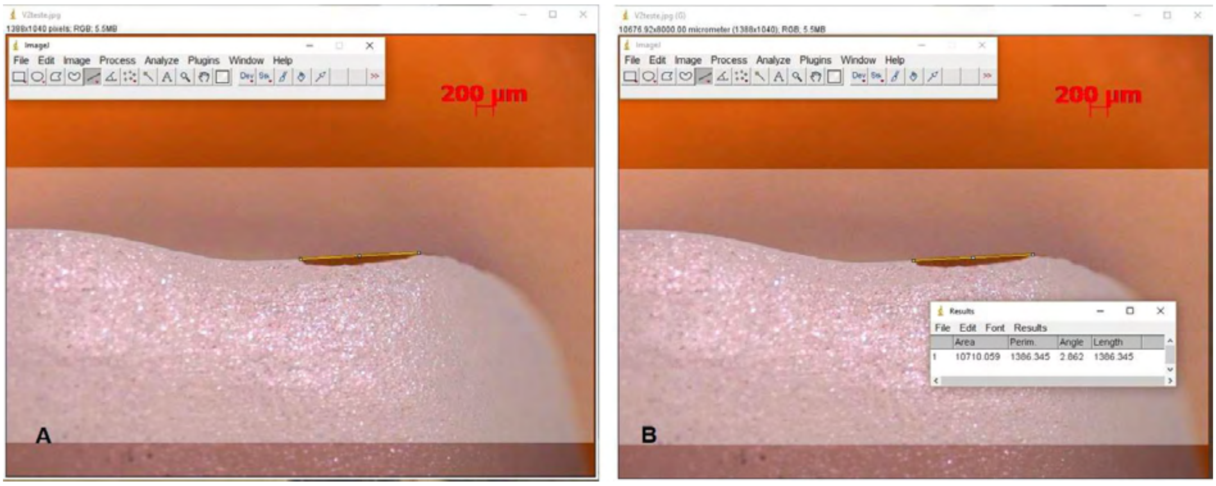


Fig 7


ImageJ
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1 10710.059 1386.345 2.862 1386.345
B

Fig 8

Fig 9

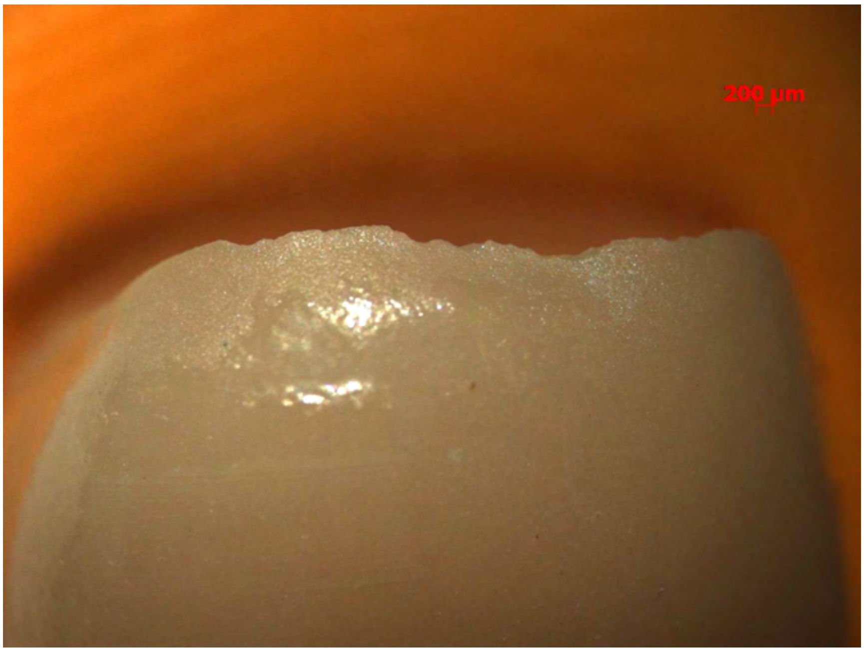
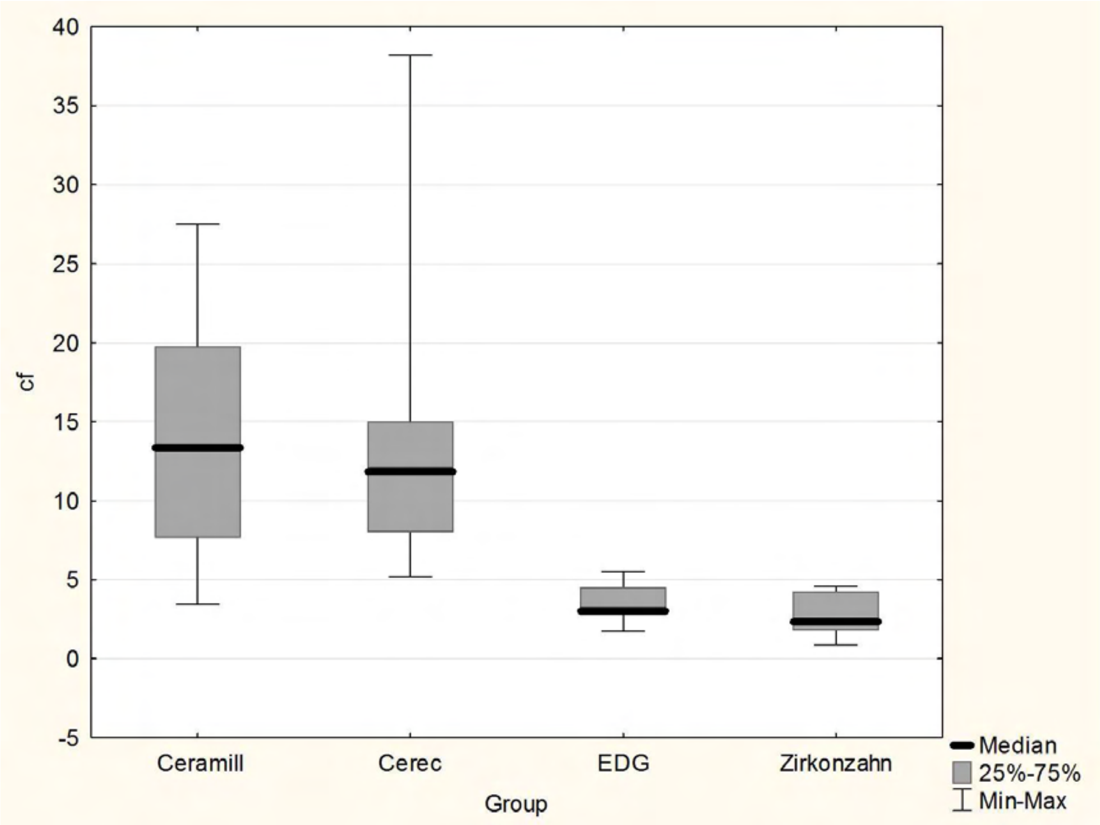


Fig 10



40
35
30
25
20
15
10
5
0
-5
cf
Ceramill
Cerec
EDG
Zirkonzahn
Group
Median
25%-75%
Min-Max

Fig 11

Table 1. Mean CF and standard deviation of CAD/CAM systems

CAD/CAM SYSTEM	MEAN CF	SD
CERAMILL	14,5	8,3
CEREC	13,4	9,4
EDG	3,4	1,2
ZIRKONZAHN	2,8	1,3

3 Discussion

3 DISCUSSION

Prosthesis longevity can be affected by many factors, including marginal adaptation, internal fit and the quality of laboratory processing.[11-13] If the marginal integrity presents discrepancies or gaps, it will directly influence the marginal adaptation and might result in higher susceptibility to secondary caries, plaque retention, marginal discoloration and also prevent the final adjustment.[16-23]

In this *in vitro* study, the marginal integrity of monolithic lithium disilicate (IPS e.max CAD) crowns manufactured by four different CAD/CAM systems was evaluated by quantitative image analysis, in order to determine if there is a difference in this characteristic among manufacturing systems.

The index used to determine de marginal integrity was the chipping factor (CF). The results showed an increase of the CF in CEREC (13,35%) and Ceramill (11,84%) groups. On the other hand, the EDG (3,02%) and Zirkonzahn (2,33%) groups presented lower CF rates . Multiple comparison analyses presented statistically significant differences between the groups with high and low CF ($p<0,05$).

The data obtained in CEREC and Ceramill groups are opposite to a previous study using copings, which present lower values of CF.[45] Direct comparison can be realized in CEREC group with 0º bevel angle copings, where the mean CF was 2,8% compared with 13,35% found by this study. It is important to emphasize that the difference of design between copings and crowns may affect the results, since the CAD-CAM manufacturing process produce in copings a collar at the margins, which function as a support while the crowns are milled until the final shape, increasing the possibility of marginal chipping. [45]

Tsitrou et al.[44] correlated the machinability of glass ceramic materials through the chipping factor and brittleness calculation by single CAD/CAM system. They used the CEREC system to mill lithium disilicate crowns finding 69.8% of marginal chipping, which was significantly greater than present study. Moreover, their results showed a perfect positive correlation between brittleness and CF, however, in this study only one glass ceramic was used, which standardized the samples. Another finding to emerge from the analysis is related to occurrence of differences in milling process of CAD/CAM systems which have different effects on the quality of the restorations.

The variations between groups could be related to the machinability of CAD/CAM systems. The machining processes create, through the milling burs contact, trace lines inducing few microscopic defects. Although microscopic, these defects, represented by sharp cracks and scratches, promote surface damages that enable stress concentration increasing the susceptibility for crack initiation that, in turn, may increase with mastication. Therefore, microscopic flaws lead to small cracks, which can grow and result in larger cracks reducing strength and fatigue life or even causing catastrophic failure.[46-49]

The marginal thickness is another relevant issue that requires attention. Usually, the studies do not exhibit this information, which is essential for this type of evaluation. According to the manufacturing companies, the amount of ceramic present at the margin of the restoration can vary without affecting the adaptation. It is supposed that a smaller thickness of material in margin may turn the margin of restoration more susceptible to damage derived from the milling process.

The margin ramp width also is an important factor, since it establishes the length of the area that the restoration rises from the dental preparation. Minimally invasive preparation must maintain sufficient space to guarantee the adequate ceramic properties, however the reduced width of finish lines produce restorations with low thickness, which may hamper the manufacture. Furthermore, the burs diameter of CAD/CAM systems cannot be compatible with the thickness restoration and provide damages in milling resulting in margins defects.

The extension of damage can be influenced by the size of the bur, wear of the cutting tool, number of axes, applied load and grinding speed.[38, 50-52] The size of the burs limites the accuracy of the milling process, since the crowns fine details can be incompatible with them.[52] In this study, the burs indicated by each system were used considering the fabrication of a monolithic lithium disilicate crown. For the CEREC system two burs were used, one with ,31 mm diameter (Step Bur 12S, ref. 6240167) and the other with 1,8mm (Cylinder Pointed Bur 12S, ref. 6240159).[53] For the Ceramill system were used four burs with 0,4mm (ref. 760627), 1mm (ref. 760624), 1,4mm (ref. 760625) and 1,8mm (ref. 760626) diameter.[54] For EDG, Ball Nouse burs with 1mm, 1,5mm and 2,5mm diameter were used and for Zirkonzahn, 0,6mm (ref. ZBAC2006), 1,25 mm (ref. ZBAC2016) and 2,5mm diameter (ref. ZBAC2026).[55]

Regarding to number of axes, all systems present 5 axes that enable linear movement and rotations in three spatial directions X, Y, Z. The ceramic block rotates around X axes and milling spindle rotation around Y axes. These freedom of rotation allows higher accuracy of the milled restorations.[38,42] However, since the amount of rotations cannot be equal, the 5 milling axes vary among systems.

Another factor that could influence the final aspect of the margin is the time consuming for the milling operation. The shorter is the process, the is greater the production rate, although the probability for inaccuracy and marginal chipping will be higher, resulting in reduced success rate.[42,52] In the present research, the time spent for manufacturing was 14 min (CEREC), 30 min (Ceramil), 30 min (EDG) and 40 min (Zirkonzahn). The CAD/CAM systems have a numerical control program, which guide the CAM to realize specific axis movements based on feed rate and specific spindle speed to rotate the milling tool. This program is not controlled for material machinability, therefore, it can be altered to create faster tool feed rates.[56] Thus, the CAD/CAM systems have the option of changing the milling time, speeding up or not the process. Often, this decision is determined by the operator. Further studies, that considers these variables, need to be undertaken.

The CF method analysis was initially described by Tsitrou et al.,[44] who performed a series of images through digital camera of the perimeter crowns and a top view image of the margins of the restoration to measure the circumference. Afterwards, estimation of the degree of chipping factor was conducted according to equation detailed previously.

In the present study, image acquisition was a problem, since the zoom ratio hinders the detailed observation of crown margins. This complication could compromise the reliability of the measures. For this reason, a scanning stereomicroscope Stemi 2000-C was used (Zeiss, Oberkochen, Alemanha) with a sufficient zoom to analyze the margins.

Furthermore, the equation was adapted to guarantee that the chippings were measured and belonged to the right perimeter. Therefore, the perimeter extent was unique for each section. Another modification was applied to the setting of the measures, which were performed subsequently to overlaying of images allowing that all chipping areas were involved. The impossibility to predict the marginal chipping in previous method was the main reason for this change, since that calculating the CF before restorations milling was impossible.[44]

The correlation between the amount of degree of marginal chipping and longevity of all-ceramic restorations remains unknown. Consequently we cannot be assertive of what chipping percentage is necessary to affect the survival rates.[45] However, previous researches have suggested the possibility of structural surface flaws acting as stress concentration sites. The stress magnitude will depend on the severity of the surface defect, thus the greater the surface defect, the higher the stress concentration. Consequently, the potential of flaws to become crack initiation sites, affecting survival probability increases.[46] The occurrence of these defects can be related to the manufacturing process or masticatory load after cementation, since that leads to microstructural defects within the ceramic. Furthermore, flaws may assume the form of micro cracks and are unlikely to allow visual detection, due their sub-millimeter scale.[47]

Therefore, understanding the damages produced by CAD/CAM milling, it is important to highlight the marginal integrity role in success of ceramic restorations. It is necessary greater emphasis in parameters selection during the design process to guarantee better results of marginal adaptation, marginal integrity and internal fit. Future investigations could clarify questions about the theme.

4 Final Considerations

4 FINAL CONSIDERATIONS

The present study was designed to determine the degree of marginal chipping of lithium disilicate crowns manufactured by four different CAD/CAM systems and evaluate the accuracy of its production.

Within the limitations of this *in vitro* study and the lack of detailed information about some CAD/CAM systems, it was concluded that the chipping factor of monolithic lithium disilicate crowns exhibit statistical differences among the test groups ($p<0.001$). Zirkonzahn showed the uniform distribution and the lowest percentage of chipping in marginal region. The current data highlight the influence of the restorations design, settings and tools of CAD/CAM systems have in final integrity of the prosthesis margin.

Furthermore, the clinical importance of chipping margin remains unclear, which suggests future *in vivo* studies to evaluate the marginal chipping and clinical performance of monolithic crowns made from different CAD-CAM systems.

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ANNEXES

ANNEX A – Guidelines for The Journal of Prosthetic Dentistry:

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