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Integrated Master in Dentistry

Finite elements analysis of ceramic restorations with and without cusp coverage

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Abstract

Background: Ceramic restorations are able to restore the natural tooth morphology with high survival rates and good aesthetic results. Restorative procedures such as caries removal or cavity preparation are accompanied by reduction in tooth stability, decreased fracture resistance, increased deflection of weakened cusps and also decreased cusp stiffness. A maximum practicable protection of the natural enamel is the main principle and rule of all preparation, so in the era of modern adhesive dentistry a question arises: is cusp coverage really needed? The aim of this study was to make a 3D finite elements analysis of von Mises stress in two different designs/preparations for restoring a premolar with a large class II MOD cavity, simulating a frequent clinical situation when we have great tooth substance loss. Those options were restoration with or without cusp coverage.

Material and methods: A premolar tooth was isolated from a previous model and then worked with the software SolidWoks to create two designs/preparations of class II MOD, one with cusp coverage and the other without cusp coverage. They were submitted to three loads (200 N, 500 N, 800 N) in two different directions (11º and 45º with the long axis of the tooth) and analysed by finite elements analysis. The von Mises stresses were measured.

Results: Similar pattern on von Mises stress distribution were observed for the two designs/preparations. For the 11º load appliance we observe stress accumulated on the palatal cusp (preparation wall and outside wall) with growing intensity from 200 N to 500 N and to 800 N. At 800 N some differences between mesial and distal surfaces emerged with higher stress areas at distal. For the 45º load appliance the stress areas were concentrated at the buccal cusp, and other areas of stress were observed at the

palatal and buccal surfaces nearby the tooth insertion, here again with growing intensity from 200 N to 500 N and to 800 N.

Conclusion: There were no significant differences between the two designs/preparations for the loads of 200 N, 500 N and 800 N at 11º direction and at 45º direction. For all the loads applied at 45º direction we observed higher stresses than with a 11º direction. Further studies are needed.

Keywords: inlays, onlays, overlays, ceramic restorations, finite elements analysis (FEA)

Análise de elementos finitos de restaurações cerâmicas com e sem recobrimento cuspídeo

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Resumo

Introdução: as restaurações cerâmicas são capazes de restabelecer a morfologia natural do dente com altas taxas de sobrevivência e bons resultados estéticos. Os procedimentos restaurativos como sejam a remoção da lesão de cárie ou a preparação de cavidades são acompanhadas pela redução da estabilidade dentária, diminuição da resistência à fratura, aumento da deflexão das cúspides fragilizadas e também da diminuição da rigidez das cúspides. A proteção máxima, praticável, do esmalte natural é o principal princípio e regra das preparações, pelo que na era da adesão na medicina dentária moderna uma questão se levanta: será mesmo necessário fazer recobrimento cuspídeo? O objetivo deste estudo foi realizar uma análise de elementos finitos tridimensional da distribuição dos stresses de von Mises em duas diferentes preparações para restaurar um pré-molar com uma ampla cavidade classe II MOD, simulando uma frequente situação clínica quando estamos perante uma grande perda de estrutura dentária. Essas opções foram restauração com e sem recobrimento cuspídeo.

Materiais e métodos: um dente pré-molar foi isolado a partir de um modelo prévio e depois foi trabalhado com o software SolidWorks para criar duas preparações de uma classe II MOD, uma com recobrimento cuspídeo e a outra sem recobrimento. Foram submetidas a três cargas (200 N, 500 N, 800 N) em duas direções diferentes (11º e 45º em relação ao longo eixo do dente) e feita a análise de elementos finitos. Os stresses de von Mises foram medidos.

Resultados: padrões semelhantes na distribuição dos stresses de von Mises

foram observados para as duas preparações. Para a carga aplicada a 11º observamos stress acumulado na cúspide palatina (na parede da preparação e na parede externa) com intensidade crescente de 200 N para 500 N e para 800 N. Com 800 N algumas diferenças entre as faces mesial e distal emergiram com maior stress na face distal. Para a carga aplicada a 45º as áreas de stress concentraram-se na cúspide vestibular, outras áreas de stress foram observadas em palatino e vestibular na proximidade da inserção do dente, aqui também com intensidade crescente de 200 N para 500 N e para 800 N.

Conclusão: Não houve diferenças significativas entre as duas preparações para as cargas de 200 N, 500 N e 800 N com a direção de 11º e com a direção de 45º. Para todas as cargas aplicadas com a direção de 45º observámos valores superiores de stress do que com a direção de 11º. São necessários mais estudos.

Palavras-chave: inlays, onlays, overlays, restaurações cerâmicas, análise de elementos finitos (AEF)

Introduction

Dental caries is still a common disease worldwide and results in tooth substance loss. (1) The World Health Organization (WHO) estimates the prevalence of dental caries to be over 90% among adults worldwide. When the loss of tooth substance due to decay is minor, the dentist fills the tooth cavity with composite. When having a substantial loss of tooth substance, the dentist often treats the tooth with a crown, which presents the problem of further destroying sound structure. Composites, large amalgam or build-up amalgam restorations are also used in such cases in many countries; however, amalgam is being abandoned for environmental reasons, especially in Europe. An intermediate technique consists of manufacturing an inlay or onlay for the tooth and this type of restoration has become common because it is a minimally invasive solution. (2)

According to cusp coverage, the types of restorations can be classified as inlays (no cusp is covered), onlays (at least one cusp is not covered), or overlays (all cusps are covered). (3, 4)

The loss of dental structure due to trauma, caries, or cavity preparation drastically diminishes tooth resistance when compared to sound teeth. Restorative procedures such as caries removal or cavity preparation are accompanied by reduction in tooth stability, decreased fracture resistance, increased deflection of weakened cusps, and also decreased cusp stiffness. (5)

With the advent of adhesive dentistry and new and better materials, it is important that professionals are made fully aware of the importance of preserving the natural structures such as enamel, dentin, and pulp vitality. However, it is also important that the preparation is adequate to fulfil the aesthetic and functional requirements of the restoration. (6)

Ceramic restorations are able to restore the natural tooth morphology and usually achieve high survival rates and acceptable aesthetic results. The long-term success is influenced by the indication, the material properties and the quality of the adhesive bond. In particular, ceramic inlays have been proven for the reconstruction of Class II cavities. (7) Ceramic restorations are considered an excellent option to restore posterior teeth when aesthetics is required and the size of the cavity preparation has exceeded the conventional indication for direct resin composites. Ceramic systems can combine aesthetics with wear resistance, being considered a reliable treatment choice. (8) These restorations also present colour stability, chemical durability, fluorescence, resistance to

compression, biocompatibility, and improved fatigue resistance in the oral environment. (5)

Maintaining the maximum practicable protection of the natural enamel is the main principle and rule of all preparations. Although gold inlays or onlays can be designed without risking fracture of the restoration, this is not possible using ceramics due to their vulnerability to tensile stress. Therefore, the stability of ceramic inlays or onlays depends on their size and the material used. (7)

Although short and long-term clinical studies have shown low failure rates of adhesively bonded ceramic inlay and onlay restorations, some drawbacks have been reported, with bulk fracture and marginal discoloration being the most commonly cited problems. Deterioration of marginal quality has been addressed with regard to cement wear, which may be accelerated due to high differences in elasticity modulus between ceramic and resin cement materials, while bulk fracture has been associated with crack propagation through the ceramic, due to the brittle characteristic of the ceramic material. Also, some other factors have been reported as coadjutants on the ceramic crack propagation, such as the microstructure of the ceramic material, the fabrication technique, the surface finishing, and the luting protocol. (8)

The restorative material is considered to be a factor that affects the biomechanics (the stress distribution and deflection of the cusp) during occlusal loading. Ceramic materials are fragile and stiff and tend to increase the rigidity of the tooth's structure, thus decreasing the cusp deflection. (6)

Several studies refer the normal masticatory forces variating from 222 N to 447 N (9, 10). Pishevar *et al.* make reference to values of 300 N in the premolar area (11). Other authors refer values between 161 N and 351 N for the premolar and molar areas, with an average force of 21.7 Kgf (about 212 N) (6), or even higher, with age and gender differentiation as in Varga *et al.* study (18 years males 777.7 ± 78.7 N and females 481.6 ± 190.42 N and aged 15 years old males 522.3 ± 181.7 N and females 465.1 ± 243.55 N), or in Braun *et al.* study (18-20 years) 738 N and Sasaki *et al.* study 720 N (12), Mynampati *et al.* also refers values of 900 N in the case of bruxism or chewing hard objects (9).

The combination of various materials with complex geometries and different mechanical properties makes the analysis of stress distribution in a restored tooth complicated. Thus, the construction of numerical models for biomechanical analysis is an important tool for predicting clinical behaviour. (13)

The finite element analysis (FEA) is considered an important tool in the study of complex systems, as it offers significant information that can assist the identification of sites within the tooth/restoration complex that are more susceptible to failure on either external or internal surface of the models. FEA also allows the identification of stress distribution that cannot be evidenced by other methods. (14)

When an indirect restoration is determined to be the best treatment option, the clinician must then determine the geometric configuration of the cavity preparation. Cusp coverage seems to be the most controversial point with respect to the final cavity preparation design for posterior teeth. (15)

The aim of this study was to make a 3D finite elements analysis of von Mises stress in two different designs/preparations for restoring a premolar with a large class II MOD cavity, simulating a frequent clinical situation when we have great tooth substance loss. Those options were the restoration with or without cusp coverage.

The null hypothesis is that there are no differences between the two designs/preparations.

Materials and methods

From a maxillary model (fig 1) that was kindly donated by Brazilian Engineer Estevam Barbosa De Las Casas (IEAT Director, School of Engineering, Federal University of Minas Gerais (UFMG), Belo Horizonte MG, Brasil), ISEC (Instituto Superior de Engenharia de Coimbra, Coimbra, Portugal) students André Oliveira, Rui Catarrinho and Júlio Regado, from the 4th year of the Mechanical Engineer Masters, under coordination of Professor Luis Roseiro (discipline Cálculo Automático de Sistemas Mecânicos), using the computer software SolidWorks (SolidWorks 2015, Waltham, Massachusetts, USA) - a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) - isolated a tooth (fig 2), on which they work to make the different 3D models and preparations.
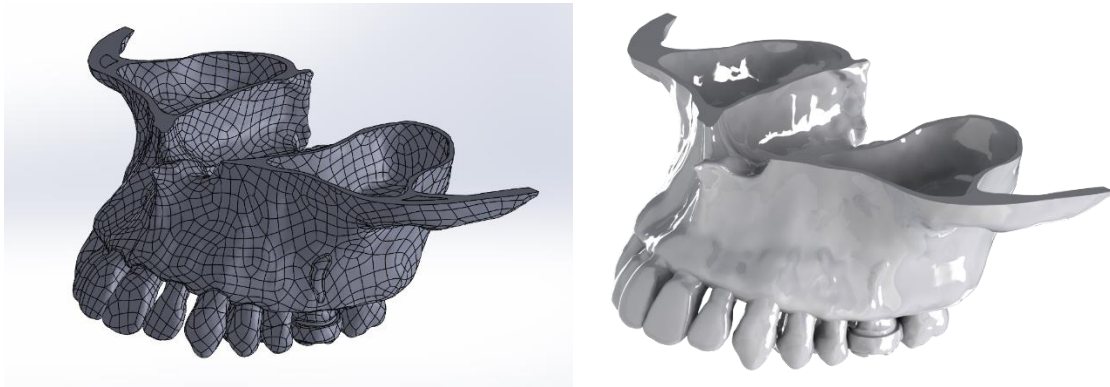
Fig 1 – Initial model from where we isolated the tooth for our study
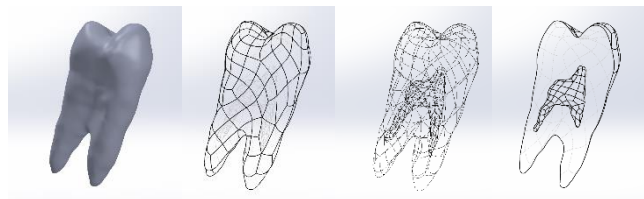
Fig 2 – Isolated tooth from the initial model: different views and cut

The solid model consists of a maxillary first premolar (14), without periodontal ligament. The cement was included in the dentin layer and pulp tissues weren't taken into account. The surrounding cortical and trabecular bones were represented.

As the solid model came with no enamel layer ISEC students, under our directions, built the enamel layer using the literature references. Those references were 1.8 mm for the occlusal enamel thickness, and 1.4 mm for the axial enamel thickness.

The tooth has a crown 7 mm high and the buccal-palatal and mesio-distal distance is 10,3 mm and 6,1 mm, respectively (fig 3).
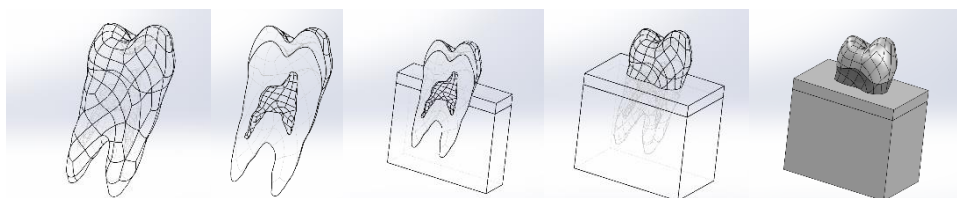

Fig 3 – Tooth after enamel built up: different views and cuts with and without cortical and trabecular bone

The premolar (14) was prepared again, under our directions, with two designs/preparations – without and with cusp coverage. The first preparation was a large class II MOD, with the internal walls having a 3º of occlusal divergence and round angles, except for the axio-pulpar/floor walls (the reason for this were technical difficulties). The measures used were 1.9 mm for cavity depth, 5,0 mm for de width, and the proximal boxes were left at a minimum value of 0.5 mm above the cement-enamel junction (CEJ) with a depth of 1.5 mm to the axio-pulpar wall in the distal box and 0.5 mm in the mesial box (the reason for this were technical error) (fig 4).
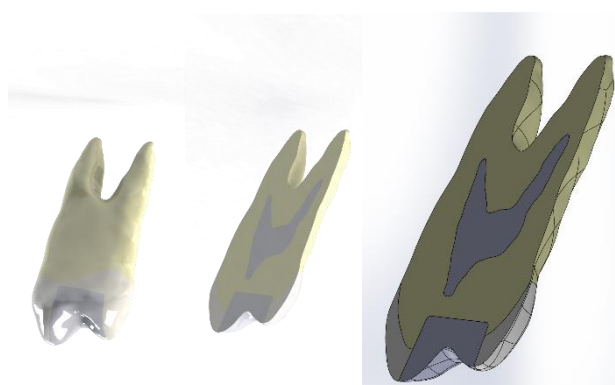
Fig 4 – Tooth with the design/preparation without cusp coverage: different views and cuts

For the preparation with cusp reduction, the same design/preparation was used, but in this case cusp reduction was also made. The buccal cusp was reduced by 1.6 mm, while the palatal cusp was reduced by 0.7 mm (fig 5).
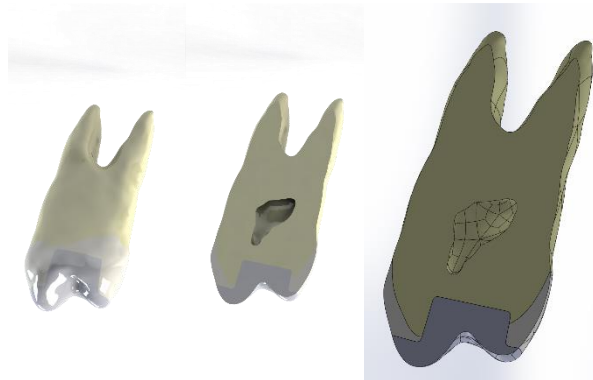

Fig 5 - Tooth with the design/preparation with cusp coverage: different views and cuts

Cavo-superficial angles were left as they were without any kind of preparation, for both designs.

The adhesive and the resin cement weren't taken into account because they are extremely small elements that couldn't be recreated in this model.

Ceramic restoration was obtained by Boolean operations converting the materials that were cut for the preparation into the ceramic bulk, and for this study we've consider a lithium disilicate glass-ceramic – IPS e.max® Press.

For the finite elements analysis (FEA), we've consider linear elastic, homogeneous and isotropic material properties of the tooth tissues, bone and restorative materials, that were assigned according to the volume definition from previous literature (16), as can be seen in table I.

 A convergence test was made, resulting in a Solid Mesh model (fig.6) with a curvature based mesh type with 4 Jacobian points and curved polygonal (tetrahedral) elements, each one with 10 nodes

Table I: Material properties (Young's modulus and Poisson's ratio)

Material	Young's modulus (GPa)	Poisson's ratio	References
Enamel	41.0	0.30	(16)
Dentin	18.6	0.31	(16)
Trabecular bone	1.37	0.30	(16)
Cortical bone	13.7	0.30	(16)
IPS e.max® Press	95±5	0.23	(17)
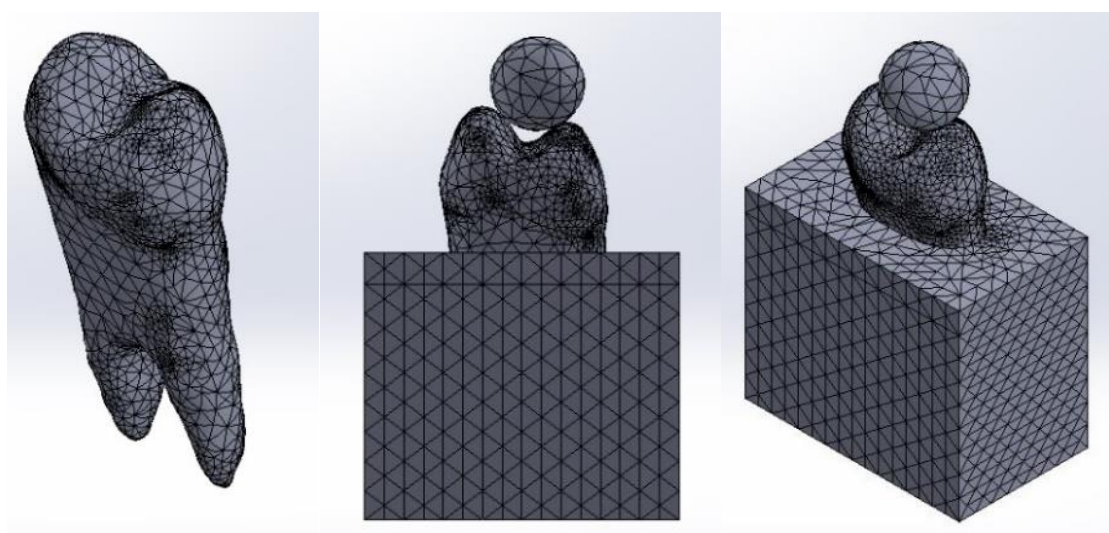
Fig 6 – Images of the solid mesh

In the preparation without cusp coverage, the size of the maximum element is 1,5 mm and the minimum element is 0,3 mm with high quality and 3 degrees of freedom, finally resulting in a model with 134.981 elements and 204.200 nodes. This model has a 98,9% element percentage with ratio <3, which makes it a reliable study.

For the preparation with cusp coverage the size of the maximum element is 1,5 mm and the minimum element is 0,13 mm with high quality and 3 degrees of freedom, finally resulting in a model with 100.765 elements and 151.991 nodes. This model has a 97,9% element percentage with ratio <3, which makes it a reliable study.

The contact conditions between the structures were defined as fixed. Before carrying out mechanical analysis, and as a boundary condition, the FEA models were fixed at the margins of the bone as far away as possible from the region of interest.

Compressive forces were applied on the centre of the ceramic restorations, with buccal and palatal cusp contact, for simulating the axial load, with a 4 mm diameter metal sphere, at 45º and 11º to the long axis of the tooth. A 200 N force was first applied, and other loads were posteriorly applied to simulate approximately the natural biting force (500 N) and a force higher to this physiologic force (800 N) (fig 7).

A   B
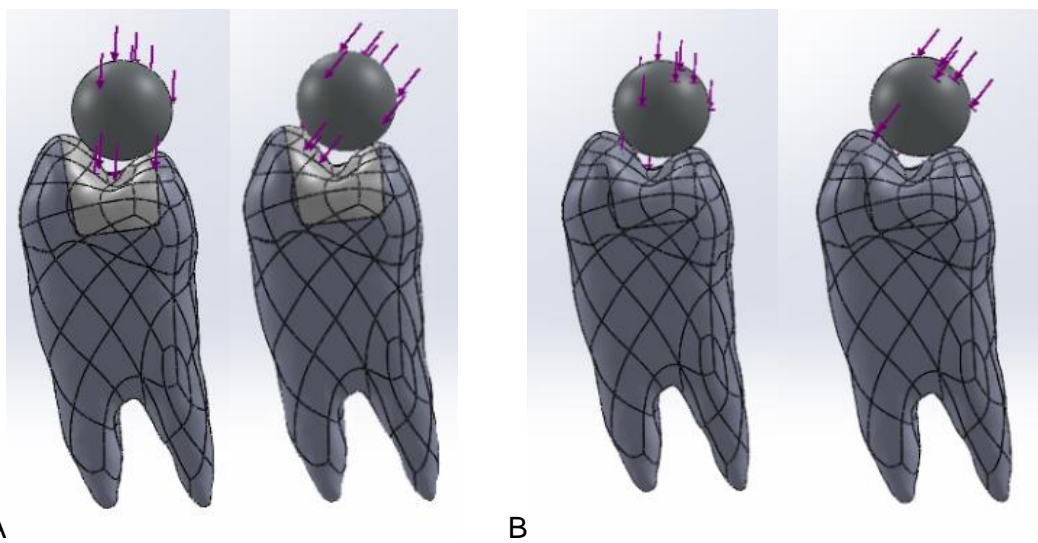
Fig 7 – Compressive forces being applied at 11º and 45º. **A** – preparation without cusp coverage; **B** – preparation with cusp coverage

After carrying out the simulation, the von Mises Stress (also known as distortion energy theory) could be measured (in MPa) at the nodes of the FEA 3D models.

Results

Due to the complex geometry of all structures here represented and to the inherent technical limitations of the software program used (SolidWorks), when we were analysing the data collected from this study we've became aware of some errors that occur. Thus, we will only report graphically the results of the von Mises stresses and compare them, between the two designs/preparations by load and direction of the force applied (further study is being done at ISEC by Professor Luis Roseiro and his team with another software program – MSC Nastran/Patran - that presents improved capacities in the intent to solve the limitations of SolidWorks software, but due to time limitations it is not possible to present yet the results).
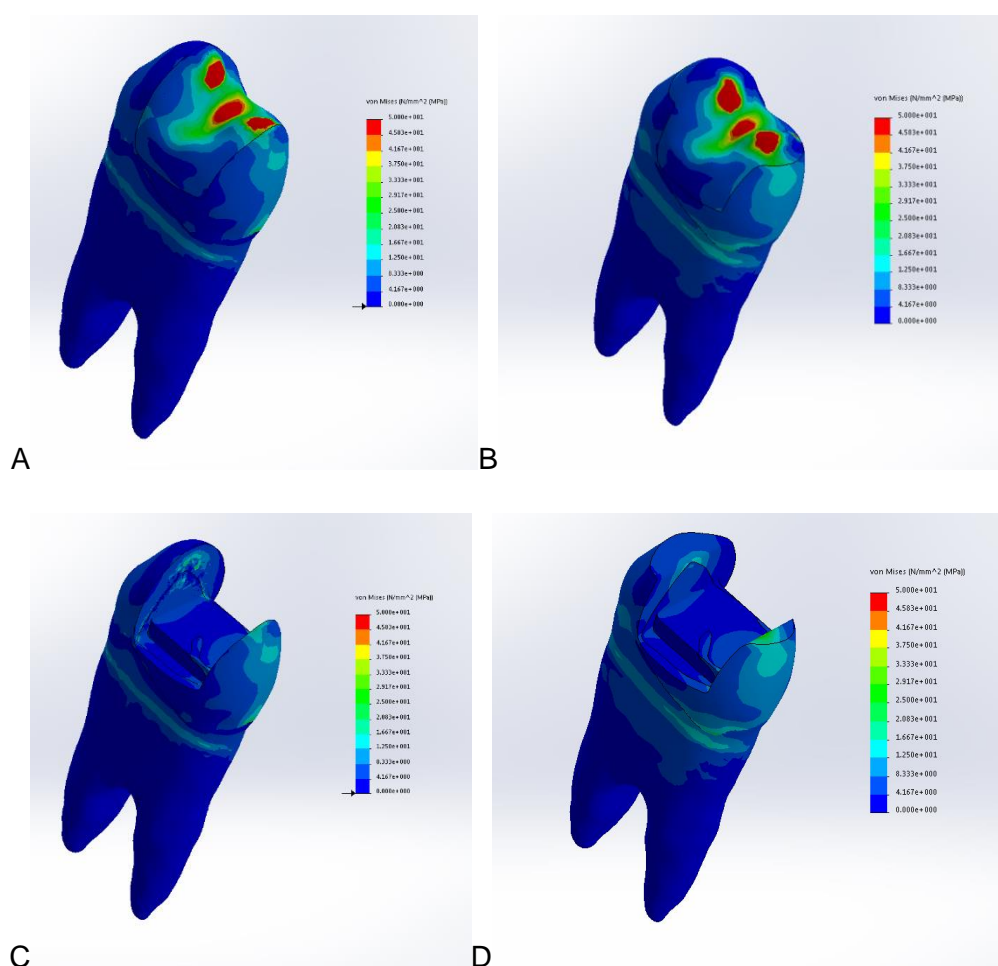
Fig 8 – Distal perspectives of von Mises stresses at 200 N with 11º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

For the 200 N load and 11º direction (fig 8 - 9) we could see an increased stress on the central groove exclusively on the ceramic bulk and two other areas of stress could be seen on the contact zone: with the metal sphere but here they are contact stresses generated by hertzian forces; within the palatal cusp at the preparation wall another area of stress is present in both preparations.
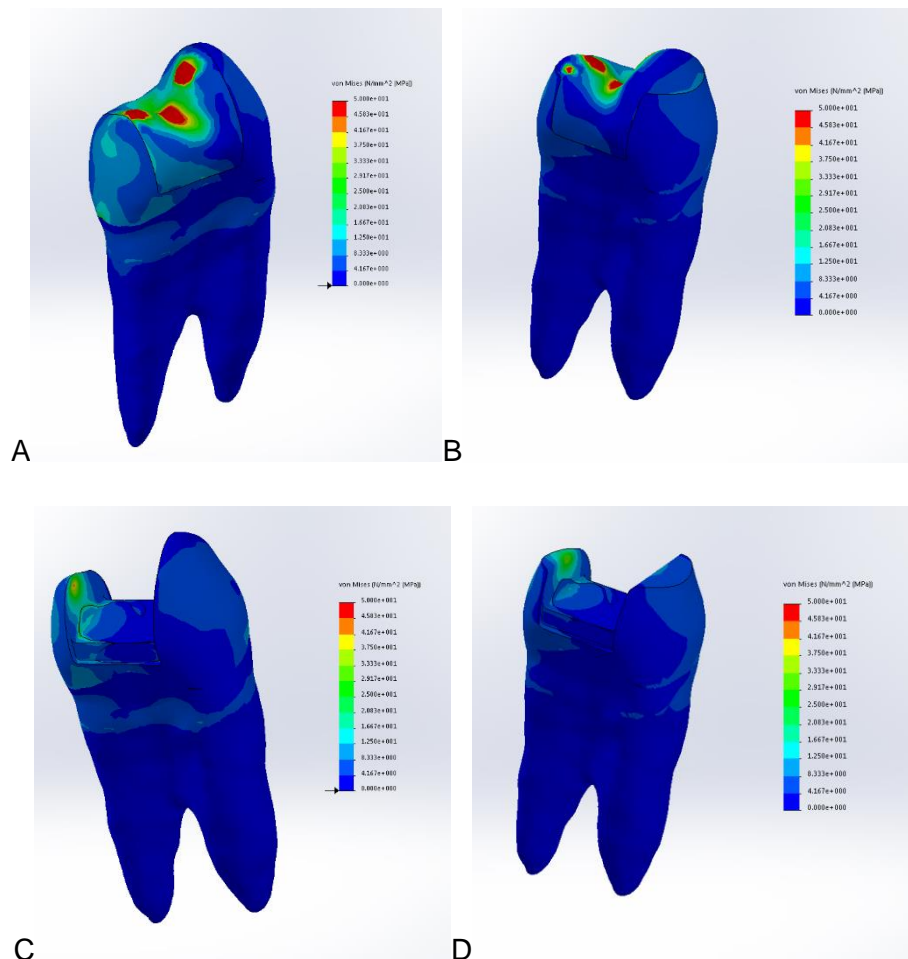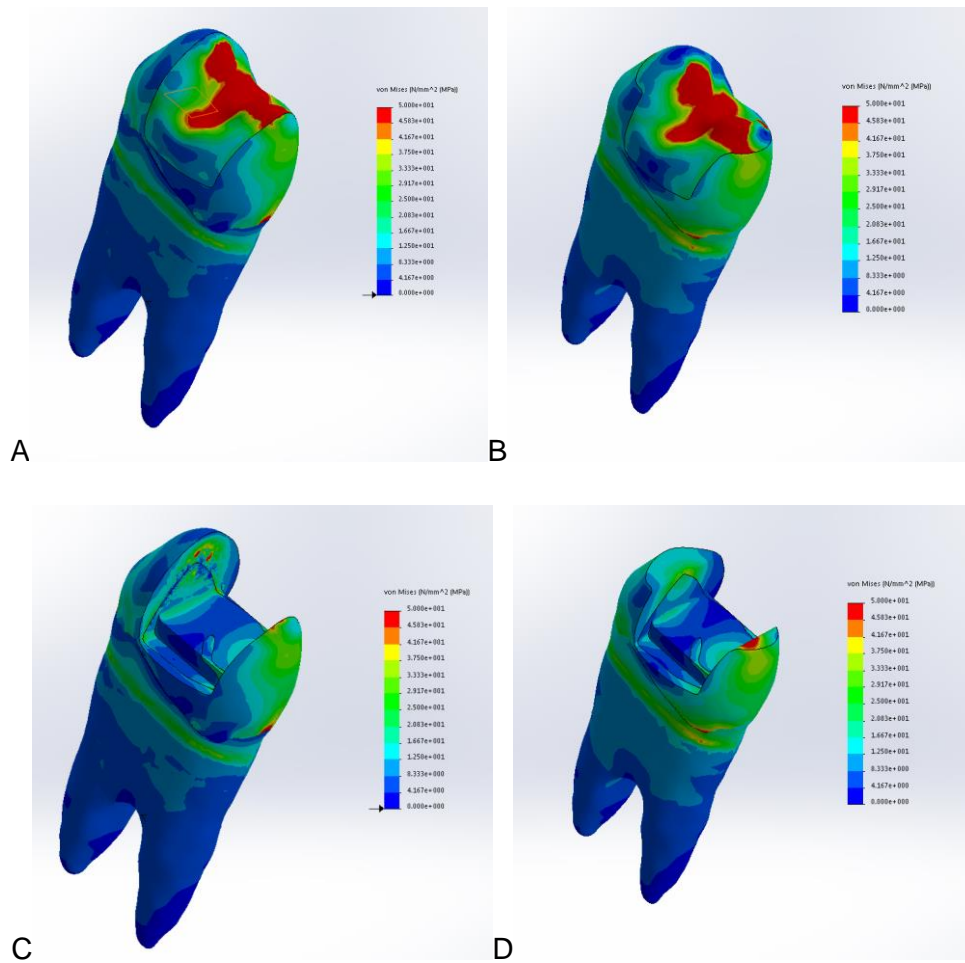

Fig 9 – Mesial perspectives of von Mises stresses at 200 N with 11º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

At the application of a load of 500 N with a 11º direction (fig 10 – 12) the situation is similar to the 200 N load situation but in an augmented scale. Additionally, other areas of stress appear on the outside wall of the palatal cusp and at the area where the tooth makes its bone insertion.
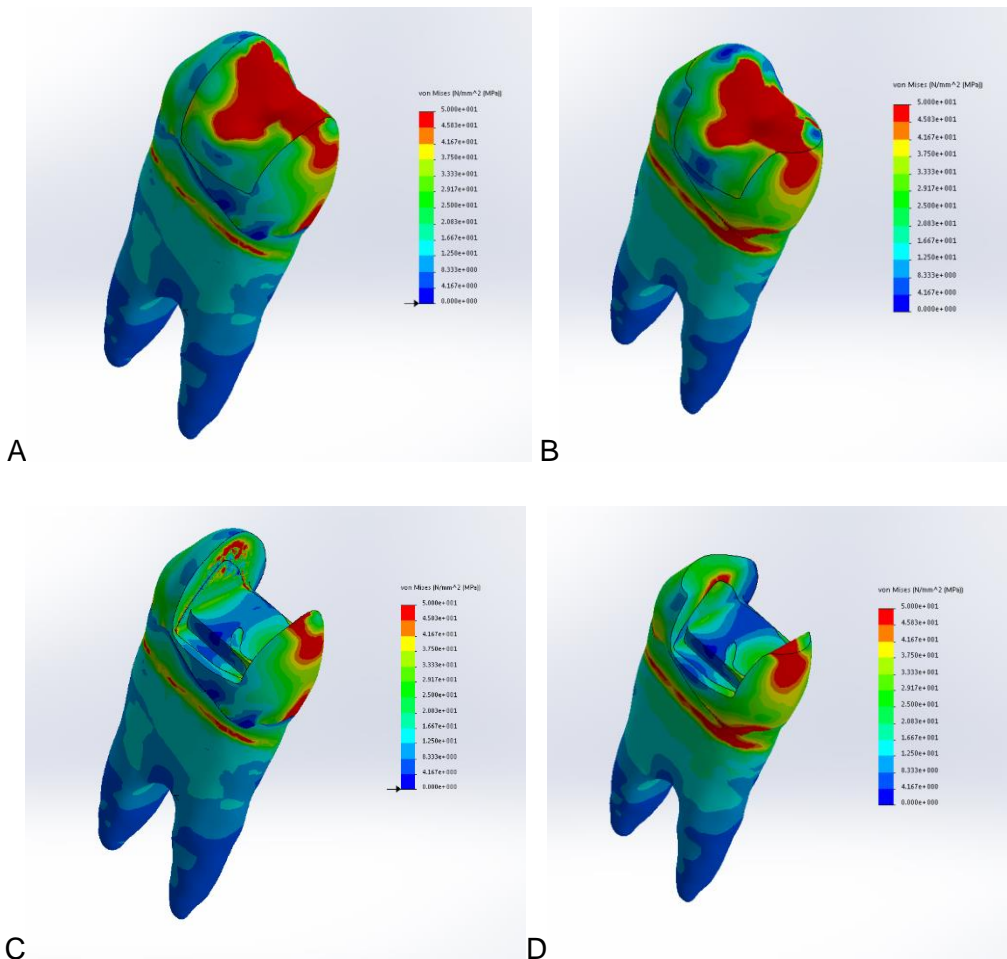
Fig 10 – Distal perspectives of von Mises stresses at 500 N with 11º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.
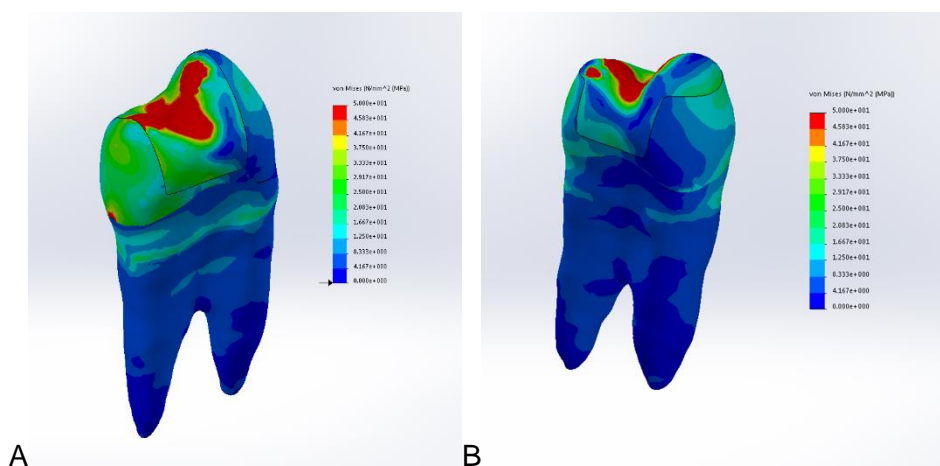
Fig 11 – Mesial perspectives of von Mises stresses at 500 N with 11º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration.
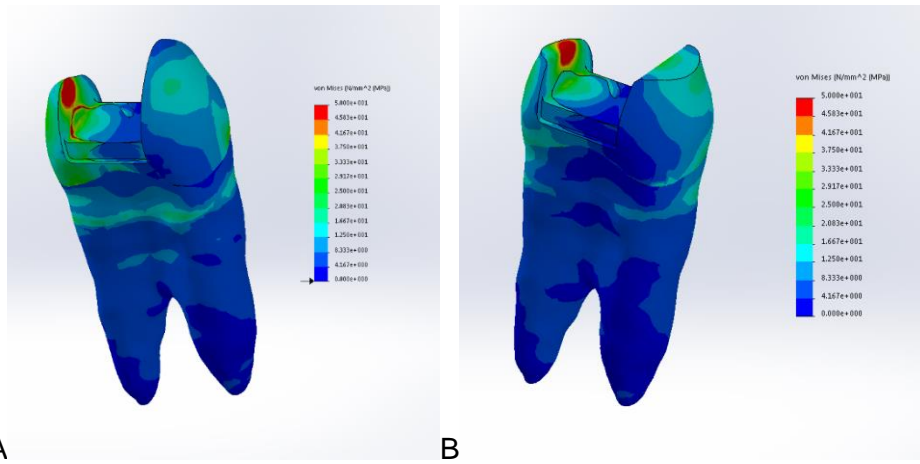
Fig 12 – Mesial perspectives of von Mises stresses at 500 N with 11º. **A** – without cusp coverage without the ceramic restoration; **B** – with cusp coverage without the ceramic restoration.

Fig 13 – Distal perspectives of von Mises stresses at 800 N with 11º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

For the load of 800 N at 11º direction (fig 13 – 14), we have similar stress areas, and again in an augmented scale but with some differences between the mesial and distal surfaces more pronounced above tooth insertion.
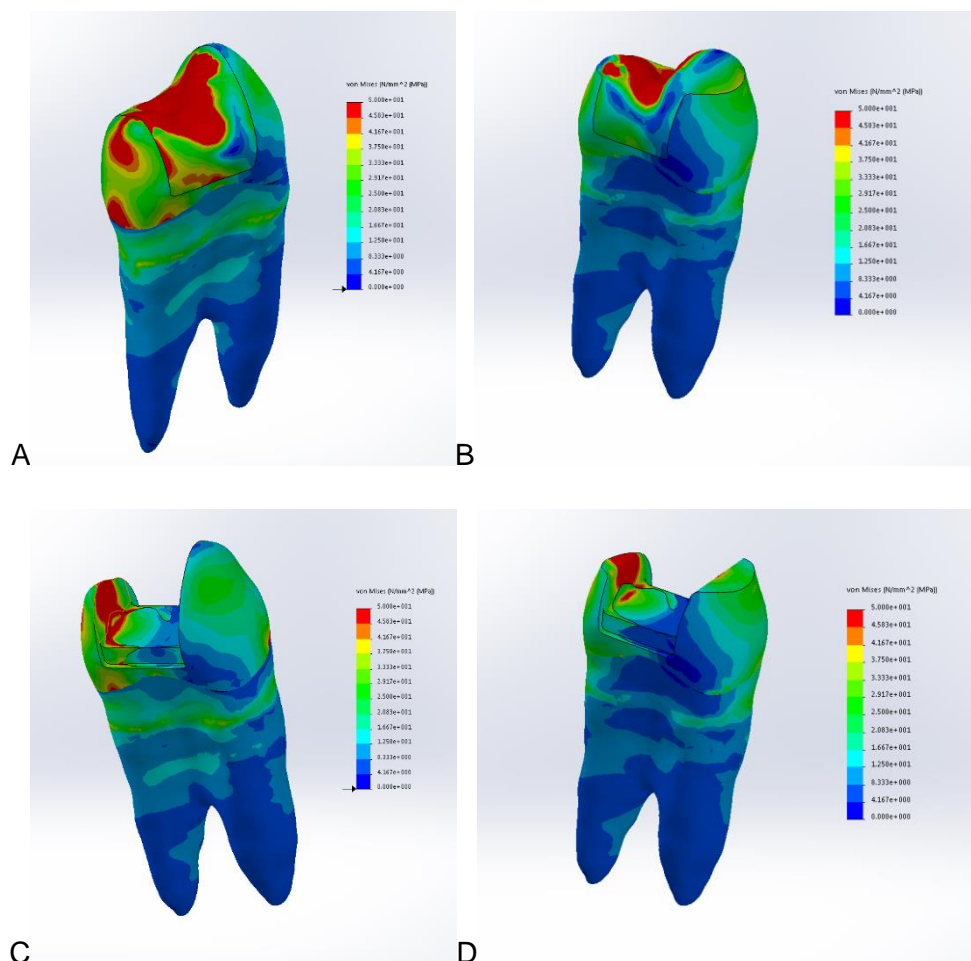

Fig 14 – Mesial perspectives of von Mises stresses at 800 N with 11º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

Looking now for the same range of loads, but now with different direction of the force, at 45º.
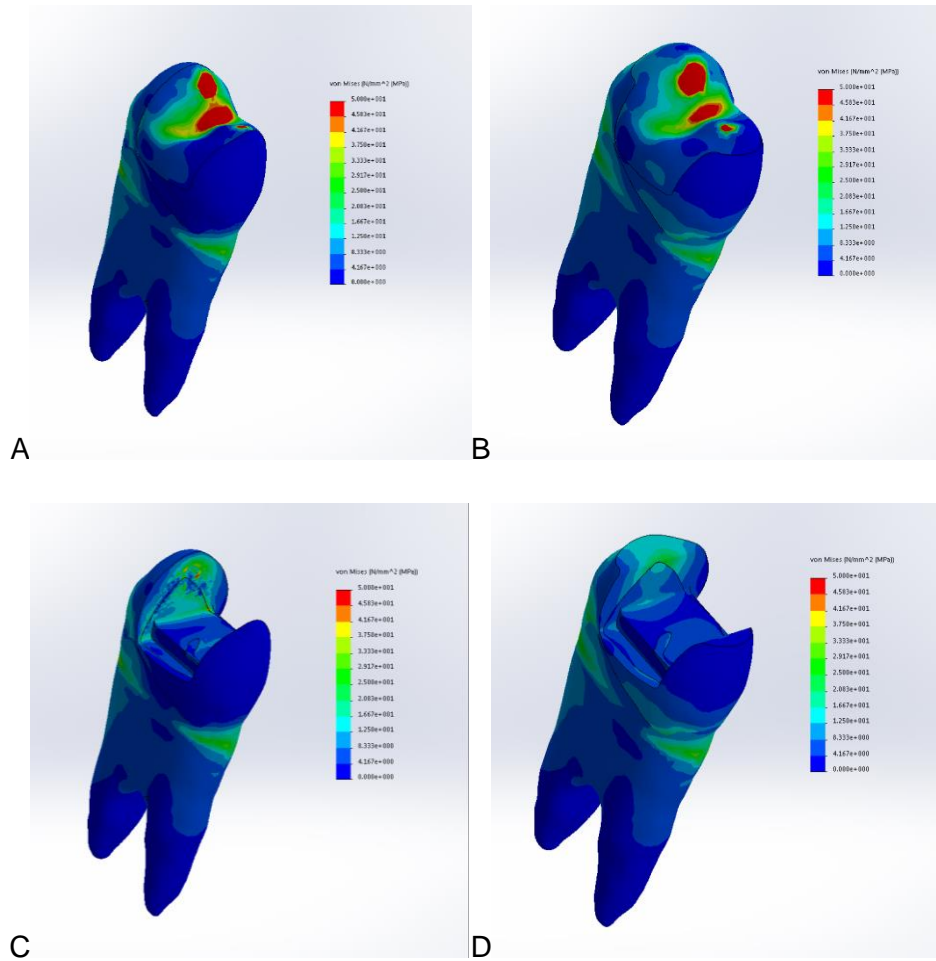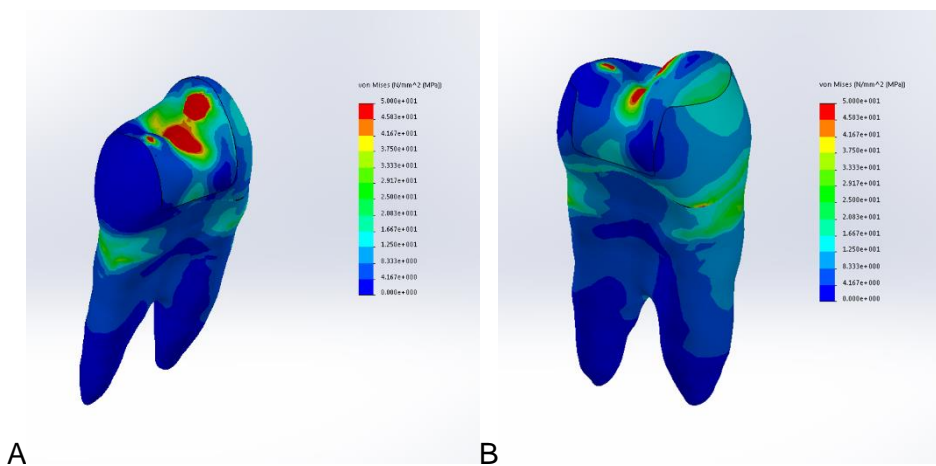
Fig 15 – Distal perspectives of von Mises stresses at 200 N with 45⁰. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

Fig 16 – Mesial perspectives of von Mises stresses at 200 N with 45⁰. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration.
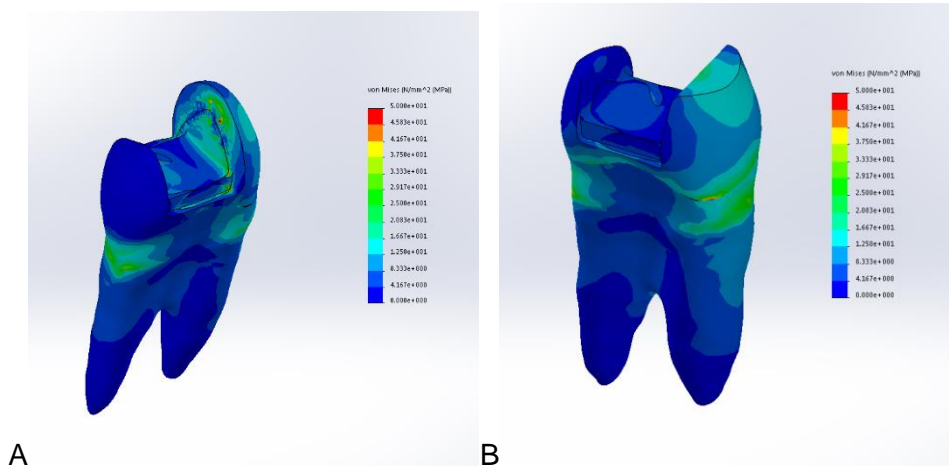
Fig 17 – Mesial perspectives of von Mises stresses at 200 N with 45⁰. **A** – without cusp coverage without the ceramic restoration; **B** – with cusp coverage without the ceramic restoration.

For a load of 200 N with a direction of 45⁰ (fig 15 – 17) we could see areas of stress in the central groove, as well on the contact areas with metal sphere (contact stresses). In buccal and palatal surfaces some areas of stresses above tooth insertion are also seen.

When a load of 500 N was applied (fig 18 – 20) we could see that the stress areas move towards the buccal cusp, and that the stress areas on buccal and palatal surfaces nearby tooth insertion are of higher intensity as well on the facial surface of buccal cusp.
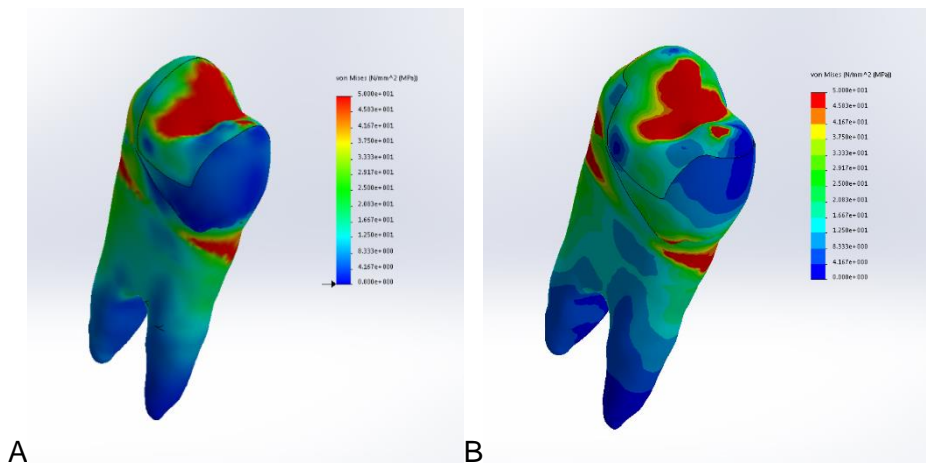

Fig 18 – Distal perspectives of von Mises stresses at 500 N with 45⁰. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration.
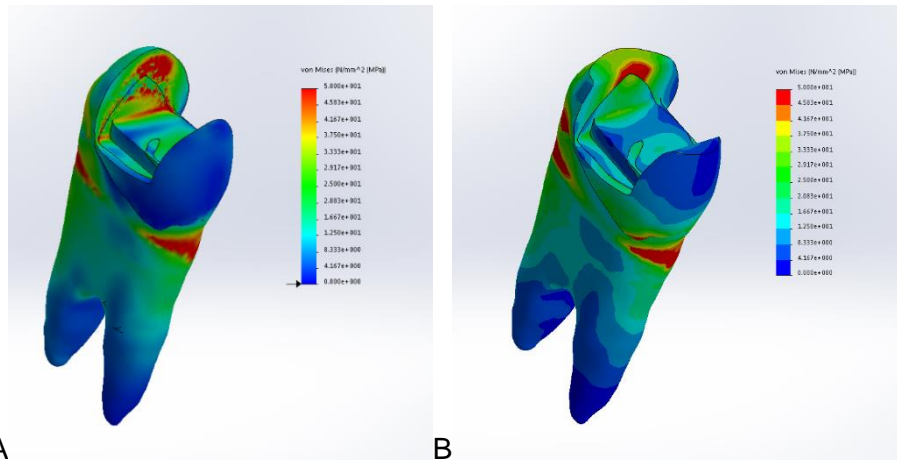
Fig 19 – Distal perspectives of von Mises stresses at 500 N with 45º. **A** – without cusp coverage without the ceramic restoration; **B** – with cusp coverage without the ceramic restoration.
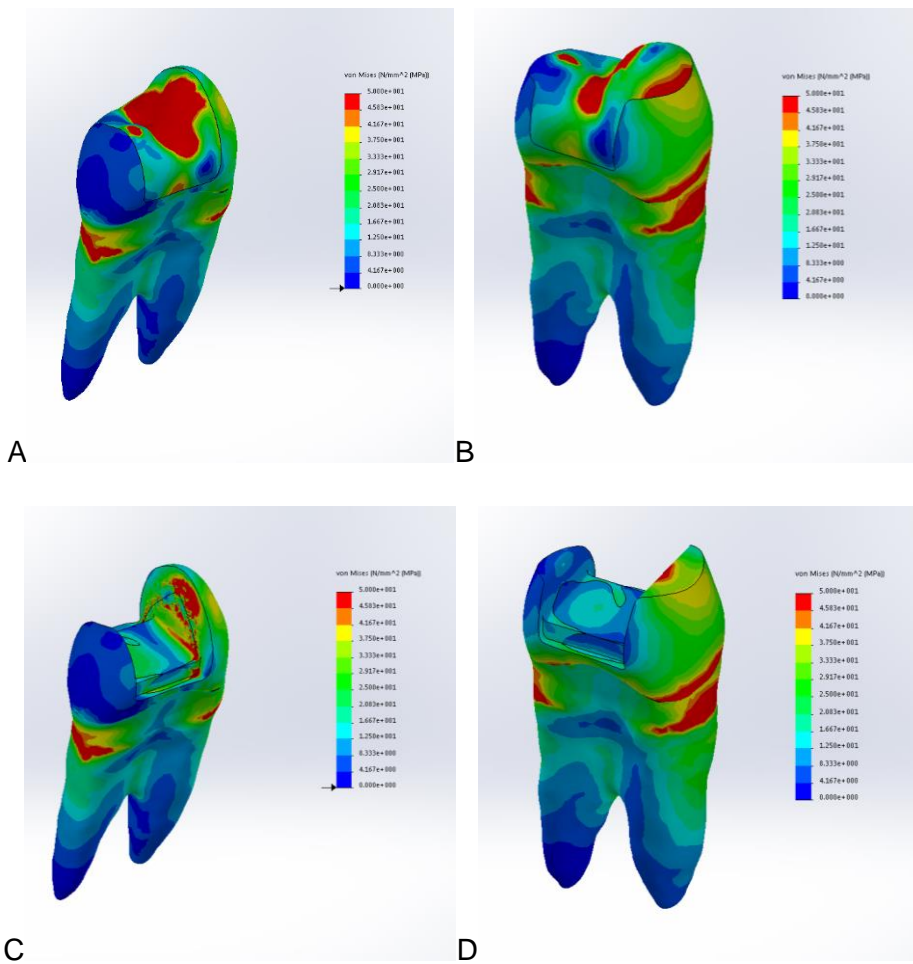

Fig 20 – Mesial perspectives of von Mises stresses at 500 N with 45º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

Fig 21 – Distal perspectives of von Mises stresses at 800 N with 45⁰. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.
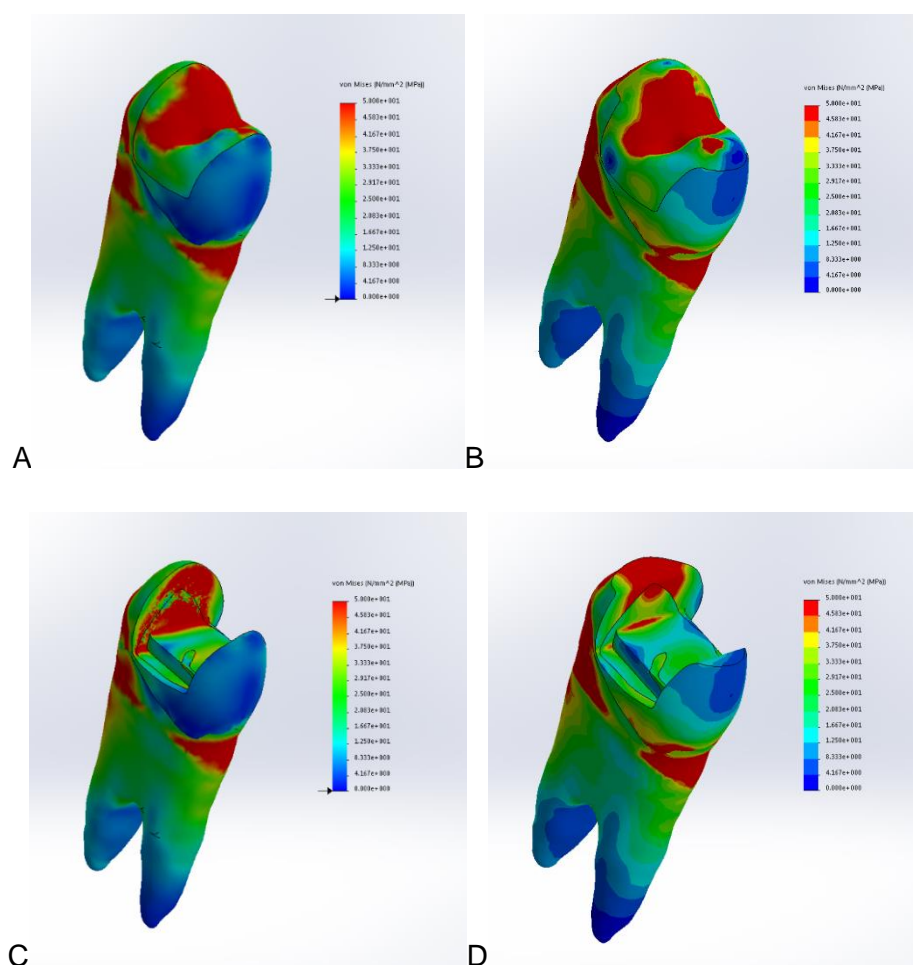
For a load of 800 N in a 45⁰ direction (fig 21 – 22) besides what has been said for the loads of 200 N and 500 N we could see great stress areas on the buccal cusp whereas on bulk ceramic or facial surface, as well on the cervical region at almost part of tooth perimeter.
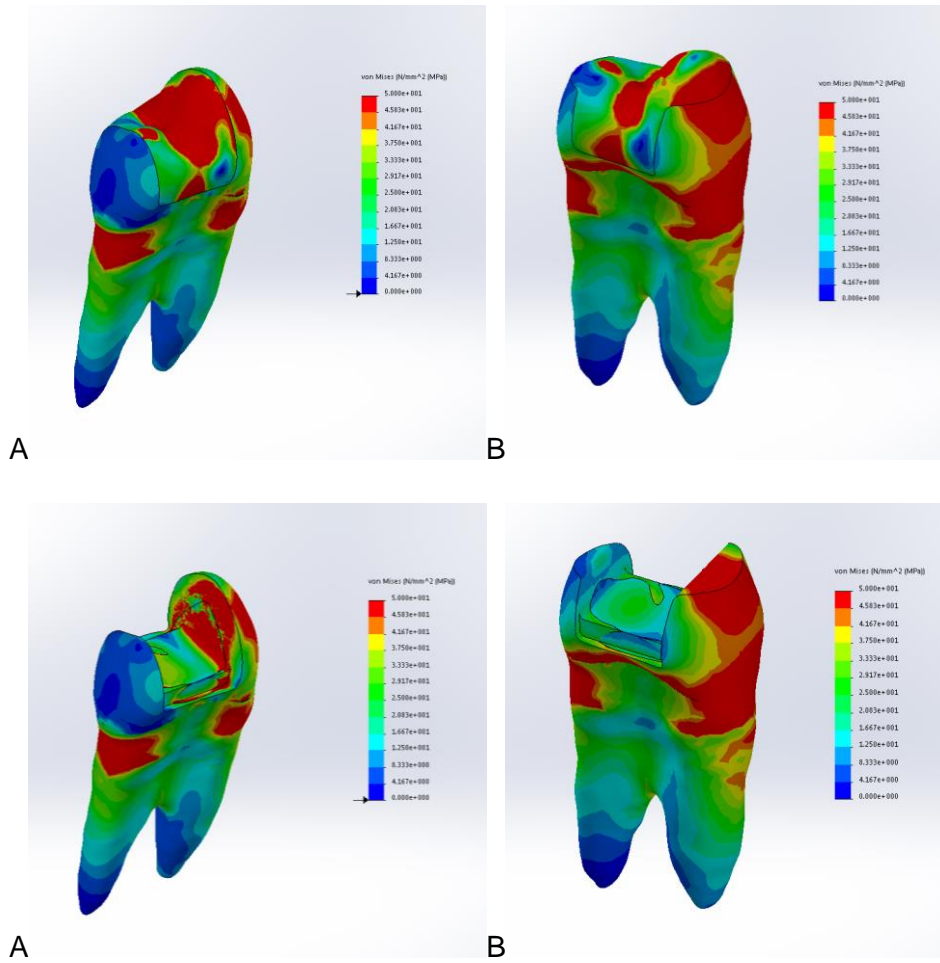
Fig 22 – Mesial perspectives of von Mises stresses at 800 N with 45º. **A** – without cusp coverage with the ceramic restoration; **B** – with cusp coverage with the ceramic restoration; **C** – without cusp coverage without the ceramic restoration; **D** – with cusp coverage without the ceramic restoration.

Discussion

The purpose of this study was to compare between two different designs/preparations for restoring a premolar with a large class II MOD, using a 3D finite elements analysis. Those options were ceramic restoration without cusp coverage and the other was ceramic restoration with cusp coverage. Three different loads (200 N, 500 N and 800 N) were used, in accordance with literature references for the range of normal occlusal forces, that varies between 161 N and 777.7±78.7 N (6, 9-12), and with two directions of applied load, at 11º (concentric force) and at 45º (eccentric force).

Finite elements analysis (FEA) is, as it was said before, an important tool in the study of complex systems, offering significant information that can assist the identification of sites within the tooth/restoration complex that are more susceptible to failure on either external or internal surface of the models. FEA also allows the identification of stress distribution that cannot be evidenced by other methods (14), and have been proven in many dental studies thus far (7).

In this study we performed a qualitative analysis of stress distribution using von Mises stress diagrams. It should be understood that von Mises stress is essentially an aggregated stress which combines tensile, compressive and shear stresses. Although qualitative analysis may predict the possibility of damage, the total strength of the restored models was not evaluated in this study. Therefore, the results cannot be directly compared with FEA maximum principal stress, used in other studies, since strength was not measured and no distinction was made between tensile and compressive stress (14).

Advances in adhesive technologies and escalation in aesthetic demands have increased indications for tooth-coloured, partial coverage restorations. Partial indirect restorations enable conservation of the remaining dental structure, promoting reinforcement of a tooth compromised by caries or fractures. Morimoto *et al*. in his meta-analysis refers to survival rates of 95% in 5-year follow-up and 91% in 10-year follow-up for ceramic partial indirect restorations, with low complication rates (4). Chabouis *et al*. on their systematic review makes reference of 97.1% success rate after 3 years of ceramic inlays (1). Morimoto *et al*. stated that apparently, strong and durable adhesion of resin cements to ceramic increased the survival rate. The tooth ceramic bond ensures re-establishment of tooth strength, and a reduction in deflection of the cusps is reflected in the low failure rates (4).

Holberg *et al*. refers in his study that the fracture risk is apparently more influenced by the ceramic used and potential manufacturing defects within the material (7), so in

accordance with this we used a lithium disilicate ceramic – IPS e.max® Press – which has a fracture strength higher than other ceramics (360 MPa) (7).

In regard to the design/preparation, and to the best of our knowledge, this was an original study. Several studies have been made on inlays or onlays or overlays but none has a design/preparation like the one we idealized, so comparing results is not possible. Nevertheless, we could infer some results of other studies.

Costa *et al.* refers that by removing the marginal ridge, a marked decrease in fracture resistance occurs, regardless of the amount of tissue removed and that inlays with a conservative preparation, even with a higher average of resistance to fracture, also did not differ from inlays with an extensive preparation. This is because the reduction of fracture resistance is due to the removal of marginal ridges rather than the uniting and supporting of the buccal and palatal cusp, as well as to the increase in the isthmus and the depth of preparation in the occluso-gingival direction (6).

Holberg *et al.* states in his article that the traditional preparation guidelines for ceramic inlays should be continuously modified and adapted if modern ceramic materials are used. For example, the often-recommended minimum thickness of ceramic inlays (1.5 mm) could be adjusted downwards (7).

Shibata *et al.* refers in his study, that the ceramic inlay thickness and volume varied between groups due to the cavity design – a variable that could influence tooth strength in each group. However, the finite element analysis showed that the fracture risk of ceramic inlays was more associated with ceramic type rather than ceramic thickness; e.g., more rigid ceramics, such as lithium disilicate, have a lower principal stress, ranging between 20.7 to 22.1 MPa. Conversely, leucite ceramic (a less rigid ceramic) had a greater principal stress, i.e., 27.6 to 29.2 MPa, even when different thicknesses were tested. He also refers that Krifka *et al.* demonstrated that preparations with reduced cusps resulted in better marginal integrity and reduced crack formation than teeth without cusp reduction. (18).

Homsy *et al.* states that it seems that depth of the preparation and the remaining inter-axial thickness were among the most critical factors that reduced the fracture resistance of teeth (19).

Hopp *et al.* refers that due to the inherently brittle nature of ceramic materials, adequate tooth reduction is necessary to provide sufficient bulk for the ceramic to withstand functional loads. Preparation margins should ideally be located in enamel, which will result in a strong and durable bond when resin luting agents are used (20).

Souza *et al.* in his study refers that the presence of extensive MOD preparation, weakened cusps and endodontic treatment increased the stress concentration within the tooth structure. This stress developed markedly in the cervical region, near the gingival wall of the preparation, which explains the pattern of fracture that produced the largest loss of tooth. He also refers that Scotti *et al.* showed that cusp coverage should provide improved fracture resistance in maxillary premolars, especially when the residual wall thickness is less than 2 mm. In his study, the remaining wall thickness was 2 mm, so the effect of weakening was highlighted. He stated that the restorations without cusp coverage, when subjected to axial loads produced by dental contact, induce a wedge effect, leading to a deflection of the cusps. This becomes more critical in a posterior tooth where there is the loss of major dental structures, especially the marginal ridges, enamel ridges, and the roof of the pulp chamber (21).

Analysing the results of our study we see that there are no relevant differences between the two designs/preparations, so the null hypothesis was accepted.

For the 11º direction of applied load (a concentric force) we observed that the majority of stress in concentrated at the bulk ceramic which absorbs a great part of the load due to high fracture strength (360 MPa) (7), nevertheless some areas of stress appears on tooth at palatal cusp in accordance with other studies by Souza *et al*. (21) and Costa *et al*. (6).

When we applied de load in a direction of 45º along with the long axis of tooth (an eccentric force thus more destructive) again great part of load is absorbed by the bulk ceramic but some areas of stress could be seen on the tooth at the buccal cusp and at cervical areas on palatal and buccal surfaces, proving the more destructive action of an eccentric force.

Our study has some limitations both on built up of the 3D model and on the finite elements analysis. Finite element method has limitations that are inherent to simulation computer studies; for instance, the properties of the tested materials were considered isotropic, continuous and elastic, which differs from the clinical situations (14), we didn't consider the adhesive layer or the periodontal ligament because it is a very small element with some peculiar characteristics such as its hyper-elastic proprieties, which are very difficult to represent in the model and would make a non-linear study that is plentiful more complex. However, this is a comparative study between two models, so it is not substantial.

Some problems emerge inherent to the software program used – SolidWorks - This program is a basic program to do 3D reconstruction and modelling of objects and finite

element analysis. It's good to teach students or people starting to work in this area, but to be used in complex studies like this one, it's not the most indicated due of the inherent limitations of the program. The principal limitation that we observed was the non-convergence of some nodes in the transition from one type of material to another. This is more evident when zooming the transitions, as mesh imperfections resulted from the presence of some little gaps that explain the discontinuous stress distribution at the enamel-dentin junction, and was the main reason why we didn't take values of stress.

Further studies should be made in order to overcome these difficulties and to approach as much as we could to the reality of the oral environment. The inclusion of the periodontal ligament and of the adhesive layer in a non-linear study should bring more reliable results.

Conclusion

Within all the limitations of this study, we reached the following conclusions:

I)   There are no significant differences between the two designs/preparations for the loads of 200 N, 500 N and 800 N at 11º direction and at 45º direction.

II) For all the loads applied at 45º direction we observed higher stresses than with a 11º direction.

III) Further studies are needed.

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