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# FINITE ELEMENT ANALYSES OF FIRING BEHAVIOR OF METAL-CERAMIC CROWN MARGINS

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**Abstract:**

*Considering the deformations appeared after the firing process of ceramic, we tried to establish if there is any relation between these and the type of peripheral preparation, on the one hand, and the coefficient of thermal expansion of metal and porcelain, on the other hand.The study is original and was conducted in COSMOS DesignSTAR, consisting in finite element analysis of firing process. The tested objects were created in RhinoCeros Nurbs modeling for Windows, version 4.0. It consists of three models, each one with abutment, metal cape and ceramic veneer, but with different type of peripheral preparation: shoulder with metal collar, shoulder without metal collar and chamfer with metal collar.The results suggested that the shoulder without metal-collar model recorded the highest marginal distortion and the chamfer model the smallest, and the higher the difference between thermal expansion coefficients the higher the marginal distortion .*

**Ключевые слова:**

*finit element analyses, ceramic firing, peripheral preparation, thermal expansion coefficient*

**Introduction**

The deformation of the metal-ceramic bridges, appeared after casting the metal framework or after applying the ceramic veneer, leads to the appearance of a marginal discrepancy or a hiatus between restoration and the abutment. This area will represent a place for plaque accumulation, evolving to cervical caries and periodontal lesions.

The deformation of the metal framework *per se* has as etiology technological stages which can lead to alterations of the inner structure of the alloy or which can explore limits of physical parameters of the materials: dilatation at the level of concentration areas in the alloy (*Tuccillo, Bertolotti, Anusavice, Yamamoto*), the release of the residual stress resulted after casting (*DeHoff, Campbell*), the release of the residual stress resulted after processing and finishing the surface of the metal-framework (*Yamamoto, Campbell, Shillingburg, Anusavice*), the discordance between the thermal dilatation coefficients of the alloy and ceramic (*Bridger, Silver, Tuccillo*), the formation of an inadequate layer of oxides at the surface of the alloy, the metallurgical changes in the mass structure of the alloy (*Silver*).

The purpose of this research was to quantify and visualize the deformations which can appear in different hypothesis / working scenarios using finite elements analysis as an experimental method. The method suited to our intention to eliminate the variables induced by the laboratory phases and, therefore, to isolate only the deformations resulted from the firing process.

**Materials and methods**

The finite element method is a numerical approach and offers considerable advantages compared to other. The method is available for analysis of complex geometries and can determine the solicitations and deformations of a tridimensional component.

The stages of the research consisted of: object 3D modeling (transformation into solid) (*RhinoCeros Nurbs modeling for Windows,* version 4.0); export of the 3D model to FEA software (*COSMOSDesignSTAR 4.0*); defining the physical properties of the used material; constraints definition = definition of the thermal cycle; meshing of the models; defining of the contact types between the components of the models; running the working hypothesis = solving the equation system; results display (chromatic and alpha-numeric); running the diagnostic study

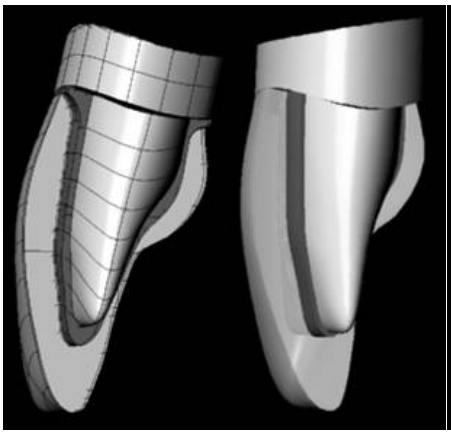

**Fig. 1.** Shoulder with metal collar

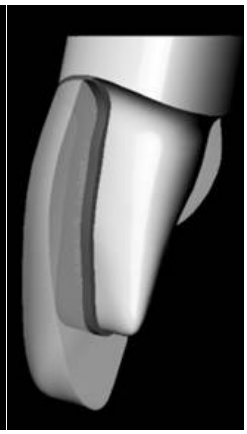

**Fig.2.** Shoulder without metal collar



**Fig. 3.** Chamfer with metal collar

The models are designed as 3 solid bodies: the tooth abutment (which varied in the 3 models only by the type of peripheral preparation), and three correspondent metal-ceramic crowns (Fig. 1, 2, 3) with different cervical margins: shoulder with metal collar, shoulder without metal collar, chamfer with metal collar. The width of the threshold is 1 mm and of the metal cape is 0,4 mm.

In a first phase of the experiment, we set to asses the importance of the crown cervical margins design. Therefore, we tested all three thresholds under identical conditions: same materials, same thermal conditions. The used materials were: an Au-Pb based alloy - *Olympia* (*J.F. Jelenko and Co, Armonk, N.Y.*) and the *Will-Ceram* (*Williams Dental Co*.) ceramic, strictly respecting the properties of the materials and the firing cycle established by the producers (Tabel 1).

In a subsequent phase, in order to establish the role of dilatation coefficient of materials, we chose to consider three different coefficients for Will-Ceram, creating therefore two

**Table I**

**The parameters of the studied materials**

| PARAMETERS OF MATERIAL | OLYMPIA | WILL-CERAM |
|---|---|---|
| **Elasticity module ($N/m^2$)** | $10,8x10^{10}$ | $6,3x10^{10}$ |
| **Constant of Poisson** | 0.33 | 0.19 |
| **Density ($kg/m^3$)** | 0.013 | 0.0024 |
| **Stretch resistance ($N/m^2$)** | $672x10^{-6}$ | $24,8x10^{-6}$ |
| **Compression resistance ($N/m^2$)** | $672x10^{-6}$ | $21,6x10^{-6}$ |
| **Coefficient of thermal expansion** | $14,1x10^{-6}$ | $15,94\text{-}16,23x10^{-6}$ |

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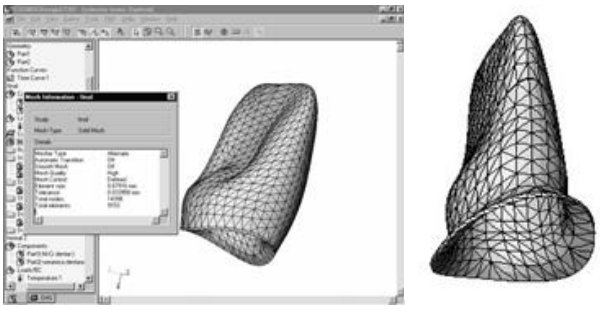

**Fig. 4.** Meshing of the 3D models

**Table II:**
**Thermal cycle for firing the Will-Ceram opaque for ceramic**

| | | *Pre-heating* | *Rate of temperature increase* | *Maximum temperature* |
|---|---|---|---|---|
| **Will-Ceram** | ***opaque*** | 538°C / 6 min. | 55°C | 999°C / 30 - 60 s |

new materials, one with a very low thermal dilatation coefficient and one with a very high value of the dilatation coefficient. In this new test scenario, for the designated alloy ($14,1x10^{-6}$) we used the three above mentioned ceramic masses: with lower, equal and higher coefficients than that of the alloy. Therefore, we established for the ceramic mass the following coefficients: $1,27x10^{-5}$/°C , $1,4x10^{-5}$/°C and also the highest value declared by the producers, $16,23x10^{-6}$.

The imposed thermal cycle was identical to that of opaque firing in Will-Ceram technique. We chose this firing phase because it takes place at the highest temperature, favoring deformations (Tabel II).

**Results and discussions**

Through running this working hypothesis on the computer, the following results were obtained, at the cervical margins of the metal framework, in the middle of the buccal and lingual surfaces (Fig. 5, Table III).

The marginal adaptation of the crowns and the deformations of metal-ceramic reconstructions were studied in literature in different stages of ceramic layers applying.

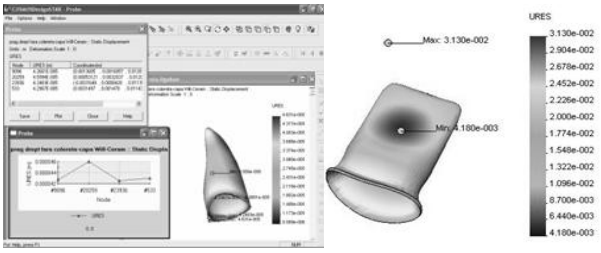


**Fig. 5.** Chromatic display of the results
Red (dark gray) - maximum deformations
Blue (light gray)- minimum deformations

**Table III.**
**Recorded displacements at the cervical margins of the metallic cape ($x10^{-5}$)**

| | | SHOULDER WITHOUT METAL COLLAR | SHOULDER WITH METAL COLLAR | CHAMFER |
|---|---|---|---|---|
| ***Low* dilatation coefficient** | *buccal* | 4.735 | 2.173 | 2.475 |
| | *lingual* | 5.014 | 2.338 | 2.581 |
| ***Equal* dilatation coefficient** | *buccal* | 5.109 | 2.322 | 2.6 |
| | *lingual* | 5.459 | 2.436 | 2.799 |
| ***High* dilatation coefficient** | *buccal* | 5.438 | 2.51 | 2.913 |
| | *lingual* | 5.743 | 2.725 | 3.093 |

Only two from the early studies reported that the highest deformation appears during porcelain applying (*Shillingburg*). These results seem controversial because more recent research sustain that the highest alterations appear during the oxidation cycle, being minimal in the following firing stages (*Anusavice, Campbell, Buchanan, Gemalmaz*). Besides, also recent investigations reveal that there is no concordance between the type of reconstitution margins and the degree of deformation (*DeHoff*), compared to older research that sustain the opposite (*Shillingburg, Anusavice, Campbell, Silver, Tuccillo, Buchanan*).

These last authors explained the appearance of the deformations through the difference between the thermal dilatation coefficients of ceramic and metal and not producing a sufficient thickness of the metal at the level of threshold. If to all that an incorrect fire cycling and a critical design of cervical margin are added, the result can be striking through the obtained dimensional error. On the other hand, there are authors who sustain that there is no clear evidence that the incompatible materials would determine essential deformations (*Anusavice*).

These experiments, developed in the laboratory, suppose different stages before firing which can be sources of errors. Therefore, there are theories which sustain that the deformation of the metal frame noticed after the oxidation process may be due to the residual stress accumulated in the phase of casting the metallic component and after processing and finishing the metal framework and which is released after the first thermal treatment.

As it can be noticed from the table and graphics, our study reveals that there are important differences between the three types of threshold, which sustains the idea that the marginal design has importance in marginal adaptation and in the technological stage of making metal-ceramic restorations.

The highest displacements appear in the case of shoulder without metal collar, deformation explained by a ceramic/metal report favorable at this level for ceramic, which makes the binding contraction to be even more powerful, and the metal not being capable of opposing to that tendency.

A cervical hiatus of 40 μ is permitted, from the clinical point of view, but what it exceed that threshold is a potential source for the periodontal disease.

The smallest displacements were recorded at the level of shoulder with metal collar, due to high thickness in the area of para-pulpar angle.

The chamfer presented reduced displacements, close as value to that of the shoulder with metal collar, but higher than that.

Through the change of dilatation coefficients of the ceramic mass, there were also obtained variations of deformations, which sustains also the importance of this technological aspect. It should be remembered that it is absolutely necessary to know the material parameters of the alloys and ceramic masses, to be sure of their compatibility.

The minimal deformations were found in the case of reduce expansion coefficient, which incriminates, one more time, the ceramic mass. The highest deformations, cumulated, were recorded in the case of the shoulder without metal collar, with a ceramic mass with increased dilatation coefficient.

It is proven, one more time, how important the making of a metal collar is, despite the fact that it comes against the esthetical principles, but it is a factor that contributes to the guarantee of abiding by biological principles.

The study forewarns on the importance of realizing a correctly configured metal framework, which could efficiently oppose to the tendency of accentuated shrinkage of ceramic. In the case of superficial preparations on the cervical level, there is the tendency to reduce the thickness of collar, which does not resolve the situation itself and, be-

sides, it comes with a supplementary, error generating factor.

The advantage of such a method is that there can be tested multiple variants, changing one or more parameters and without material waste. But, on the other hand, for an analysis to be pertinent, there should be elaborated some models according to the anatomical reality.

The most existent experiments, with an analysis through finite element analysis, start with bi-dimensional modeling or with some plates of material being in contact.

Associating this kind of data, obtained through simulations, with those from the laboratory, which we will certify or infirm, it will be possible soon to reach chance to anticipate and predict the behavior and evolution of some restoration effectively made.

Naturally, there should be an unlimited and easy access to a series of information which help taking decisions when using these materials is desired. Unfortunately, often, the producers keep silence on some disadvantages of materials, from commercial reasons, remaining for the practitioner to understand from where some of the failures of his activity appear.

**Conclusions**

- The study of the behavior of cervical margins of mixed crowns, as a consequence of ceramic sintering realized through finite elements analysis thermal study, in CosmosDesignStar. The obtained results were similar to those from literature, which entitles us to sustain that the method was reliable or, at least, has a considerable potential.
- The verification of the method was realized through rolling "scenarios" with known results and which were considered as references.
- The present study aims for establishing an inter-relation between the type of threshold and the behavior of the cervical margins of metal-ceramic restorations, subjected to the thermal treatment of firing for ceramics, and also between the margins deformation of the metal-ceramic restorations and the coefficients of thermal dilatation of the interested materials.
- Both the type of threshold and the thermal dilatation coefficients have an uppermost influence on marginal deformation. The type of marginal termination in the shape of shoulder without collar presents the highest deformations, and the chamfer termination with metal collar the lowest.
- The more reduced the threshold and the thinner the metal framework were, the higher the displacement was, a sufficient thickness of metal not being able to oppose to the ceramic contraction.

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**АНАЛИЗ МАРГИНАЛЬНЫХ МОДИФИКАЦИЙ МЕТАЛЛОКЕРАМИЧЕСКИХ КОРОНОК В ПРОЦЕССЕ СЖИГАНИЯ МЕТОДОМ КОНЕЧНЫХ ЭЛЕМЕНТОВ**

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**Аннотация:**

*Исходя от появления модификаций и деформаций во время процесса сжигания при изготовлении металлокерамических коронок, в этой работе мы предлагаем исследовать роль влияния методов препарирования зубных субструктур и коэффициента термической экспансии на финальную маргинальную адаптацию.Исследование проводилось методом COSMOS Design STAR. Тестированные модели были изготовлены в Rhino-Ceros Nurbs modeling для Windows version 4.0. На основании экспериментальных исследований можно констатировать что коефициент термической экспансии и методы препарирования зубов для металлокерамических коронок играет важную роль в финальной маргинальной адаптации .*

**Ключевые слова:**

*металло-керамические коронки, коэффициент термической экспансии, деформация, маргинальная адаптация, метод конечных элементов*