Comparative Assessment of Resistance Against Experimental Forces of Mixed Prosthetic Restorations

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The oral cavity can be considered a complex biomechanical system. Most researches about oral environment's biomechanics, related to restorative dentistry, endodontics, orthodontics, prosthodontics and implantology are conducted in vitro. Applying the principles of engineering in dentistry contribute significantly to understand aspects of oral biomechanics. We conducted comparative research by finite element method on mixed prosthetic restorations with metal frame of CoCr and NiCr, subjected to the same experimental occlusal loading to determine what type of metal substrate has a better biomechanical behavior.When applying forces in the frontal region, the area of weakness is, according to carried out analyzes, disto-incisal angle of the lateral incisor and at the application of forces in the lateral region, the most vulnerable is disto-palatal cusp of the second molar. Overall, for the particular case analyzed, it is recommended to make metal-ceramic prosthetic restoration with metal support of CoCr, which is less distorted and strained at the experimental application of masticatory forces, compared with metal-ceramic restoration made of NiCr.

Keywords: FEA, occlusal loading, mixed prosthetic restoration

Mechanical tests can be performed to determine the resistance to fracture, behavior and mechanical properties of dental restorative materials, but they provide no information about the internal behavior of structures analyzed [1].

When a force is applied to a structure, deformation and stress arise, and if stresses are excessive and go beyond the elastic limit, can cause fractures [2] in the materials.

These stresses cannot be measured directly and it is difficult to understand why and when a failure is initiated in complex structures and also how we can optimize strength and longevity of stomatognathic system's components [1].

Finite element analysis (FEA) is used widely since the 1960's with applications in the fields of engineering and bioengineering. The finite element method (FEM) is a numerical procedure used to analyze structures [1]. Most often, the problem addressed by this method is too difficult to be resolved satisfactorily by conventional analytical methods. The method comprises analyzing stress, deformation, heat transmission and propagation of the fracture line [1] in a structure.

Discretized structures are analyzed by FEA in solid elements interconnected via nodes. Selecting the appropriate mathematical model type and degree of meshing components are important elements that contribute to deliver results characterized by great accuracy. The clear benefits of this method compared to other research methods are reduced costs, decreased working time and the information obtained is not available through experimental studies [2].

Experimental part

We studied a metal-ceramic restoration with implant support by 7 elements, manufactured by CAD-CAM technique. Restoration was comparatively studied in two versions: with metal frame of CoCr, and NiCr respectively.

The restoration design was produced as STL file with the 3D scanner software. Using a specialized program (3-matic © Materialise NV) we created the optimal mesh structure to carry out numerical analysis by finite element method (FEM).

Fig. 1. Mesh of the metal-ceramic restoration structure

Discretized model was imported into ANSYS © SAS IP, Inc. The analysis with finite element method was performed for both restorations (CoCr and NiCr skeleton) in two versions: applying a force of 180 N on the front group to simulate the food incision and applying a force of 300 N on the lateral group to simulate food trituration.

Results and discussions

Force on frontal teeth group

Analyses were performed initially in terms of force of 180 N on the anterior teeth. The results are summarized in table 1.

It has been calculated von Mises equivalent stress criterion for the two metal-ceramic restorations at applying the same experimental force.

For both types of restorations, the maximum equivalent stress was recorded in the disto-incision area of lateral incisor, and in all surfaces that restores lateral teeth crowns were recorded minimum values.

The maximum principal stress was registered for restoration with CoCr metal frame at the junction between the cingulum and the marginal mesial enamel ridge of the central incisor and the minimum value in disto-incisal portion of the lateral incisor, across the entire bridge being found a relatively constant value about 0.46766 MPa.

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	CoCr		NiCr	
	Min	max	min	max
Equivalent (von-Mises) Stress, MPa	3.2378×10^{-6}	12.222	8.8772×10^{-6}	12.575
Principal Stress, MPa	-2.372	4.0172	-2.999	4.1773
Normal stress X Axis, MPa	-4.9236	2.9385	-5.4259	3.1191
Normal stress Y Axis, MPa	-6.9107	2.3745	-7.1466	2.6325
Normal stress Z Axis, MPa	-8.5489	1.8124	-8.5129	1.9574
Shear stress, MPa	1.814×10^{-6}	6.5129	5.112×10^{-6}	6.7273
Total deformation, mm	0	1.3328×10^{-4}	0	1.4209×10^{-4}
Directional deformation X Axis	-3.1607×10^{-5}	8.6848×10^{-5}	-3.5287×10^{-5}	9.3134×10^{-5}
Directional deformation Y Axis	-3.1119×10^{-5}	2.425×10^{-5}	$- 3.1682\times10^{-5}$	2.544×10^{-5}
Directional deformation Z Axis	-1.3144×10^{-4}	1.0966×10^{-5}	-0.0013896	1.1594×10^{-5}

Table 1
ANALYSES PERFORMED AT FORCE OF 180 N ON THE ANTERIOR TEETH

The maximum principal stress for the NiCr metal frame restoration was recorded on the contact point area between the lateral incisor and canine. The minimum value was at halfway between canine's cusp and cingulum.

For Normal stress on OX axis at the experimental application of force on the anterior teeth on restoration with CoCr support, the extreme values were recorded in the area of the neck, the maximum on lateral incisor and minimum on the central incisor. For the restoration with NiCr support, the recorded maximum value of Normal stress on OX axis was at the contact point of the distal lateral incisor and the minimum value below the distal contact point of the central incisor.

For both types of restorations, the Normal stress on OY axis had minimum values in the disto-incisal zone of the lateral incisor and maximum values in supercingular area of central incisor.

Normal stress on OZ axis recorded for both types of restorations had minimum values in the area between the tip and canine cusp and maximum stress in neck lateral incisor area.

Shear stress show in both cases the maximum values in the disto-incisal zone of the lateral incisor and minimum values throughout the entire lateral area.

Total deformation of the restorations, whether they were made of CoCr or NiCr, peaked a maximum value in incisal portion of the oral face of upper central incisor and a minimum value in canine's infracingular portion.

In both cases:

- deformation on OX has a maximum value on the central incisor's edge and a minimum on the lateral incisor's neck, orally;
- deformation on OY has a maximum value in the tip of the canine's cusp and a minimum level at central incisor's incisal edge;
- deformation axis OZ recorded a minimum level of lateral incisor's incisal edge and a maximum on crowns corresponding to second premolar and molars and on buccal portion of other teeth.

Force on lateral teeth group

The study continued by applying an experimental 300 N force on the occlusal face of distal elements of the restoration (premolars and molars). The results are summarized in table 2.

In both cases, the equivalent von Mises stress had a maximum peak at the disto-palatal cusp of the second molar and a minimum value on central incisor's neck, on mesial.

The principal stress at loading of posterior teeth recorded a minimum level at the disto-palatal cusp of first molar and a maximum on the disto-palatal cusp of the second molar.

Normal stress on OX recorded in case of the restoration with CoCr support had a minimum value on first premolar, below the mesial contact point, and the maximum value in an area of distal enamel crest of second molar.

In the case of restoration with NiCr support, normal stress on OX had a minimum value on canine, below the distal contact point and maximum value on disto-palatal cusps of second molar.

Normal stress on OY recorded in case of the restoration with CoCr support had a minimum value on second

	CoCr		NiCr	
	Min	max	min	max
Equivalent (von-Mises) Stress, MPa	4.5703×10^{-5}	13.81	10.945×10^{-5}	13.097
Maximum Principal Stress, MPa	-2.1215	9.3237	-3.7712	9.3466
Normal stress X Axis, MPa	-4.5515	5.5859	-4.7508	5.9747
Normal stress Y Axis, MPa	-3.2242	6.8273	-4.7523	7.2452
Normal stress Z Axis, MPa	-11.248	2.1623	-12.721	2.3899
Shear stress, MPa	2.6372×10^{-5}	7.9721	6.2018×10^{-5}	7.5612
Total deformation, mm	0	3.0345×10^{-4}	0	3.3249×10^{-4}
Directional deformation, X Axis	-6.3847×10^{-5}	1.1425×10^{-4}	-7.0803×10^{-5}	1.2763×10^{-4}
Directional deformation, Y Axis	-8.7192×10^{-5}	1.8352×10^{-4}	-9.5669×10^{-5}	1.9875×10^{-4}
Directional deformation, Z Axis	2.7909×10^{-4}	2.8071×10^{-5}	3.0432×10^{-4}	2.8463×10^{-5}

Table 2
ANALYSES PERFORMED AT FORCE OF 300 N ON THE LATERAL TEETH

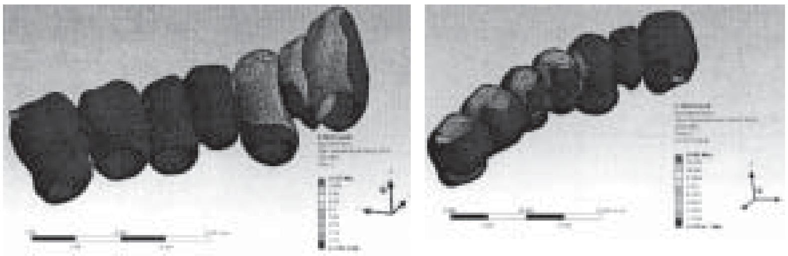

Fig. 2. Variation of von Mises equivalent stress when applying the force on anterior (left) and posterior (right) area of restauration with metal support of CoCr

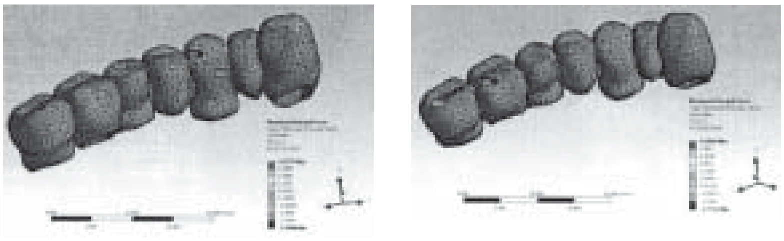

Fig. 3. Variation of principal stress when applying lateral force to the anterior (left) and posterior (right) area of restoration with metal support of NiCr

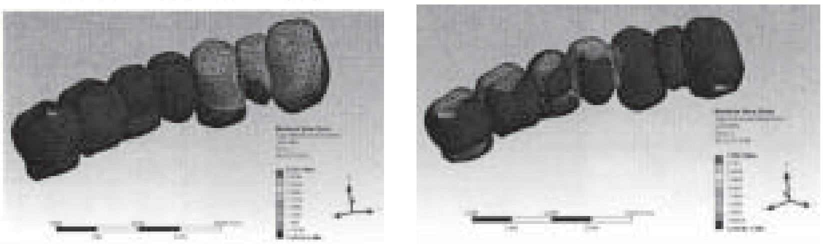

Fig. 4. Variation in shear stress when applying lateral force to the anterior (left) and posterior (right) area of restoration with metal support of NiCr

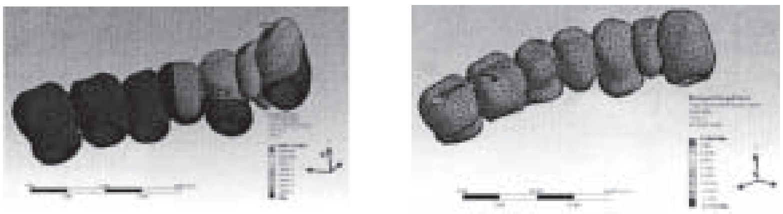

Fig. 5. Variation in total deformation when applying lateral force to the anterior (left) and posterior (right) area of restoration with metal support of CoCr

premolar, below the mesial contact point, and the maximum value on oral cusp of second premolar.

In the case of restoration with NiCr support, normal stress on OY had a minimum value on disto-palatal cusp of first molar and maximum value on oral cusps of second premolar.

Normal stress on OZ recorded in both cases a minimum value on first premolar, in neck zone of oral face, and a maximum value on disto-palatal cusp of second molar.

Shear stress recorded in restoration with CoCr support had the minimum value on mesial face of the central incisor, at the neck of crown, and the maximum value on distal marginal enamel ridge of the second molar.

In the restoration with NiCr support, minimum shear stress was also at the site of the neck on the central incisor, at mesial, and maximum value on disto-palatal cusps of second molar.

Total deformation in both cases had a maximum value on occlusal face of the first premolarand a minimum value on oral face of the canine, in the cingulum zone.

In both cases:

- directional deformation on OX ranged between a minimum value, registered on the oral face of first premolar, at the neck level, and a maximum value recorded in the mesial marginal enamel ridge of the second molar;

- directional deformation on OY range between a maximum recorded in the tip of the buccal cusp of first premolar and a minimum at the oral face of same tooth.

In case of the restoration with metal support of CoCr, at the experimental application of force about 300 N on the lateral area, the directional deformation on OZ recorded a maximum value at the junction between oral and distal faces of first premolar, in the middle third. The minimum amount of deformation was recorded on the face of occlusal molar 2.

In case of the restoration with metal support of NiCr, the directional deformation on OZ recorded a maximum in the occlusal third of oral face of first premolar, and a minimum value on second molar, occlusal.

Complex geometric shapes, material properties, and various boundary conditions, which are difficult to replicate in experiments can be simulated in finite element modeling [3].

Finite element analysis is widely applied in determining the stress distribution model in treated teeth [4- 9]. Results are displayed as colored graded bars, each color corresponding to domain values [10]. The different colors indicate the different value: purple indicates the maximum and dark blue indicate minimum values [11, 12].

Dynamic loading, although more realistic than static load, is more difficult to model using a computer and therefore most analyzes with finite element use static loading which can be axial, non-axial or mixed [13].

Different materials used for making single [14] or multiple [15] restorations have been studied and evaluated in terms of the transfer requests by prosthetic restorations to the bone adjacent to implants, without taking into account the possibility of restorations failure to adapt in vertical direction.

It was suggested that the materials used in the manufacture of restorations are very important for biomechanical reasons. When occlusal forces are applied to the superstructure, they create stresses within them that are transferred to the implant and the bone-implant interface [16]. Applied forces influence the lifetime of restoration and distribution of tensions in the bone around the implants [17]. Initially, gold alloys were most often used in making restorations, but due to high costs, were introduced in dentistry alternative alloys, such as cobalt chromium, silver-palladium or titanium alloys [18].

Due to superior aesthetics and biocompatibility, ceramic dental restorations have become far preferable for making fixed prosthetic restorations [19].

Finite element analysis is a useful technique for evaluating stress distribution, and has been used extensively in studies in recent years [20-22].

Research has shown that the type of fixation material has no particular effect on stress distribution pattern in the layer of cement [23].

Studies carried out by the finite element method for prosthetic implants generally focus on the analysis of stress distribution in the bone adjacent to the implant.

In this study we analyzed only biomechanical behavior of metal-ceramic restoration, with the metal substrate NiCr or CoCr intended to aggregation by cementing on dental implants.

If food incision simulation with a 180 N force applied to the anterior of the restoration, the maximum stresses and deformations were recorded in all analyzes performed at deck level of NiCr.

A number of parameters, such as equivalent stress von Mises, normal stress on OY and OZ, shear stress, shear stress in the plane YZ, elastic stress normal OX, total deflection and deformation of the 3 axes were recorded for both restorations with maximum values in the application requests the same points in the frontal region.

In the case of trituration food simulation with a force of 300 N applied to the posterior teeth, the parameters such as the equivalent stress to von Mises mains stress, the normal stress to the axis OY and OZ, the shear stress in the plane XZ, total deflection and deformation of the OX and OY, for both types of restorations have detected maximum values of crowns in the same area.

Conclusions

For particular clinical case analyzed by FEM, we recommended making metal-ceramic prosthetic restoration with metal support of CoCr, which is less distorted and strained the experimental application of masticatory forces, compared with metal-ceramic restoration made of NiCr.

When applying forces in the frontal region, the area of weakness is, according to analyze carried out, in disto-incisal angle of the lateral incisor and at the application of lateral forces in the region, the most vulnerable is disto-palatal cusp of the second molar.

The study conducted by FEM enables:

- selection of biomechanically optimal restorations, depending on the particular clinical case;
- direct transfer of results to the patient from the study;
- conduct further research involving different materials used for making dentures.

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