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BIOMECHANICAL INTERACTIONS BETWEEN BONE AND METAL-CERAMIC BRIDGES COMPOSED OF DIFFERENT TYPES OF NON-NOBLE ALLOYS UNDER VERTICAL LOADING CONDITIONS

BIOMEHANSKA INTERAKCIJA MED KOSTJO IN KOVINSKO-KERAMIČNIM MOSTIČKOM IZ RAZLIČNIH VRST NEPLEMENITIH ZLITIN PRI VERTIKALNIH OBREMENITVAH

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The purpose of this study was to compare the mechanical properties of three metal-ceramic bridges of different types of dental alloys and to present and evaluate the possible biomechanical interactions between a marginal bone and metal-ceramic bridges during vertical loading. The research was done as an experimental study. A mandible with an intact anterior region was used. The preparation of the remaining teeth for receiving three types of porcelain-fused-to-metal (PFM) restorations was performed. Vita VMK 95 was used for all three metal-ceramic restorations. These three metal-ceramic bridges composed of different alloys, nickel and non-nickel, served as different models: the Niadur-nickelferous model, the Wiron 99-nickel model and the Wirobond C-cobalt-chrome model. The maximum compressive strain of 5 % for all three virtual models is observed in the region of central incisors. The Niadur model has the lowest mean strain (2.62 %) in comparison with the other two models. The mean strain of Wiron 99 is lower, by 0.10 %, than the mean strain of the Wirobond model. Biomechanical behavior of the presented models caused by the vertical-loading conditions is explained as an interaction between the marginal bone and the metal-ceramic bridges. All of them, nickel and non-nickel models, indicate a similar strain (deformation) distribution; however, from the biomechanical perspective, Niadur is more favorable than the other two materials.

Keywords: basic alloys, deformation, biomechanics

Namen te študije je bila primerjava mehanskih lastnosti treh kovinsko-keramičnih mostičkov z različnimi vrstami dentalnih zlitin ter predstavitev in ocenitev morebitne biomehanske interakcije med navidezno kostjo in kovinsko-keramičnim mostičkom med vertikalnim obremenjevanjem. Raziskava je bila opravljena kot eksperimentalna študija. Uporabljena je bila čeljust z nepoškodovanim področjem. Izvršena je bila priprava preostalih zob za namestitev 3 vrst nadomestkov (PFM) iz porcelana, spojenega na kovino. Za vse tri kovinsko-keramične nadomestke je bil uporabljen porcelan Vita VMK 95. Ti trije kovinsko-keramični mostički so bili sestavljeni iz različnih zlitin, z nikljem in brez njega, za pridobitev različnih modelov: Niadur-nikelj železo, Wiron 99-nikelj in Wirobond C-kobalt-krom. Opažen je bil največji tlačni raztezek do 5 % v območju centralnega sekalca pri vseh treh navideznih modelih. V primerjavi z drugima dvema modeloma je imel Niadur najmanjši raztezek 2,62 %. Povprečni raztezek pri Wiron 99 je bil za 0,10 % manjši kot pri modelu Wirobond. Biomehanično vedenje predstavljenih modelov pri vertikalnih obremenitvah je razloženo z interakcijo med navidezno kostjo in kovinsko-keramičnim mostičkom. Vsi modeli z nikljem ali brez njega kažejo podoben raztezek (deformacijo), razen Niadura, ki je s stališča biomehanike bolj ugoden.

Ključne besede: osnovne zlitine, deformacija, biomehanika

1 INTRODUCTION

Besides aesthetics[1] and biocompatibility,[2] dental metal ceramics used for prosthetic reconstruction should have good biomechanical properties.[3,4] As other restorative materials, dental ceramics have disadvantages mostly due to their inability to resist the functional masticatory forces that are present in the oral cavity.[5,6] From the mechanical view point, the life-time of a metal-ceramic bridge depends on the ceramic and alloy mechanical properties.[7] In a ceramic system, the stress intensity (K_1) may exceed the fracture toughness (K_{1c}).[8,9] The toughness that is defined as the discrete (i.e., critical) stress intensity level (K_c) is more expressed in an all-ceramic system than in metal-ceramic restorations.[10] During mastication, compressive, flexural, shear and tensile stresses acting on the ceramic are exerted on the alloy framework, too.[11] Unlike the ceramic responsible for the aesthetics, the alloy framework should be able to withstand the masticatory forces.[12,13] The entire metal-ceramic construction should preserve the marginal-bone integrity to a certain extent.[14]

The following study describes biomechanical behaviors of three different types of dental alloys under vertical-loading conditions, identifying the best one from the biomechanical perspective. The digital image correlation method (DIC) was used for a detailed strain analysis. The purpose of this study was to compare the mechanical properties of three metal-ceramic bridges of different types of dental alloys and to present and evaluate the possible biomechanical interactions between the marginal bone and metal-ceramic bridges during vertical loading.

2 MATERIAL AND METHOD

The research was performed as an experimental study. A mandible with an intact anterior region was used. The mandible was borrowed from the Laboratory for Anthropology, Institute of Anatomy, School of Medicine. According to the data from the Laboratory archive, the mandible donor was female, in her late 60s. The mandible was previously prepared and exposed to occlusal loading.

The preparation procedure was followed by placing the mandible in a saline solution, the drying process and the preparation of the anterior abutment teeth.[15] The preparation of the remaining teeth for receiving three types of the porcelain-fused-to-metal (PFM) restorations was performed. Vita VMK 95 was used as the "ceramic of choice" for all three metal-ceramic restorations. Nevertheless, these three metal-ceramic bridges were composed of different alloys: Niadur-nickelferous (a Cr-Ni alloy), Wiron 99 (a Ni-Cr alloy) and Wirobond C (a Co-Cr alloy). After the first metal-ceramic bridge (Niadur + Vita 95) was obtained, it was pressed with elastomer gum in a standard tray to get an elastomer mold (**Figure 1**) for the next two metal-ceramic bridges. In this way, three models with similar forms were obtained.

The narrow space between the dental roots and the alveoli was coated with a silicone membrane, similar to a periodontal ligament, to reduce the vertical force to a certain extent (**Figure 2**).The mandible with the metal-ceramic bridges positioned in situ was used for obtaining three experimental models: the Niadur model, the Wiron 99 model and the Wirobond C model. Each model had a metal-ceramic bridge made of a different type of alloy. After the preparation procedure, the model was exposed to vertical loading. The average masticatory force was reported to vary between 11 and 150 N, whereas the force peaks were reported to be 200 N in the anterior, 350 N in the posterior and 1000 N in the subjects with parafunctional habits. The load of 300 N was used for the in-vitro experimental analyses. A vertically directed load was applied onto the incisal and occlusal surfaces of

Figure 1: Elastomer mold (impression) for shaping equal metal-ceramic bridges
Slika 1: Forma za elastomer (odtisek), ki se uporablja za enake kovinsko-keramične mostičke

Figure 2: Thin silicone layer imitating a periodontal ligament
Slika 2: Tanek sloj silikona posnema parodontalne vezi

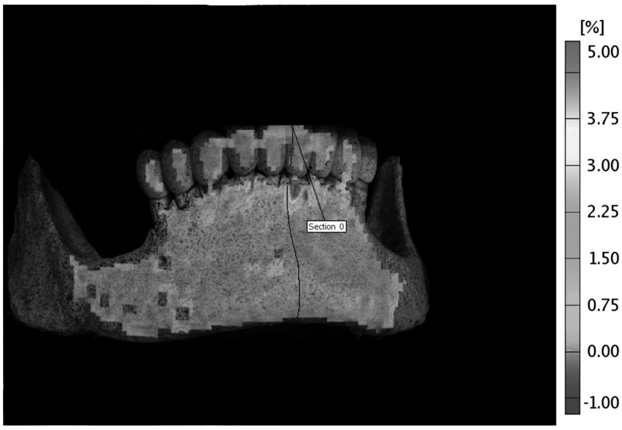

Figure 3: Mandible restored with a metal-ceramic bridge composed of Niadur
Slika 3: Obnovljena čeljust s kovinsko-keramičnim mostičkom iz Niadura

Table 1: Strain values (*e*) and fracture toughness for three mandible models restored with metal-ceramic bridges composed of different base alloys
Tabela 1: Raztezki (*e*) in lomna žilavost pri treh čeljustnih modelih, obnovljenih s kovinsko-keramičnimi mostički iz zlitin z različno osnovo

Tested model (F = 300 N)	e_{min}/%	e_{max}/%	mean strain (%)	No. of measurements before a fracture of the ceramic or marginal bone
NIADUR	0.25	5	2.62	6
WIRON 99	0.5	5	2.75	5
WIROBOND C	0.7	5	2.85	9

the metal-ceramic bridges. The measuring was performed three times for each model, but for each new measurement the next model was used. So, every metal-ceramic model was loaded three times with a gap of 10 min between the measurements. After three cycles of the preliminary loading of different models, they were being loaded until a fracture occurred. The numbers of the cycles leading to the fractures are presented in **Table 1**.

The strain measurement was performed using the equipment from the GOM manufacturer.[16] When a model was loaded, a camera photographed the model stage and the Aramis software processed the obtained data and visualized the strain field. This is represented with virtual models (**Figures 3** to **5**).

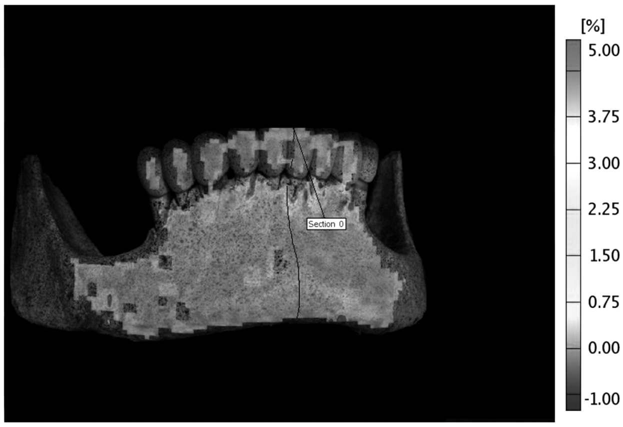

Figure 5: Mandible restored with a metal-ceramic bridge composed of Wirobond C

Slika 5: Obnovljena čeljust s kovinsko-keramičnim mostičkom iz Wirobonda C

3 RESULTS

The maximum compressive strain of 5 % in all three virtual models is observed in the region of the central incisors. All three models have the same strain propagation in the upper part of the mandible body. Nevertheless, the marginal bone in the Wirobond model suffered from a greater overall strain in comparison with the other two Ni-Cr models. This can be explained with the fact that the marginal bone of almost every abutment of the Wirobond model deforms to a greater extent (**Figure 5**) than in the other two cases. The strain values detected on the vestibular surfaces of the metal-ceramic bridge framework are slightly higher in the Wirobond model. Nevertheless, the strain may exceed 3 % in the contact region between the central incisors in the Co-Cr model. The Vita 95 ceramic in the Wirobond model was fractured after nine cycles of the vertical-loading exposure which is slightly better than in the other two models (**Table 1**). Niadur does not induce a higher strain than Wiron 99 (**Figures 3** and **4**). Also, it is noticed that the Niadur model has the lowest mean strain (2.62 %) in comparison with the other two models (**Table 1**). The highest strain in all three virtual models is mainly concentrated in the region of the anterior teeth, especially the incisors. In this region, just below the marginal edge of the metal-ceramic bridge, we notice the highest strain of 5 %, presented with line section 0. **Figure 6** shows the variations in the strain within the section line connecting the two points with the shortest distance (43.9 mm): the incisal edge of the metal-ceramic bridge and the lowest point of the mandible body. The diagram in **Figure 6** indicates that the section line in the region of the metal-ceramic bridge and the marginal bone has the highest strain value in the Wiron 99 model. Although the overall strain in the Wirobond model has a similar distribution to the one in the Wiron 99 model, the mean strain for Wiron 99 is by 0.10 % lower than for the Wirobond model.

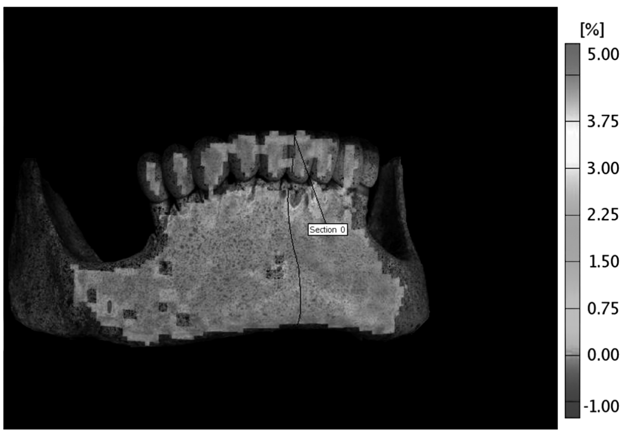

Figure 4: Mandible restored with a metal-ceramic bridge composed of Wiron 99

Slika 4: Obnovljena čeljust s kovinsko-keramičnim mostičkom iz Wirona 99

4 DISCUSSION

For the elderly, losing posterior teeth may influence their chewing ability or cause an abrasion of the anterior teeth and a loss of the vertical dimension. In such a situation, fully covering porcelain-fused-to-metal crowns

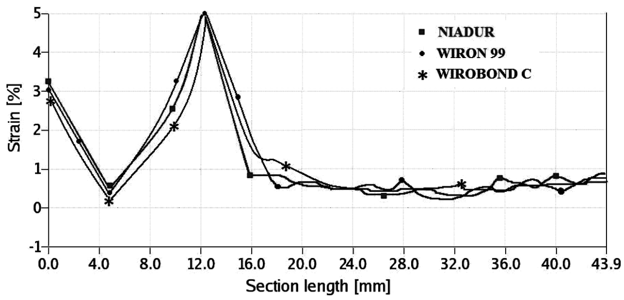

Figure 6: Diagram of the strains within the section lines positioned by the software for every model

Slika 6: Diagram raztezkov vzdolž odsekov, ki jih določi programska oprema za vsak posamezni model or metal-ceramic bridges may be the best choice, having advantages over an all-ceramic system because the fracture failure is more expressed in an all-ceramic system than in metal-ceramic restorations.[17] It is known that most of the elderly persons are not so interested in a removable partial denture because of its discomfort,[18] also rejecting implants in conventional therapy, probably because their expensiveness or surgical procedure. Thus, they occasionally choose a simple solution, deciding not to have all 28 teeth but to save or restore what is left. This study took into account the fact that 8–10 teeth in a jaw (with a minimum of 2 premolars) are enough for elderly persons.[19] As elderly persons with shortened dental arches mostly bite with the anterior teeth, these teeth have to be restored because of the damages (the teeth wear) on their incisal and vestibular surfaces.[20,21]

Many in-vitro techniques for evaluating the mechanical properties of dental alloys or ceramics have been proposed.[22,23] In spite of their apparent simplicity, indentation techniques are burdened with a number of shortcomings related to the specimen preparation, analytical techniques and mathematical analyses.[24] This in-vitro study tends to evaluate and measure the strains caused by loaded metal-ceramic bridges consisting of different alloys. The novelty in this research is that DIC visualizes biomechanical impacts of the frameworks of various alloys on the mandible under vertical loading. This is an elegant and innovative method for researching dental biomechanics that can better explain a distribution of exerted vertical loads. Due to the fact that the applied model (mandible+fixed restorations) is most similar to natural circumstances, it has a great advantage over a standardized specimen.

The study is not a conventional investigation with a standardized specimen. It is an in-vitro investigation where a cadaveric mandible model is loaded within the boundary conditions.[25] A silicone layer was used for the amortization of the applied loads, simulating the periodontal ligament and physiological conditions.[26] Also, a silicon mold was used for standardizing the metal-ceramic frameworks of three different alloys. In this way, similar metal-ceramic models could be obtained and the investigation was conducted with high precision and under the same conditions. The number of loading cycles exerted before the ceramic fracture indicates the fracture toughness[27] of the applied metal-ceramic bridges.

Niadur and Wiron 99 are non-precious alloys, very often used in contemporary dental practice because of their low costs. In dentistry, cobalt-chromium alloys are frequently used for partial denture frameworks. Aditionally, Co-Cr alloys have a substantially higher biocompatibility than Ni-Cr alloys[11,28,29] and, for this reason, they are much more favorable in dental practice. As can be seen in **Table 1**, the Co-Cr model is more resistant to the ceramic fracture than the other two models. This may be explained with the fact that the bond strength is higher in Co-Cr alloys, which is in correlation with the previous finding.[30] This is why the Co-Cr alloy was the alloy of choice when compared with Ni-Cr alloys.

Besides other factors (the metal-ceramic bond strength and the elastic modulus) the extent of the marginal-bone loss may influence the rate of clinical survival of metal-ceramic bridges.[11,31] The study examined and compared three types of ceramics and their impacts on the marginal bone and it was found that there is no significant difference in the strain distribution between the nickel and non-nickel alloys. It was found that a wider strain field is detected on the loaded Co-Cr alloy than on the Ni alloys (**Figure 3**). In this case, every abutment suffered from the same strain intensity. Nevertheless, both nickel alloys (Niadur and Wiron 99) have a similar strain distribution with the highest strain in the region of central incisors (**Figures 1** and **2**). Although dental Co-Cr alloys are widely used in dental practice due to their good mechanical properties and excellent corrosion resistance,[32] this study does not give an advantage to one over the other alloy. However, it is good to know that a Co-Cr based alloy may be an excellent alternative, especially when combining fixed and removable prostheses.[33]

5 CONCLUSION

Within the limitations of this study the following conclusions may be reached:

- The biomechanical behaviors of the presented models caused by vertical-loading conditions are explained as the interactions between the marginal bone and metal-ceramic bridges;
- The aforementioned biomechanical interactions are described as the force-induced strains in the upper part of the mandible bone tissue;
- All the Ni-Cr and Co-Cr models indicate a similar strain distribution, but Niadur is more favorable than the other two from the biomechanical perspective;
- Wiron 99 has a larger impact on the marginal bone than the Wirobond C or Niadur alloys;
- The overall strain has a larger impact in the upper part of the mandible in the case of the Wirobond C model;
- The maximum strains in all the virtual models have the same PIC values that do not exceed 5 %;
- All three semicircular metal-ceramic bridges show the highest strain in the central position between the first incisors.

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