ABSTRACT:
Introduction: Simulation tests may significantly decrease the cost and time needed for planning and production of prosthetic restorations, providing both computer simulation as part of the refinement process and experimental testing.

Aim: Comparative simulation testing with functional loading of two denture framework materials.

Materials and methods: Upper model cast denture for bilateral edentulous areas posterior to the natural teeth (Kennedy Class I) was produced on the “Frasaco” phantom model. The denture was scanned by a 3D optical laboratory scanner. The 3D model was transformed into an STL-file and was processed with “Cinema 4D” software before the application of the program “SOLIDWORKS” v.2018. Parameters of two materials – metal alloy I-MG EKO (Interdent, Slovenia) and injection molded resin BioDentaplast (Bredent, Germany) were applied.

Simulations were performed by equivalent loading according to the Third strength theory (von Mises stress-test) and loading with deformation and shift at constant force 0.1N/mm² at a maximal number of 159 181 segmented elements of the 3D object. Tests were held upon unilateral loading on the working side, and support was provided by reciprocal clasp arms on the working and non-working side, denture flanges and major connector.

Results and discussion: Results showed insignificant differences between the common reflected load of the two tested materials but with different distribution - on the major connector, it was 0.4N for the alloy and 0.87N for the resin, at the flanges – 2.26N and 5.6N respectively, for the clasps – 5.1N and 5.7N.

Conclusion: The tested metal alloy is rigid and resistant material which provides distribution of the reflected load between clasp elements and denture saddle, especially distally, while the tested injection molded material possesses relatively high flexibility and elasticity, which hides a risk for the teeth bearing clasps.

Keywords: injection molded resin, partial denture, simulation.

INTRODUCTION:
Removable partial dentures are widely used in the clinical practice and have some advantages compared to fixed prosthetic restorations and over-implant dentures, especially in elderly patients. Denture frameworks are often produced by dental alloys, usually cobalt-chromium, which possess some disadvantages like possible allergic reactions, aesthetic problems from the visible metal parts, problems concerning corrosion and galvanic reactions, and even forming a biofilm containing pathogenic microorganisms [1].

Metal-free denture framework may be fabricated from polymer materials, but their mechanical properties and wear resistance and the patients’ comfort are not well studied. Nevertheless, the alternative materials are always a matter of interest for the dental industry, especially in cases, in which the new materials may provide better properties and behavior.

The main complaint of the patients wearing removable partial dentures with metal framework is the poor esthetics because of the visible metal parts of the clasps and connectors. Recently injection molded thermoplastic materials have been used to producedenture frameworks. These materials have good tensile strength, compressive strength, and flexibility, and some advantages compared to metal alloys [2]. All the thermoplastic denture framework materials are provided for solving the problem with esthetics, present at metal alloys, but esthetics should not be the only reason for their use. Mechanical characteristics must be considered. Retentive and reciprocal clasp arms and the occlusal rest of the clasps must fulfill their functions no matter the material they are made of. The retentive clasp arm is placed in the undercut area of the tooth and must be able to pass through the equator area and return to the initial position without permanent deformation. The unwanted stress effects on the tooth should be minimized [3, 4, 5].

For understanding the problems which may arise in the body, it is important to know human anatomy and morphology, and the way in which the components work together to achieve normal functionality. Considering the geometry of different components, their behavior in the human body and the use of CAD software it is possible models with a high level of complexity to be defined. Simulation testing may significantly decrease the cost and time.
AIM:
The aim of the study was to provide a comparative simulation testing with functional loading of two denture framework materials.

MATERIALS AND METHODS:
Upper model cast partial denture for bilateral edentulous areas, posterior to the natural teeth (missing first, second and third maxillary molars) was produced on the “Frasaco” phantom model for the creation of a linear supporting field. Clasps over the teeth anterior to the defects and a major connector with the shape of a strap in the middle of the palate were designed (Fig. 1).

Fig. 1. The denture on the model.

The denture was scanned by 3D optical laboratory scanner Vinyl (Smart Optics, Germany). The denture was treated as a three-layer object—the framework, the covering layer of PMMA, and the artificial teeth. Scanning was done by a camera with a resolution of 1.3 MP. The denture 3D model was transformed into an STL-file and was processed with “Cinema 4D” software—a program for 3D model processing, which allowed simplification of the denture 3D image and facilitated the uploading into another software for conducting simulations.

Program “SOLIDWORKS” v.2018 was used for creating the simulations. At the first stage, functions Import and Mesh were applied. Import function allowed importing the STL-file of the object in the program, in this case—the denture 3D model. Mesh function, which was in collaboration with the other program functions and applications, allowed segmentation of the 3D image in elements with mutual apexes. In our study, due to the Mesh function, the number of elements of the imported object was changed from 30,836 (triangles) to 159,181 with element size within 3.23 – 3.46 mm. This difference came from the fact that the imported object was initially segmented only on the surface, and during the simulations, segmentation was provided both on the surface and within the 3D object (Fig. 2).

Fig. 2. Segmented denture

The testing was conducted at unilateral loading on the working side, and support was provided by reciprocal clasp arms on the working and non-working side, denture flanges and palatal major connector (Fig. 2).
RESULTS:
I-MG EKO metal alloy simulations
1. Stress-test (fig. 3)
The results showed that at constant force 0.1N/mm², the reflected load was within 7.64 – 2.79 N. The biggest load was calculated over the clasps and denture flanges on the working side where pressure was applied. The values of the load on the palatal major connector were minimal and an insignificant level of reflected load over the non-working side was noticed.

![Fig. 3. Metal alloy stress-test.](image)

2. Loading tests with deformation and shift

At unilateral loading on the working side, the areas with the greatest stress and deformations were reciprocal clasp arms, clasp bodies and denture flanges on the working side (Fig. 4). Zones bearing the biggest load were clasps, therefore abutment teeth, and denture flanges, while the palatal major connector and the non-working side were minimally loaded (Fig. 5). According to the program software, the reflected load values were 0.4 N at the major connector, 2.26 N at denture flanges and 5.1 N at the clasp. The stress at the major connector was 5 times smaller than that at the flanges and 12 times smaller than that at the clasps. Stress at the flanges was 2 times smaller than that at the clasps.

![Fig. 4. Deformations and shift (occlusal surface).](image)

Bio Dentaplast injection molded resin simulations
1. Stress-test

Results for injection molded material were similar to the results for the metal alloy but with different parameters (fig. 6 – a, b). The reflected load was in the range from 7.63 to 2.91 N, which demonstrated insignificant differences with the metal alloy. The biggest stress was detected over the reciprocal clasp arms, clasp bodies and denture saddle.

![Fig. 5. Deformations and shift (internal surface).](image)

2. Loading tests with deformation and shift

After calculating the data from the different zones received during the loading test with shift and deforma-
tions, results showed that the reflected load at the major connector was 0.87 N, at the flanges – 5.6 N, and at the clasp – 5.7 N. The stress at the palatal major connector was 6 times smaller than that at the flanges and 6 times smaller than that at the clasps (fig. 7–a, b).

Fig. 7. Deformation and shift of Bio Dentaplast – a) external surface; b) internal surface

DISCUSSION:

The use of software product for simulation testing provides numerous advantages. It is a fast method for obtaining results after segmentation, applying a 3D model, and incorporating values for three parameters of the tested material. The actual fabrication of a denture of the tested materials is not needed. The model for scanning may be produced even from wax and then transferred into a 3D image. The human factor (dental technicians, dentists, patients, researchers) is eliminated. The software provides simulation of the function of the antagonists and the jaw on which the denture is placed. That was the reason because of which the working model and the antagonists were not scanned. The software provides creating load from forces with vertical and oblique direction, and a choice of the place for applying the load.

A disadvantage of the method was that the specific characteristics of the denture foundation – the pliability of the mucosa, the bone elasticity, the movement of the supporting teeth in the alveoli, and the elasticity of the periodontal ligaments, were not taken under consideration.

Results confirmed the fact that metal alloys are rigid and resistant materials with limited elasticity, which contributes to the distribution of the reflected load between reciprocal clasp arms, clasp bodies and denture saddle, especially distally. Compressive strength was greater than the one of the injection molded material and the clasps provided better retention [1]. This decreases the movements around the supporting tooth and provides less harmful effect on the tooth. Thus, the action of the appearing lever of first order in cases with defects posterior to the natural teeth decreases and protects the abutment teeth from overloading. In edentulous areas posterior to the remaining teeth Alwan et al. and Bahrami et al. observe the highest values of reflected load distally of the abutment teeth next to the edentulous area [6, 7]. Greater load is observed on the working side and on the non-working side, it is approximately 1/3 lower [8, 9]. But because of the rigidity of the metal alloy a bigger force is needed for passing through the equator zone when placing and taking the denture out of the mouth [10]. According to Oliveira et al., the value of deformation over the abutment tooth with a direct retainer next to the edentulous area depends on the value of the applied tensile strength [11]. Resistance to deformation may be exceeded when increasing the tensile strength values. A risk of transforming the clasp into a point of rotation appears.

Our results confirm that injection molded materials possess relative flexibility and elasticity. Polyoxymethylene is a thermoplastic material with good mechanical properties like high compressive strength, tensile strength, resistance to abrasion, low creep strain, high hardness, low coefficient of friction, good wear resistance and stable dimensions [12, 13, 14]. This material also has high resistance to chemical agents, low absorption of water and high biocompatibility [7, 15].

The basic load received over the reciprocal clasp arms, clasp bodies and denture saddle is evenly distributed but benefits neither the stress relieving from abutment teeth, nor elimination of the action of the first order lever. The results from the study are within the accepted range. It may be concluded that this thermoplastic material may be used for denture framework production in edentulous areas posterior to the natural teeth because it shows good adaptation to the prosthetic field [16, 17, 14], but strict observation of the indications and individual assessment of each clinical case is needed. The presence of sagittal rotational movement in the free distal zones of the denture flanges leads to a significant increase in the reflected load and denture shift during mastication, and an appropriate guiding plane is needed. The occlusal pressure applied over the edentulous area posterior to the present teeth defines the level of the reflected load. The area where the occlusal pressure is applied defines the maximal load value but does not influence the exact area of maximal load. A greater shift is detected at the distal saddle ends, and the shift values depend on the point of the force application. Our investigations confirm the studies of O’ Brien according to which when the framework of these types of dentures is produced from injection molded resins, the load over the abutment teeth is greater than the one appearing when the framework is produced from a metal alloy [9].
Removable dentures with framework made of injection molded materials create big pressure over the underlying mucosa in the zone of force application, which is in significant difference with other denture framework materials. The tested injection molded material has lower elasticity and higher flexibility compared to other polymer materials and some authors recommend the use of this material in combination with metal alloy [2]. Clasps made of injection molded materials have lower retentive force compared to the metal clasps [18]. The denture framework material must possess flexibility and must return to its initial shape without deformation so that the clasp must be able to pass over the equator zone to fulfill its retentive function. Furthermore, the shifting of the clasps and their movements around the abutment tooth should not induce a load outside the physiological limits [19, 20, 6]. Alwan et al. and Bahrami et al. recommend the use of injection molded materials for denture production only in cases of short distally unbound defects in order to prevent overloading of the teeth next to the defects [6, 7]. Similar recommendations are given by other authors [16].

In the design of our study the parameters of the two tested materials are used. A limitation of the study was the use of a denture model for only one type of partially edentulous arch, so the behavior of the tested materials and the distribution of the occlusal forces are analyzed only for the chosen Kennedy class. It is possible different results to be obtained in other clinical situations. Further investigations are needed.

CONCLUSION:
The tested metal alloy is a rigid and resistant material which provides distribution of the reflected load between clasp elements and denture saddle, especially distally, while the tested injection molded material possesses relatively high flexibility and elasticity, which hides a risk for the teeth bearing clasps.

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