EVALUATION OF THE FORCE RETENTION WITHIN THE TELESCOPIC CROWNS WITH DIFFERENT TAPER ANGLES BY FINITE ELEMENT ANALYSIS

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Nowadays with the aid of digital dentistry, the telescopic crown systems used in dental restauration can be efficiently manufactured with limited technical errors, reduced processing time and with customized features, adapted to the clinical needs. In addition, by using finite element analysis, which is an approximate method, the design of the telescopic systems along with the materials used to fabricate it, can be evaluated in simulated conditions to obtain the best outcomes. The aim of the current study was to validate the experimental results regarding the retention forces corresponding to different telescopic systems used in removable prosthetic dentures through finite element analysis (FEA). The FEA results are in good agreement with the experimental results obtained through mechanical tests, indicating that the numerical method is a reliable tool which can enhance the manufacturing process in terms of proper selection of materials, or design.

Keywords: finite element analysis; telescopic crowns; taper angles

1. Introduction

According to "The Glossary of Prosthodontic Terms" [1] a telescopic denture is defined as "any removable dental prosthesis that covers and rests on one

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or more remaining natural teeth, the roots of natural teeth, and/or dental implants; a dental prosthesis that covers and is partially supported by natural teeth, natural tooth roots, and/or dental implants”.

Initially, the telescopic crowns were introduced as retainers for the removable partial dentures at the beginning of the 20th century [2,3]. This dental prosthesis uses a system made of two crowns, in which the inner crown is the primary one (PC), which is also attached to the natural tooth, its root or a dental implant, while the outer crown is the secondary one (SC) [4].

The telescopic crowns are also known as *Konuskrone* [2], a German term which describes a cone shaped design. The retention between the two crowns is achieved by fitting the outer crown on the inner crown [5–7].

Among the benefits of this type of dental restoration are found, prevention of bone loss, proper distribution of the forces on the abutment [8], effective good oral hygiene, enhanced aesthetic compared to other types of dental restorations [9], proper jaw alignment, improved chewing efficiency [10], and a good survival rate [11]. These types of dental restorations are commonly used in countries such as Germany and Sweden, but also in Eastern Asia [12].

Regardless the reported benefits, the telescopic system can be affected by the manufacturing technique and design parameters. Compared to the cylindrical system whose retention is achieved due to the friction between the external surface of the primary crown and the inner surface of the secondary crown [13], the conical ones appear to be more suitable due to the wedging action which is strong enough to secure the prothesis retention [14].

The most common materials used to fabricate telescopic crowns are titanium, Co-Cr alloys of the non-precious metal alloys class, precious metal alloy, ceramics (zirconia) and some polymers such as the one of the polyaryletherketone class, of which the most known is polyetherketoneketone [15–17].

Even though casting is the most common technique used to manufacture telescopic crown, nowadays with the aid of digital dentistry, this type of dental restauration can be efficiently manufactured with limited technical errors, reduced processing time and with customized features, adapted to the clinical needs [9,18].

Among the most used methods to solve nonlinear problems are found the numerical methods, which are based on the principle that a nonlinear problem can be approximated through a sequence of linear elementary problems [19]. The advantages of this methods consist in their versatility, simplicity, the possibility of implementation on a computer and the possibility of evaluating the order of magnitude of the error of the approximate solution.

Since the calculation is iterative, the difference between the solutions obtained by two successive iterations is an indication of the error of the approximate solution compared to the "exact" solution. It is specified that within this context the exact solution is FEA, which is in fact approximate [20]. The main disadvantage of these methods is the large volume of computation, which has now lost its importance due to the impressive performance of the computing systems.

The most important indirect calculation methods are incremental, iterative, and mixed, the latter one being a combination of the first two. Each of these methods has several variants of applicability.

Thus, the aim of this paper was to validate the experimental results regarding the retention forces corresponding to different telescopic systems used in removable prosthetic dentures, which was published elsewhere [17] through finite element analysis (FEA) by using Ansys software [21].

2. Materials and Methods

The telescopic systems analyzed through FEA were designed for two reference abutment teeth, namely an upper right canine (tooth no. 1.3 in FDI World Dental Federation notation) and a first upper left molar (tooth no 2.6 in FDI system). Moreover, the design included two taper angles of 0° and, 2°, respectively.

In table 1 are presented the samples analyzed through numerical method. The materials selected for the fabrication of the telescopic systems analyzed by FEA, were cobalt–chromium (Co-Cr) alloy or zirconia for the primary crowns (PC) and Co-Cr for secondary crowns (SC).

Table 1

Samples codification

Tooth	Telescopic System—Crown material		Taper Angle	Codification
	Secondary Crown (SC)	Primary crown (PC)		
tooth 1.3 (canine)	Co-Cr	Co-Cr	0°	13-CC-0
			2°	13-CC-2
		ZrO_2	0°	13-CZ-0
			2°	13-CZ-2
tooth 2.6 (1st molar)	Co-Cr	Co-Cr	0°	26-CC-0
			2°	26-CC-2
		ZrO_2	0°	26-CZ-0
			2°	26-CZ-2

The force retention was evaluated by numerical technique with finite element analysis, by using Ansys software. The numerical results of the retention forces were compared with the experimental results obtained by mechanical tests to show the agreement of the results.

Thus, for the analysis of the retention forces by Ansys, initially the finite element must be selected for the discretization. Models' discretization was performed by using the SOLID 187 finite element, with 10 nodes, which is applied for discretization of the simulated solid models [21]. The element size was imposed at a value of 0.3 mm, to achieve an optimum discretization [21]. Other two finite elements [21] used in the present study were CONTA174 and TARGE170, which have been used to simulate the contact between the two solid shapes that are interacting.

CAD–CAM technologies used for manufacturing the telescopic system components required in oral rehabilitation have led to primary and secondary crowns without deviating from the geometry required and dictated by the anatomical shape of the teeth studied. The computer-aided design (CAD) stage involves the virtual scanning and modelling of the future prosthetic work. Scanning the model for the clinical situation on which this study was based was performed with a D850 Scanner (3Shape, Copenhagen, Denmark).

In order to perform the numerical analysis, the STL model must be converted into 3D solid geometrical model. In Fig. 1, is presented a STL model which has been converted into a 3D model.

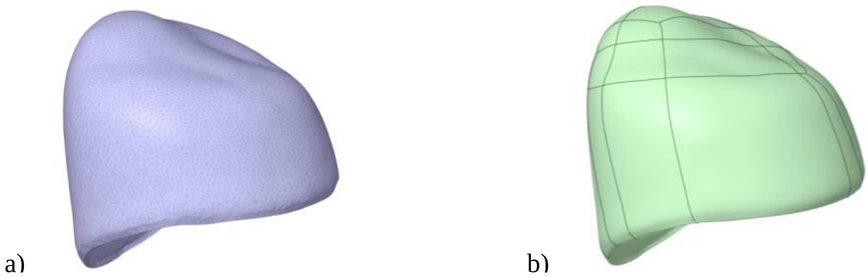


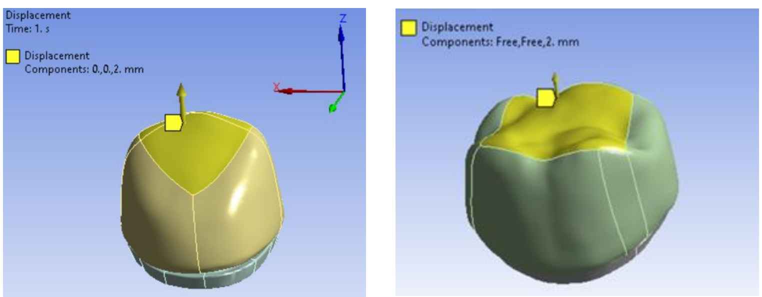
Fig. 1. The model in STL format (a) and its conversion into a 3D solid model

The required displacement distance was set to 2 mm for all the telescopic systems analyzed by FEA. In Fig. 2 are presented for both types of teeth, the secondary crowns which were set free to perform the 2 mm displacement from the primary crown which was set to a fixed position.

For all materials simulated in the model, linear-elastic, isotropic material was considered based on two constants, namely Elastic modulus and Poisson ratio. In table 2 are summarized the simulated material properties.

Canine (Tooth 1.3) | 1st molar (Tooth 2.6)

Displacement components (free on x and y direction and 2mm in z direction)



Fixed support

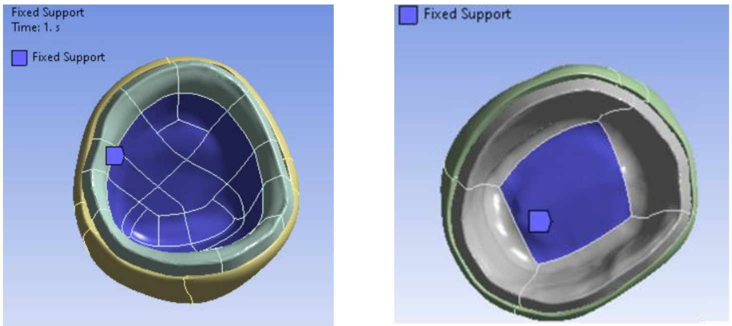


Fig. 2. Representation of the free component (secondary crown) and the fixed support (primary crown) for FEA analysis

Table 2

Mechanical properties of the materials/solid geometries used in the current study

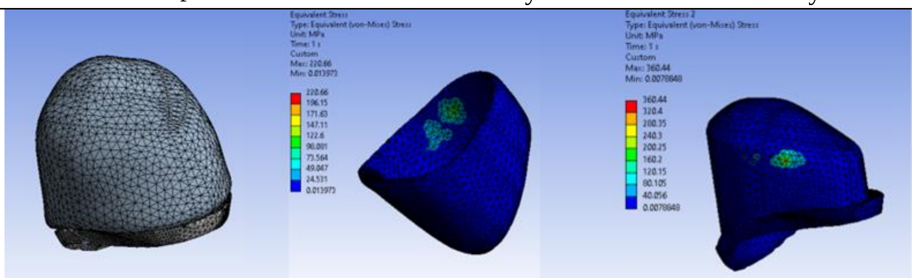
Material	Elastic Modulus (GPa)	Poisson Ratio
Zirconia (3Y-TZP)	200	0.30
Co-Cr	241	0.30

3. Results and Discussions

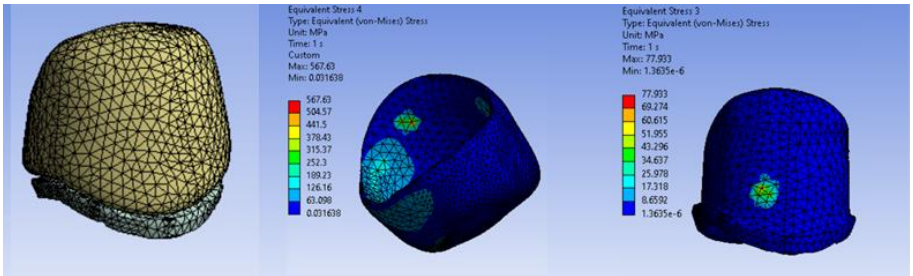
In Fig. 3. are presented the discretization model along with the stress resulted after the detachment of the secondary crown from the primary one of the telescopic systems.

Results were determined by considering von Mises criteria method which depends on the entire stress field, and it has been commonly used as indicator for the possibility of damage occurrence [22]. The red color indicates the maximum value obtained by calculation. The double crown systems evaluated through FEA presented similar contact points as the one observed in the experimental mechanical tests.

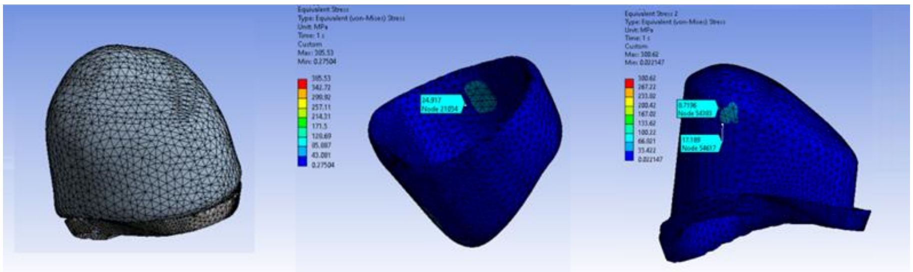
According to the stress distribution for the primary and secondary crowns, presented in Fig. 3, it can be noted that all telescopic systems present a contact in one node, irrespective of the materials and/or taper angle.

	Discretization of the telescopic model	Stress distribution after detachment	
		Secondary crown	Primary crown
13-CC-0			

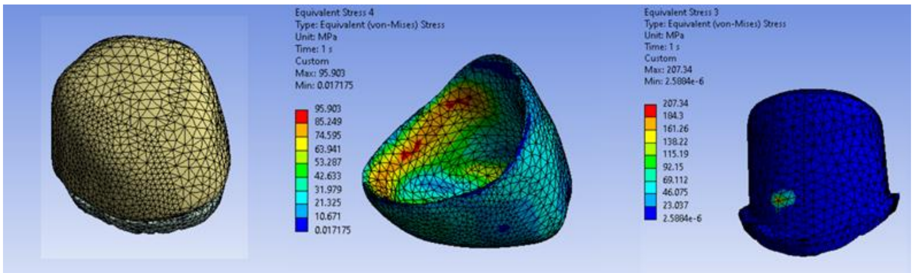
13-CC-2



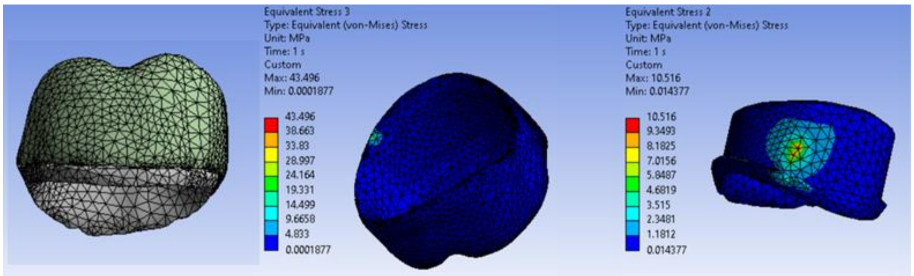
13-CZ-0



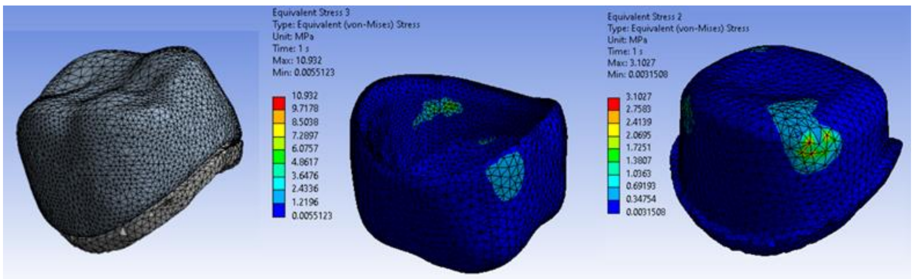
13-CZ-2



26-CC-0



26-CC-2



26-CZ-0

26-CZ-2

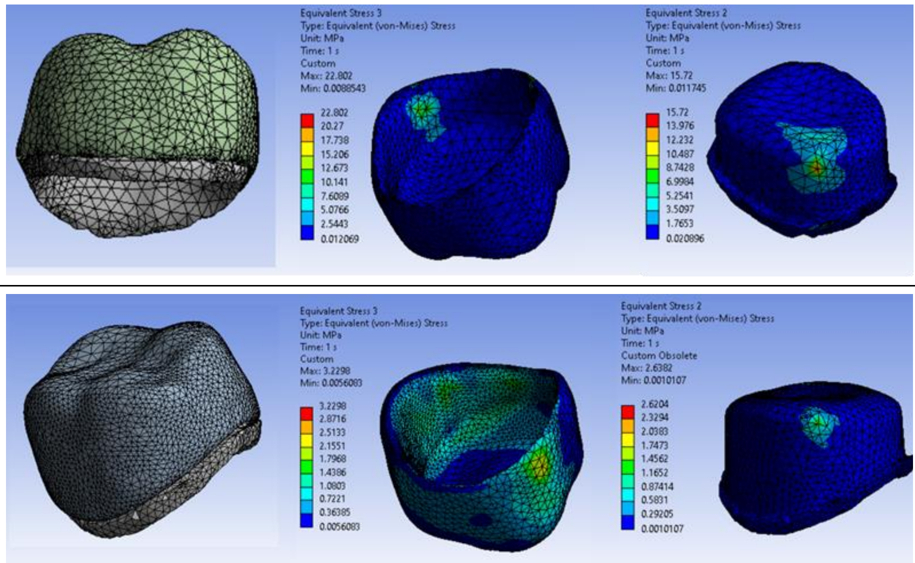


Fig. 3. Stress distribution on the secondary and primary crown of each telescopic system

In Table 3 are presented the number of nodes and elements obtained after discretization of each model along with the von-Mises stress and the retention force obtained on each primary and secondary crown after performing the simulations.

Table. 3

Information of nodes and elements in the finite element models along with the outcomes based on stress peak values and the resulted force retention

Samples Codification	FEA analysis				
	No. of Nodes	No. of elements	Stress SC (MPa)	Stress PC (MPa)	Retention force (N)
13-CC-0	64381	36088	360.44	220.66	1.99
13-CC-2	33899	18581	567.63	77.93	1.63
13-CZ-0	64381	36088	385.53	300.62	5.52
13-CZ-2	33899	18581	95.90	207.34	4.90
26-CC-0	24697	13186	43.50	10.52	2.92
26-CC-2	49435	27501	10.93	3.10	4.29
26-CZ-0	24697	13186	22.80	15.72	4.90
26-CZ-2	49435	27501	3.23	2.62	3.11

By analyzing the values of the maximum stress peak obtained for the secondary and primary crown of each telescopic system, it can be observed that higher values were obtained when the taper angle was of 0°, irrespective of the material taken into consideration for each component of the system.

Considering the von Mises criteria it can be stated that both, primary and secondary crown of each telescopic system analyzed in this study, have registered values which are found to be within the safety limits, indicating that the proposed materials can be successfully used for the fabrication of the telescopic dental systems. Moreover, the results of the von-Moises stress values reveal that the areas of maximum stress concentration were located in the upper region, with higher values being obtained for the secondary crown, when compared to the ones obtained for the primary crown, indicating a proper fitting between the two components.

The results obtained from the FEA analysis were compared with the ones obtained from the experimental ones (Table 4) which are published elsewhere [17] and the error between the results was computed according to the following equation (Eq.1):

$$Error = \frac{Retention\ Force_{experimental} - Retention\ Force_{FEA}}{Retention\ Force_{FEA}} \cdot 100\ [\%] \qquad (1)$$

Table 4

Retention force of the FEA method vs experimental, and the error

Telescopic system	Retention force		Error [%]
	Experimental [17]	FEA	
13-CC-0	1.90	1.99	4.52 %
13-CC-2	1.60	1.63	1.54 %
13-CZ-0	5.92	5.52	-7.25 %
13-CZ-2	4.52	4.90	7.66 %
26-CC-0	2.73	2.92	6.35 %
26-CC-2	1.40	1.42	1.06 %
26-CZ-0	3.82	4.29	10.96 %
26-CZ-2	3.01	3.11	3.22 %

For an easier comparison, the differences between the retention forces obtained through experimental procedure and the ones obtained in simulated conditions are presented in Fig. 4.

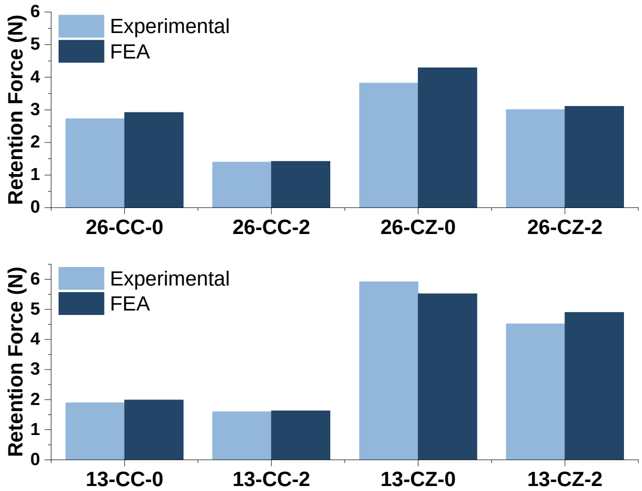


Fig.4. Retention force obtained through FEA method vs experimental one

According to the obtained results it can be observed that the telescopic systems made of Co-Cr and ZrO_2 had the higher retention forces than the ones in which both components were made of Co-Cr. In terms of tooth type, the retention forces were higher for the 1.3 teeth than for tooth 2.6, and in terms of taper angle those manufactured at 0° have higher values of retention forces.

Since the finite element analysis is an approximate method, it can be considered that the errors obtained and presented in Table 4, satisfy rigors of the performed study [23–25]. Thus, the values of the retention forces obtained through the numerical method have validated the values obtained through experiments, indicating that FEA method is a reliable resource which can be used before performing the actual experimental tests to reduce the usage of materials and production time, and to evaluate the behavior and establish if the selected design and/or materials are suitable to fulfill the clinical specifications.

4. Conclusions

The results obtained in this study indicate that the retention forces obtained by FEA method are similar to those obtained through mechanical tests which have indicated that the telescopic systems in which the primary crown was made of zirconia are more suitable for dental restoration than the ones made of Co-Cr alloy, because gave registered higher retention values. Also, the taper angle is a manufacturer parameter that can enhance the retention of telescopic crowns.

Thus, it can be said that the numerical method carried out through finite element analysis, is a reliable tool which can offer valuable information that can enhance the manufacturing process in terms of proper selection of materials, or design in order to obtain the best outcomes.

Author Contributions: All authors had equal contributions to the study and publication.

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