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ABSTRACT

of the dissertationfor work for the degree of Doctor of Philosophy

PROSTHETICS OF ANTERIOR DENTAL DEFECTS WITH CERAMIC STRUCTURES

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GENERAL CHARACTERISTICS OF THE WORK

The relevance of the topic.

Orthopedists frequently encounter patients with defects in their upper or lower anterior teeth, which can adversely affect their general health, including chewing function, aesthetics, and psychological well-being. When selecting an appropriate treatment method for such individuals, the prosthesis design must ensure reliability and safety while minimizing potential complications. In these cases, orthopedic treatment typically involves the use of fixed dental prostheses, such as metal-ceramic or complete ceramic restorations, aimed at restoring the lost dental structures[1,2].

Dental ceramics are composed of a heterogeneous group of materials that are distinguished by their specific optical, mechanical properties, and chemical stability. These types of ceramics, classified as inorganic and non-metallic materials, are used in dentistry for various purposes. They are biologically compatible with tissues, possess high aesthetic qualities, and exhibit considerable resistance to deformation under tensile and compressive forces. In recent years, several new types of ceramic materials have been developed for tooth restoration, along with processing methods designed to enhance their mechanical properties. Despite numerous advancements, discussions regarding the structure of dental ceramic materials and their reinforcement strategies are still ongoing. Dental ceramic materials primarily consist of lithium disilicate, leucite, zirconium polycrystals, and glass ceramics enriched with aluminum oxide.

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[1] Kwon, S.J. Comparison of the mechanical properties of translucent zirconia and lithium disilicate / S.J.Kwon, N.C.Lawson, E.E.McLaren [et al.] // J Prosthet Dent, - 2018. 120, - p. 132–137.

[2] Keshvad, A., Hakimaneh, S.M.R. Microtensile bond strength of a resin cement to silica-based and Y-TZP ceramics using different surface treatments // J Prosthodont, - 2018. 27, - p. 67–74.

Modern ceramic materials can include feldspar, lithium disilicate, aluminum oxide, and zirconium dioxide, depending on the chemical composition and percentage of the components[3,4].

Modern ceramic materials can include feldspar, lithium disilicate, aluminum oxide, and zirconium dioxide, depending on the chemical composition and percentage of the components[5,6].

Another notable ceramic material is composed of 5% partially stabilized yttrium oxide, and 95% zirconium oxide. Thanks to its fully crystalline microstructure, this ceramic is extremely strong and is reinforced by a mechanism known as steady transformation. Its transparency level is approximately 30%[7].

Ceramic materials used in daily dental practice must meet certain criteria.

First and foremost, ceramic materials must be strong and resistant to crack propagation. Additionally, they should possess the mechanical strength required to withstand occlusal pressures, along with favorable optical and desirable aesthetic properties. Finally, they must ensure durability and strength, which can be preemptively maintained under in vivo conditions[8].

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[3] Sagen, M.A. Debonding mechanism of zirconia and lithium disilicate resin cemented to dentin / M.A.Sagen, K.Kvam, E.I.Ruyter [et al.] // Acta Biomater Odontol Scand, - 2019. 5(1), - p. 22–29.

[4] Blatz, M.B., Vonderheide, M., Conejo, J. The effect of resin bonding on long-term success of high-strength ceramics // J Dent Res, - 2018. 97, - p. 132–139.

[5] Kwon, S.J. Comparison of the mechanical properties of translucent zirconia and lithium disilicate / S.J.Kwon, N.C.Lawson, E.E.McLaren [et al.] // J Prosthet Dent, - 2018. 120, - p. 132–137.

[6] Keshvad, A., Hakimaneh, S.M.R. Microtensile bond strength of a resin cement to silica-based and Y-TZP ceramics using different surface treatments // J Prosthodont, - 2018. 27, - p. 67–74.

[7] Ishii, R. Influence of surface treatment of contaminated zirconia on surface free energy and resin cement bonding / R.Ishii, A.Tsujimoto, T.Takamizawa [et al.] // Dent Mater J, - 2015. 34, - p. 91–97.

[8] Ausiello, P. Effect of Shrinking and No Shrinking Dentine and Enamel Replacing Materials in Posterior Restoration: A 3D-FEA Study / P.Ausiello, A.D.Piva, A.Borges [et al.] // Appl. Sci, - 2021. 11, - p. 2215.

The properties of the crown primarily depend on the pressure applied to it, meaning the rate, depth, and direction of pressure, in accordance with the characteristics of the tooth's microstructure.

The contact stress on the crown, due to the functions of the oral cavity, significantly influences the lifespan of dental restorations. With the increasing number of operations involving the replacement of orthopedic structures, there has also been a growing interest in studying the distribution of pressure on prostheses. The analysis of stresses on fabricated prosthetic structures provides orthopedists with valuable information regarding the biomechanics and displacements of the jaw. Numerous methods, such as the tensometric method, load-bearing tests, and the photoelasticity method, have been used to measure and analyze these stresses. However, traditional methods like tensometry, sensors, load-bearing tests, and photoelasticity require significant time and are costly, which limits their wide application. Moreover, due to the complex shapes of prosthetic structures, it is challenging to make scientifically sound decisions regarding crowns. In this regard, the analytical system of finite element method (FEM) has recently gained widespread use for the mechanical analysis of orthopedic structures.

Finite element analysis (FEA) is a method used to model elements with complex geometric shapes and describe their mechanical behavior, providing a simpler means of understanding key concepts; the mathematical model described by this method is based on certain working assumptions, simplifications, and generalizations [9].

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[9] Berger, G. A 3D finite element analysis of glass fiber reinforcement designs on the stress of an implant-supported overdenture / G.Berger, LF de O.Pereira, EM de.Souza [et al.] // J Prosthet Dent, - 2019. 121(5), - p. 865.e1-865.e7.

In essence, the finite element method is a numerical analysis technique for evaluating stress and deformations within a geometric structure, whereby the entire structure is divided into segments known as "finite elements." The type, arrangement, and total number of these segments impact the accuracy of the results obtained[204, s. 200-203].

Subsequent steps typically involve constructing the finite element model, determining the relevant material properties, and defining the conditions between pressures and boundaries to create the intended and desired characteristics. Various engineering software packages are available for modeling and remodeling structures of interest, such as implants or jaw bones. The three-dimensional finite element method is a more precise approach for analyzing stress within dental tissues. While it is not a fully exact method, FEA overcomes many of the limitations found in traditional methods. Today, it is widely employed in research to study the characteristics of crowns in both static and dynamic conditions [10].

During laboratory testing of a material, simulating occlusal function becomes a critical step for long-term prediction of its properties before clinical use.

Finite element analysis is a promising and essential research tool for analyzing the biomechanical properties of materials in biological studies. It is an ideal method for modeling complex structures and analyzing their mechanical properties. Today, the finite element method is widely applied as a non-invasive and valuable technique for studying the biomechanics of biological systems and the effects of mechanical forces on them. This method facilitates the visualization of structures attached to teeth and the identification of the properties of craniofacial structural materials. It

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[10] Camargos, G.V. 3D finite element model based on CT images of tooth: a simplifed method of modeling / G.V.Camargos, P.C.Lazari-Carvalho, M.A.de Carvalho [et al.] // Brazilian Journal of Oral Sciences, - 2020. 19, - p. e208910.

also allows for determining the location, magnitude, and direction of applied forces, as it theoretically identifies the stress points that can be measured. Moreover, because this method does not alter the physical properties of the materials being analyzed, it can easily be repeated multiple times.

Despite the wide variety of ceramic materials available, it is important to note that the question of whether to use metal-ceramic or all-ceramic prostheses for the restoration of anterior dental defects in the upper or lower jaws, as well as which materials to select, has not been fully resolved. Furthermore, there are insufficient solid scientific justifications for these choices. Consequently, the improvement of technologies for the fabrication of fixed dental prostheses from ceramic materials remains a necessary task.

Research object and subject.

Object of the research: Crowns made of lithium disilicate, aluminum oxide, and zirconium dioxide stabilized with yttrium oxide.

118 patients participated in the study, with 68 patients having damaged canines and 50 patients having damaged incisors.

Subject of the research: The calculation of Young's modulus, material density, and Poisson's ratio in a 3D model of the crown created using finite element analysis and cone-beam computed tomography (CBCT).

Aym of the study: The aim of the research was to enhance the efficiency of orthopedic treatment for fixed constructions in cases of various anterior dental defects in the upper and lower jaws.

The study objectives:

1.To create a three-dimensional geometric model of the crowns of the central incisor, lateral incisor, and canines in the upper and lower jaws through digital modeling using three-dimensional finite element analysis.

2. To determine the main characteristics of damaged canines and their impact on neighboring teeth using cone-beam computed tomography.

3.To investigate the strength of ceramic restorations designed for incisors.

4.To determine the modulus of elasticity and von Mises stress in the compared ceramic materials.

5.To conduct a clinical evaluation of full-ceramic restorations for incisors and canines over a 3-year observation period, based on USPHS criteria.

Research methods.

- Three-dimensional finite element analysis;
- Cone-beam computed tomography;
- Clinical studies.

Main provisions for the defense:

- The strength, Young's modulus, and Poisson's ratio of virtual crown models made of zirconium dioxide, lithium disilicate, and aluminum oxide under compression did not statistically differ from each other ($p>0.05$).
- The maximum von Mises stresses in systems composed of aluminum ceramics and zirconium dioxide with a bonding area of 9 mm^2 were specifically noted in ceramic structures.
- Damaged canines are important factors that can influence the resorption of neighboring tooth roots; when the root of a damaged canine was positioned palatally, root resorption was 3.25 times ($p<0.01$) and 4.73 times ($p<0.01$) higher than when positioned buccally or centrally, with root degradation occurring in 44.3% of cases.
- The clinical effectiveness of restorations made from zirconium dioxide, lithium disilicate, and aluminum oxide in incisors was 90.3%, 95.0%, and 91.8%, respectively; for canines, this effectiveness was 89.1%, 90.8%, and 88.1%, respectively.

Scientific novelty:

- A three-dimensional geometric model for the upper central incisor, lateral incisor, and canine was developed, and modeling was carried out using three-dimensional finite element analysis. In accordance with the manufacturer's thickness specifications, a standard model characterizing three ceramic materials—lithium disilicate, aluminum oxide, and zirconium dioxide—was developed.

- The elasticity and strength of non-metallic structures made from lithium disilicate, aluminum oxide, and zirconium dioxide during stress were comparatively studied in the restoration of defects in the upper anterior teeth.
- Using cone-beam computed tomography, the characteristics of damaged upper canines and their effects on neighboring teeth were identified.

Practical significance of the research.

The application of the Finite Element Method allows for the prediction of how biological tissues, including teeth, periodontal ligaments, and alveolar bone, will respond to the pressures exerted by orthopedic structures during prosthetics, and enables making necessary adjustments when needed. In this regard, individualized virtual models adapted to the clinical characteristics of the patient can be confidently used for predicting the pressures occurring during orthopedic treatment.

Aprobation.

The main provisions of the dissertation have been presented at the following scientific and practical conferences: the Vth International Scientific Congress on "Modern Problems of Pharmacy" dedicated to the 90th anniversary of Azerbaijan Medical University and the 80th anniversary of higher pharmaceutical education in Azerbaijan (Baku, 2021); the International Scientific and Practical Conference with training on "Modern Methods of Diagnosis, Prevention, and Treatment of Major Dental Diseases" (Odessa, 2021); and the XXIVth Republican Scientific Conference dedicated to the 880th anniversary of the great Azerbaijani poet and philosopher Nizami Ganjavi (Baku, 2021).

The preliminary discussion of the dissertation took place during the meeting No. 39 of the Department of Orthopedic Dentistry of Azerbaijan Medical University on December 27, 2023, and also during the meeting No. 10 of the Scientific Seminar of the ED 2.50 Dissertation Council of AMU on March 19, 2024.

Application of work results to practice.

The results of the dissertation are used in the educational process of the Department of Orthopedic Dentistry at Azerbaijan Medical University and in the treatment process of the Teaching Dental Clinic.

The organization where the dissertation work was performed.

Department of Orthopedic Dentistry of Azerbaijan Medical University.

Publications.

A total of 8 scientific works on the subject of the dissertation have been published, including 5 articles (3 abroad) and 3theses (1 abroad).

Volume and structure of the dissertation.

The dissertation is presented in a text format computer typed, comprising 161 pages (224,912 symbols). It includes the following sections: Introduction (14,998 symbols), Literature Review (56,057 symbols), Materials and Methods (18,845 symbols), Chapter III (50,888 symbols), Chapter IV (56,617 symbols), Summary (20,118 symbols), Results (2,878 symbols), and Practical Recommendations (1,171 symbols). The bibliography includes 224 sources. The dissertation incorporates 3 graphs, 21 tables and 27 images.

MATERIALS AND METHODS OF THE STUDY

To address the objectives of the current research, geometric models of the upper and lower incisors and canines were created, and orthopedic treatment was performed on defective anterior teeth in the upper and lower dental arches. The study was conducted in accordance with the principles of the Helsinki Declaration of the World Medical Association, and informed consent was obtained from each patient participating in the research.

The study involved 118 patients with various defects in the upper and lower anterior teeth (central and lateral incisors, canines), including both genders.

Criteria for inclusion patients in the study were.

Patients with damage to the anterior teeth (upper and lower central and lateral incisors, canines); age range from 22 to 53 years; patients with no severe somatic diseases; written consent to participate in the study.

Exclusion criteria for patients were: periodontal diseases; age below 22 or above 53 years; presence of severe somatic diseases; non-compliance with oral hygiene; inadequate dental structures; preference for metal-ceramic restorations.

Participants in the study ranged in age from 22 to 53 years, with an average age of 37.70. Among them, 51 (43.2%) were male, and 67 (56.8%) were female.

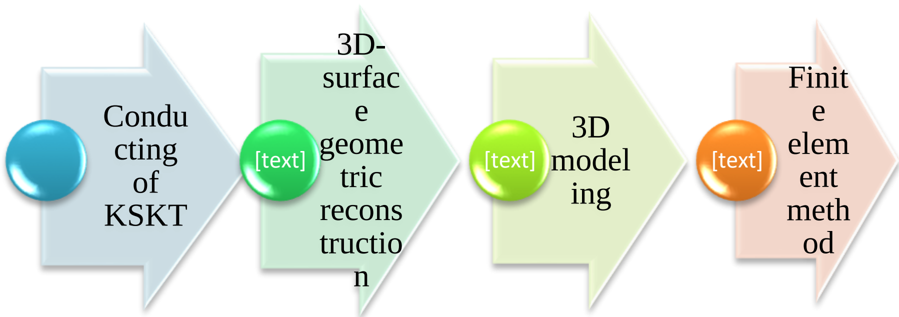
Among the 118 patients involved in the study, 68 had damaged canines, and 50 had damaged incisors (of which 26 had damaged central incisors and 24 had damaged lateral incisors). Of the 26 patients needing treatment for central incisors, 21 had damaged upper central incisors (11, 21), while 5 had damaged lower central incisors (41, 31). Among the 24 patients with damaged lateral incisors, 14 had damaged upper lateral incisors (12, 22) and 10 had damaged lower lateral incisors (42, 32).

Patients initially visited the clinic for examination and subsequently for prosthetics . In 48 patients (55.9%), the damage to the teeth was related to trauma; of these, 38 patients (32.2%) had traumatic damage to canines and 10 patients (8.5%) had traumatic damage to incisors. Carious damage to canines was observed in 30 patients (25.4%) and to incisors in 40 patients (33.9%).

Unilateral damage to canines was found in 57 out of 68 patients (83.8%), while bilateral damage was found in 11 patients (16.2%). In most cases (57.0%), the left canines were damaged, while the right canines were damaged in 43.0% of cases. Among the 26 patients, 11 (42.3%) had damage to the upper left central incisors and 15 (57.7%) had damage to the upper right central incisors. Of 5 patients, 2 (40.0%) had damage to the lower left central incisors and 3 (60.0%) had damage to the lower right central incisors.

During prosthetics, crowns made of yttrium-stabilized zirconia, aluminum oxide, and lithium disilicate were used.

Finite element analysis and cone beam computed tomography were used in the preparation of non-metallic crowns. 3D models of crowns made from various ceramic materials (zirconia, lithium disilicate, aluminum oxide) were created from samples of the upper and lower central and lateral incisors and canines of a healthy individual using computed tomography and 3D reconstruction methods (Graph.1).



Graph 1. Stages of Preparing the 3D Model of the Dental Crown

Cone beam computed tomography was conducted using the Planmeca ProMax 3D Max (Finland) device with the Planmeca Romexis software. The images were evaluated in the axial (x), sagittal, and dental crown planes. For the analysis, it was essential to first separate the components (elements) of the solid model. Mesh generation was performed using ANSYS Workbench and mesh models. ANSYS SolidWorks is one of the widely used computer programs for analysis using the finite element method.

To assess the initial state and re-evaluations of individual crowns, the criteria of the United States Public Health Service (USPHS) were used. The following parameters were evaluated: edge fit, edge surface fading, anatomical form, surface properties (texture), and color matching.

All numerical data and indicators obtained during the study were statistically analyzed considering modern recommendations.

Statistical analysis was carried out using variation (mean indicators) and discriminant ($\chi 2$-Pearson) methods. All calculations were performed using the Statistica version 16.0 for MS Windows (USA) software package. A significance level of 5% was accepted.

RESEARCH RESULTS AND THEIR DISCUSSION

CAD-CAM modeling and analysis of various solid monolithic restorations. Creation of a three-dimensional geometric model of central incisors. We assessed the impact of a preparation technique adapted to biological material on stress concentration in endodontically treated and zirconia-capped incisors. The crown model made from yttrium-stabilized zirconia was obtained using the finite element method with cone beam computed tomography. Three models of the upper central incisors were created, including the enamel layer, dentin, and periodontal ligament. These models contained 15,380 elements and 29,304 nodal points. Zero displacement was fixed on the connections at the lower surface of the cylindrical support in three spatial dimensions. The tooth and restoration material were considered to be ideally bonded.

The following models were evaluated:

- Model 1: 90° shoulder preparation;
- Model 2: 135° shoulder preparation;
- Model 3: beveled preparation method.

Computer software (ANSYS 17.2, ANSYS, USA) was used for analysis. Compatibility tests corresponding to the complete deformation and stress fields of the Fon Mises criterion were conducted according to the mechanical testing parameters of the construction and the principal maximum stress, with tensile stress as the failure criterion. Materials in ANSYS were considered isotropic, elastic, and homogeneous.

For each model, the bone base was fixed, and a 150 N load was applied at an angle of 45° along the longitudinal axis of the tooth to the cingulum area. The results were evaluated based on the distribution of stress in the crown and root, focusing on the principal maximum stress. The movement of each component was described in detail.

In the tested models, there were no fractures observed between the surfaces of the constructions or in the areas of force application. The study of the maximum principal stress in the cement, root dentin, and post system revealed no significant discrepancies among the models; however, the highest stress levels were observed in Model 3 (Table 1).

Table 1.

Maximum Stress Limits at the Crown Margin and Cervical Dentin According to Preparation Model

Model	Area	Tensile strength (MPa)
1	Crown areas	40,2
	Cervical dentin	6,0
2	Crown areas	43,5
	Cervical dentin	7,7
3	Crown areas	51,7
	Cervical dentin	4,4

Compared to Model 3, the lowest stress values were observed in Models 1 and 2. Partial increases in stress at the margin of the crown were recorded in Model 3 (51.7 MPa). When determining the distribution of transverse stress in the cervical dentin of the tooth, a higher stress value (7.7 MPa) was observed in Model 2. However, based on the analysis, Model 3 demonstrated the most satisfactory characteristics with the lowest stress levels (4.4 MPa). The transverse stress in the cervical dentin in Model 1 reached 6.0 MPa.

The contact surfaces of the lateral incisor and its ligament, as well as the connection between the ligament and the lateral incisor bone, were successfully established. Once these connections were created, the fixed surfaces were stabilized using a clamp. The mesial and distal surfaces of the jawbone were restricted. During the determination of the discretization mesh parameters for the previously constructed 3D models, the periodontal ligament and lateral incisor were used (Table 2).

Table 2.

Properties of Finite Elements for Lateral Incisors

The element	Size (mm)	Absolute deflection (mm)	The element type
Periodontal ligament	0,3	0,1	Linear tetrahedron
Lateral incisor	1,313	0,21	Linear tetrahedron

"The determination of the compressive strength of sintered aluminum was carried out on five different cylindrical samples using the INSTRON 1344 (capacity 500 kN) (Table 3).

Table 3.

Mechanical properties of aluminum oxide and lithium disilicate based on the results of compression tests.

Properties	A model made of aluminum oxide	A model made of lithium disilicate	P=
Compressive strength, MPa	1037,72	1046,26	0,834
Compressive stress at yield strength(displacement 0.2%), MPa	752,0	751,8	0,986
Young's modulus, MPa	23119,5	22887,8	0,704
Expansion caused by compression during the period of maximum compressive load, mm	2,70	2,71	0,974
Deformation caused by compression at maximum pressure, %	17,95	17,24	0,616
Poisson's ratio	0,22	0,23	0,546

"For the aluminum oxide model, we considered a vertical force of 190 N. The loading conditions were as follows: horizontal and vertical forces were 0 on the mesial side (X), the vertical force was 190 N on the vestibular side, and the horizontal force was 0; the hori-zontal force in the direction of the main axis of the tooth was 15 N.

A comparison of the obtained results showed that the type of ceramic material did not significantly affect the mechanical properties during compression, and no statistically significant differences were found between the types of crowns ($p>0.05$).

Table 4.

Maximum and minimum values for the aluminum oxide model

Type of load	Maximum stress,MPa	Minimum stress, MPa
Vertical load	388,94	0,92
Horizontal load	149,91	0,07

"The maximum stress values were recorded in the area slightly above the fixed basal region, as all free parts of the framework were constrained here. However, when a horizontal force was applied, the crown experienced bending around the framework. As a result, during secondary loading, although the anterior region was compressed and the posterior region was extended, a high-stress field developed around the framework.

In the lithium disilicate model, the maximum Von Mises stresses were as follows: in dentin – 13.7 MPa, in cement – 18.5 MPa, and in the crown – 61.8 MPa. Tensile due to contact stresses, displacements, and compressions around the lithium crown and post at the adhesive interface between the cement and dentin were 11.9 MPa, 3.5 MPa, and 17.2 MPa, respectively.

Based on the results obtained for the canine , the greatest stresses were observed on the surface of the root, alveolar bone, and periodontal ligament during bending and movement of the structure. The highest stresses on the root surface were concentrated in the cervical region, gradually decreasing toward the apex.

Although the stress distribution in the periodontal ligament was similar to that in the root, the magnitude was lower and more irregular. In the alveolar bone, the highest stresses were noted in the cervical third of the tooth and decreased toward the middle third, starting from the apical third (with values close to 0). The stress distribution during bending and torsion movements was concentrated around the cervical region of the tooth root and periodontal ligament during the four phases, with stress distributed more evenly throughout the periodontal ligament and root. It can be assumed that the cervical region of the tooth is subjected to higher pressure and could be one of the areas most prone to potential tissue damage (except for the apex), especially during bending. The stress distribution and degradation varied depending on the bending and movement of the structure body. Unlike bending, the stress degradation during movement was more uniform, and the values were lower.

At each stage of bending, the maximum stress values in the periodontal ligament were 0.0613, 0.0525, 0.0401, and 0.0328 MPa, respectively. At each stage of movement, the minimum stress values in the periodontal ligament were 0.0475, 0.0392, 0.0270, and 0.0196 MPa, respectively. The stress magnitude in these same regions gradually decreased. Overall, the areas closer to the alveolar ridge shrank more rapidly. Furthermore, the stresses in the cervical region of the alveolar bone worsened during bending compared to those during movement of the structure body—this could be explained by the greater displacement in the cervical region of the tooth, as opposed to the apical region. It is not yet clear whether this is related to faster bone resorption and remodeling.

Our research has shown that the cervical region of the tooth, excluding the apex, experiences the highest stress and may be the most susceptible to tissue damage, regardless of the nature of the movement. The results obtained can help us better understand the physiological and mechanical responses in the tooth-jaw complex and their interrelations. Based on this, it may be possible to develop an optimal force system to achieve and control the appropriate type of tooth movement.

It is important to note that the placement and shape of the upper and lower canines , their fixation in the bone, as well as the location of the bony ridge (called the cusp) on the labial side of the tooth, have cosmetic significance. These factors contribute to the overall appearance and ensure the normal expression of the face at the corners of the lips. The loss of these teeth makes their restoration significantly more difficult, almost impossible, while at the same time their presence remains essential to maintaining the natural appearance of the face throughout time.

Due to their characteristics, canines serve as support teeth for incisors and premolars, as they are located between these groups of teeth."

The crowns of canines incorporate several functional design features, which give them some similarities to the form of incisors and premolars.

The key characteristics of damaged canines and their impact on neighboring teeth were determined using cone-beam computed tomography (Table 5).

Table 5.

Characteristics of damaged canines

Parameters	Canines (n=79)	
	Absolute Quantity	%
Localization:		
Buccal	16	20,2
palatal	52	65,8
central	11	13,9
Root resorption:		
present	51	64,6
absent	28	35,4
Root dissection:		
present	35	44,3
absent	44	55,7

"In patients, the damage was predominantly located on the palatal side. Among the 51 resorbed canines, mild resorption was noted in 29 cases and moderate resorption in 22 cases; no cases of severe resorption were observed. Additionally, it was found that in 64% of cases, resorption of neighboring teeth had occurred—root resorption was associated with the lateral incisors in 33% of cases, and with the central incisors and first premolars in 67% of cases. An analysis of the distribution of resorption in neighboring teeth, depending on the location of the damaged canine, revealed that buccal resorption occurred in 16 cases (20.2%), palatal resorption in 52 cases (65.8%), and central resorption in 11 cases (13.9%). Resorption of the root in the palatal location was 3.25 times more likely compared to buccal resorption ($p<0.01$) and 4.73 times more likely compared to central resorption ($p<0.01$). In 44.3% of cases, root fractures were detected. During the study, Von Mises stress was evaluated in three ceramic systems (Table 6).

Table 6.

Von Mises stress (MPa) in ceramic systems with a surface area of 9 mm²

	Lithium Disilicate		Zirconium dioxide		Aluminum oxide	
	200 H	1000 H	200 H	1000 H	200 H	1000 H
Bone	30,2	151,8	30,8	154,0	31,0	154,8
Periodontal ligament	48,8	243,0	48,9	247,0	50,0	248,8
Root	40,0	196,0	38,8	195,2	39,0	194,7
Cement	24,0	120,0	27,0	136,2	30,0	148,7
Ceramic structure	53,0	264,8	69,0	347,4	74,7	374,0
Ceramic coating	53,0	264,0	42,8	215,0	40,0	200,0

In the lithium disilicate system, even when stress was increased up to 1000 H, the failure threshold of the crown material, which is responsible for the structural integrity of the fixed prosthesis, was not reached.

For the aluminum-ceramic system with a surface area of 9 mm² and a connector, the highest Von Mises stress was observed in the connector area within the ceramic structures. Similar results were seen in the zirconium dioxide system when stress was increased.

In our comparative study of stress distribution, we observed that as the modulus of strength for the cap material increased, the stress in feldspar ceramics decreased, making it less susceptible to deformation and less likely to fracture. While the maximum displacement stress was highest within the ceramic structure, displacement stress in the cement exhibited the lowest results (Table 7).

Table 7.

Maximum displacement stress in ceramic systems with a surface area of 9 mm² according to Von Mises stress (MPa)

	Lithium Disilicate		Zirconium dioxide		Aluminum oxide	
	200 H	1000 H	200 H	1000 H	200 H	1000 H
Bone	17,2	86,6	17,4	87,6	17,6	88,0
Periodontal ligament	26,7	133,6	27,0	135,3	27,2	137,0
Root	20,6	103,4	20,7	103,1	20,7	103,0
Cement	12,8	63,9	14,9	74,2	16,5	82,2
Ceramic structure	30,1	152,8	40,0	198,9	42,4	213,2
Ceramic coating	28,0	139,0	24,6	122,8	22,6	113,0

"In all three systems, the maximum displacement stress was high within the ceramic structure, while the lowest displacement stresses were observed in the cement structures. In the lithium disilicate system, the highest values of maximum tensile stress were recorded in the ceramic coatings. However, in the zirconium dioxide and aluminum oxide samples, the highest results were observed in the periodontal ligament system (Table 8).

Table 8.
Maximum tensile stress (MPa) in ceramic systems with a surface area of 9 mm²

	Lithium Disilicate		Zirconium dioxide		Aluminum oxide	
	200 H	1000 H	200 H	1000 H	200 H	1000H
Bone	28,3	142,7	29,0	144,3	-	-
Periodontal ligament	54,0	271,0	53,5	268,3	53,2	267,9
Root	38,1	178,0	37,0	178,2	53,1	267,5
Cement	14,1	71,4	22,1	110,0	26,0	129,4
Ceramic structure	42,0	208,8	47,3	238,0	52,0	259,0
Ceramic coating	57,3	288,0	43,1	217,1	39,9	201,8

For maximum compressive stresses, the highest values during tensile loading were also recorded in the ceramic coatings of the lithium disilicate system. However, in the zirconium dioxide and aluminum oxide systems, the highest results were observed in the periodontal ligament system (Table 9).

Table 9.
Maximum compressive stress (MPa) in ceramic systems with a surface area of 9 mm²

	Lithium Disilicate		Zirconium dioxide		Aluminum oxide	
	200 H	1000 H	200 H	1000 H	200 H	1000 H
Bone	-16,3	-82,8	-16,3	-82,8	-16,4	-83,0
Periodontal ligament	-60,8	-305,4	-60,1	-302,2	-60,0	-301,0
Root	-51,0	-253,2	-50,1	-251,8	-50,0	-251,9
Cement	-24,0	-119,0	-27,7	-141,0	-28,0	-142,0
Ceramic structure	-33,0	-166,2	-43,8	-220,0	-46,6	-232,8
Ceramic coating	-62,2	-313,1	-44,0	-219,2	-44,8	-224,9

In each examined ceramic system, the reserve factor, which allows for the identification of the working limit, was calculated (Table 10).

Table 10.

Reserve factor of the ceramic system with a surface area of 9 mm^2.

	Lithium Disilicate		Zirconium dioxide		Aluminum oxide	
	200 H	1000H	200 H	1000 H	200 H	1000 H
Ceramic structure	8,41	1,66	21,1	4,18	9,70	1,91
Ceramic coating	1,58	0,30	2,10	0,41	2,22	0,43

"The use of a material with a higher modulus of rigidity (aluminum oxide) demonstrates a higher reserve factor in ceramic coatings compared to materials with a lower modulus of rigidity, such as lithium disilicate, which can withstand greater pressures.

The reserve factor is calculated by dividing the material's strength limit by the maximum tensile stress at each pressure level. When the reserve factor is below 1, failure occurs. Higher results indicate a higher reserve factor and a significant deviation from failure.

Clinical evaluation of monolithic zirconium dioxide, lithium disilicate, and aluminum oxide over a three-year period.

After the placement of single crowns on anterior teeth, we assessed the condition of the restorations at the following intervals: immediately after fixation, and at 6, 12, 18, 24, 30, and 36 months.

The null hypothesis was that there would be no significant difference or only a minor difference in the service life and quality of restorations made from zirconium dioxide, lithium disilicate, and aluminum oxide.

As mentioned, out of 118 patients, 68 required orthopedic treatment for canines. Of these, 11 had bilateral damage, and 50 needed treatment for incisors. In total, 79 crowns were placed on canines and 50 ones on incisors, resulting in an overall assessment of 129 crowns.

Three groups were formed based on the ceramic material used for restoration: Group I – 45 single crowns made of zirconium dioxide were placed in 40 patients (14 men, 26 women); Group II – 42 single crowns made of lithium disilicate were placed in 39 patients (18 men, 21 women); Group III – 42 single crowns made of aluminum oxide were placed in 39 patients (19 men, 20 women)."

"Monolithic zirconium dioxide crowns were applied to 27 canines and 18 incisors, while crowns made of lithium disilicate and aluminum oxide were applied to 26 canines and 16 incisors, respectively.

Critical failures were considered impossible clinical fractures that required the necessary complete replacement of the restorations; unacceptable failures (according to the Delta criterion or unrepairs according to the Charlie criterion) included untreated caries, fractures in the restorations, or dislodgement. Relative failures included minimal cohesive fractures, minor cracks and marginal stains, slight misalignment of margins, and any other defects in the restorations that were clinically acceptable and could be resolved intraorally.A comparative study of the characteristics of restorations immediately after fixation and during subsequent follow-ups showed no statistically significant differences between zirconium dioxide and lithium disilicate restorations ($p>0.05$), zirconium dioxide and aluminum oxide ($p>0.05$), and lithium disilicate and aluminum oxide ($p>0.05$). Furthermore, these differences remained consistent throughout the observation period. All crowns maintained their integrity during the observation period, resulting in 100% compliance."

Additionally, there were no marginal changes observed in any of the crowns across all groups. In Group I, the frequency of marginal color changes in restorations increased from 3.7% at 24 months to 7.4% at 36 months. In Group II, changes were only noted at 36 months. In Group III, the frequency of marginal changes increased from 3.8% at 6 months to 7.7% at 30 months and 11.5% at 36 months.

Regarding the evaluation of anatomical contours, changes were observed at the start of the study in all three groups, with no statistically significant differences between the groups ($p>0.05$). In Group I, changes in the 'Surface Texture' category varied from 7.4% to 3.7% over 18 months. In Group II, the frequency of changes remained stable at all time points (6, 12, and 18 months) and did not vary from the initial level. In Group III, the frequency of changes in restorations was 7.7% at the beginning and 6 months, decreasing to 3.8% at 12, 18, and 36 months.

In Group I, the frequency of changes in the 'Color Match' category decreased dynamically from 14.8% at the start to 3.7% by the end of the observation period. In Group II, the frequency decreased from 7.7% at the beginning to 3.8% by the end. In Group III, color changes were observed in 7.7% of restorations at the start and at 6 months, but remained constant at 3.8% throughout all subsequent stages.

Overall, the evaluation of restorations in all groups showed no changes during the observation period. Marginal color changes were not detected, indicating that this parameter was consistently rated as 100% in all three groups.

Regarding anatomical form, it should be noted that only in Group II were no changes recorded. In Group I, the frequency of restorations changing in terms of anatomical contours was 5.6% at the beginning of the study and remained constant during subsequent observations, only beginning to increase after 36 months. In Group III, the frequency of altered restorations at the beginning of the study was 6.3%, and this rate remained unchanged throughout the entire observation period.

In the "surface texture" section, in Group I, the texture was observed to change from 5.6% at the beginning of the study to 11.1% after 30 and 36 months. In Group II, changes in texture occurred at the beginning of the study and then every 6 months thereafter, but no changes were recorded after 24 months or later. In Group III, the frequency of altered restorations was 6.3% at the beginning of the study, remained the same during subsequent examinations, and no altered restorations were observed after 36 months.

In Group I, with respect to "color matching," this indicator increased by 5.6% at the beginning of the study and after 24 months, reaching 11.1% during subsequent observation periods. In Groups II and III, no color changes were observed, although the frequency of altered restorations was 6.3% during the 24-month and later observation periods, respectively.

According to the results obtained from the study, Group II had relatively better outcomes, although no statistically significant differences were detected between the groups.

CONCLUSİONS

1.Using three-dimensional finite element analysis and digital modeling, the creation of a three-dimensional geometric model of the crowns of central incisors, lateral incisors, and canines in the maxilla and mandible should be conducted in three stages. In Stage I, the following tasks are performed: generating an image of the tooth contours using cone-beam computed tomography (CBCT); applying a scale factor of F1=0.05309038 to obtain actual measurements; scaling the bone, teeth, and periodontal ligaments; and assembling the model. In Stage II, tasks include measuring the tooth's diameter, determining the tooth's diameter-to-periodontal ligament diameter ratio, and selecting the central point of the tooth. In Stage III, the geometric displacement of the tooth and its connection to the jawbone is calculated; the finite element method is applied; and the modulus of elasticity (Young's modulus), tensile strength, and ultimate strength under maximum deformation for the bone, tooth, and periodontal ligament are determined, along with the calculation of the Poisson's ratio [3, 4, 6].

2. Damaged canines are significant factors that can influence the resorption of neighboring tooth roots. When determining the primary characteristics of damaged canines in the maxilla and their

effects on adjacent teeth through CBCT, resorption was detected on the buccal side in 16 cases (20.2%), on the palatal side in 52 cases (65.8%), and in a central position in 11 cases (13.9%). Resorption on the palatal side was found to be 3.25 times more frequent than buccal resorption ($p<0.01$) and 4.73 times more frequent than central resorption ($p<0.01$). Root splitting was identified in 44.3% of the cases [1, 2, 5].

3. For incisors, no significant difference in the strength of monolithic crowns made of lithium disilicate, zirconium dioxide, and aluminum oxide was found ($p>0.05$). However, crowns with a ceramic coating made from aluminum oxide, which has a higher modulus of elasticity, demonstrated higher strength reserves and were able to withstand greater pressure [8].

4.When the stress increased from 200 N to 1000 N , the defect threshold of the crown material responsible for the structural strength of the fixed prosthesis in the lithium disilicate system was reached, while in the aluminum oxide and zirconium dioxide systems, the defect threshold was reached in the connector areas of the ceramic structure. As the modulus of elasticity of the ceramic material increased, the stresses in the lithium disilicate ceramics decreased, causing it to undergo less deformation and therefore break down more slowly. While the maximum displacement stresses were high in the ceramic structure, this parameter showed the lowest values in the cement [3, 8].

5.During a 3-year clinical evaluation of full ceramic restorations on incisors and canines, based on USPHS criteria, the effectiveness of zirconium dioxide, lithium disilicate, and aluminum oxide restorations in incisors was 90.3%, 95.0%, and 91.8%, respectively; for canines, the effectiveness was 84.1%, 90.8%, and 83.1%, respectively. Statistical analysis showed that the best results were observed in crowns made of lithium disilicate, although no statistically significant differences were detected between the groups ($p>0.05$) [4, 7].

PRACTICAL RECOMMENDATIONS

1.Considering that finite element analysis is a promising and important research tool for investigating the biomechanical properties of materials in biological studies, it can be confidently applied in orthopedic dentistry as an accurate and informative method for modeling complex prosthetic structures and studying their mechanical properties.

2.The results of finite element analysis have shown that when crowns are manufactured according to the manufacturer's recommendations, the strength of the ceramic coating significantly exceeds the stresses caused by the expected occlusal pressures in the anterior region. The crowns studied are clinically comfortable and meet patients' aesthetic expectations. Furthermore, no significant difference was found in the strength of monolithic crowns made of lithium disilicate, zirconium dioxide, and aluminum oxide for anterior teeth. Therefore, monolithic crowns made from these materials can be reliably used for the restoration of the crown portion of these teeth.

3.Based on our research findings, which show that damaged canines are significant factors that may influence the resorption of neighboring tooth roots, it is advisable to conduct continuous monitoring of canines during reconstructive procedures involving the anterior teeth.

LIST Of SCIENTIFIC PUBLICATIONS ON THE DISSERTATION TOPIC:

1. Панахов Н.А., Усубова Н.Р. Результаты конусно-лучевой компьютерной томографии пораженных клыков верхней челюсти. Клиническая стоматология. Москва, 2020, №4, т. 96, с. 87-91.

2. Usubova N.R. Üst çənənin zədələnmiş köpək dişlərinin qiymətləndirilməsində konus-şüa kompüter tomoqrafiyasının tətbiqi. Azərbaycan Tibb Jurnalı. Xüsusi buraxılış. Bakı, 2020, s. 71-74.

3. Usubova N.R. Sonlu elementlər analizi metodu və onun dental protezləmədə tətbiqi. Sağlamlıq. Bakı, 2021, №3, s. 11-18.

4. Усубова Н.Р. Трехмерное моделирование передних зубов с использованием метода конечных элементов. Azərbaycan Tibb Universitetinin yaradılmasının 90, Azərbaycanda Ali Əczaçılıq təhsilinin 80 illik yubileylərinə həsr edilmiş "Əczaçılığın müasir problemləri" mövzusunda V Beynəlxalq Elmi Konqres, Bakı, 2021, s. 381-382.

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6. Usubova N.R. Dişin üçölçülü həndəsi modelində gərginliklərin paylanmasının qiymətləndirilməsi üçün sonlu elementlər analizinin istifadəsi. Dahi Azərbaycan şairi və mütəfəkkiri Nizami Gəncəvinin 880 illik yubileyinə həsr olunmuş "Doktorantların və gənc tədqiqatçıların XXIV respublika elmi konfransı", Bakı, 2021, s. 50-52.

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8. Усубова Н.Р. Прочность монолитных керамических коронок с опорой на резцы. Эндодонтия Today. Москва, 2022, №1, т. 20, с. 36-41.

The dissertation defense will be held on "26" december, 2024, at 14:00 at the meeting of the Dissertation Council ED 2.50, operating the Azerbaijan Medical University.

Address: AZ1022, Baku, A.Gasımzade Street 14, (conference hall).

The dissertation can be accessed at the library of the Azerbaijan Medical University.

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